Chemical Education and the Chemical Industry in England from the Mid-Nineteenth to the Early Twentieth Century

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Abstract

The thesis examines the relationship between formal education and the chemical industry from about 1850 to about 1920. It first surveys relevant literature and discusses historiographical and definitional matters. It then sketches aspects of the relationship between science, education and technique during the early nineteenth century. It moves on to explore the representation of that relationship during the period of the thesis proper. It argues that this was dominated by a view articulated largely by academic chemists from the mid-century. Industrial relevance was exploited as a means of promoting research and teaching. This, rather than an 'objective' analysis, influenced the view which was promoted. Alternative, more directly technical, approaches were envisaged by some industrialists. At the turn of the century a complex negotiation was in progress, focusing on the place of technological disciplines in academe.

Attempts to establish chemical technology curricula in the nineteenth century are surveyed. Reasons are suggested for their failure, particularly the difficulties in publicly transmitting and creating commercially sensitive knowledge and the pressures of curricular and institutional hierarchies. By contrast curricula in 'pure' chemistry were numerically successful. The thesis examines the recruitment of chemistry students by the industrial and educational sectors. It surveys the occupations of a sample of students from a range of English institutions. It concludes that industrial recruitment had a greater role than has been suggested by some scholars. The recruitment and employment of trained men in a number of chemical firms is surveyed, and it is concluded that their main role was in routine analysis. Expansion of this activity was slow, involving vertical routes into managerial positions rather than functional specialization and bureaucracies. A class of technically-trained routine analysts was created. The growth of chemical engineering as academic field and occupation is examined. The roles of academics and industrialists in conceptualizing the field around 'unit operations' are discussed. An account is given of the emergence of the Institution of Chemical Engineers.

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Abbreviations

BAAS	British Association for the Advancement of Science
BDC	British Dyestuff Corporation
BDL	British Dyes Ltd.
BM	Brunner, Mond & Co. Ltd.
CGCI	City and Guilds Central Institution
C&I	Chemistry and Industry
CCRO	Cheshire County Record Office
CN	Chemical News
CR	Chemical Review
CS	Chemical Society
CTJ	Chemical Trade Journal
DCI	Dickinson Card Index (at Cheshire County Record Office)
DSA	Department of Science and Art
DSIR	Department of Scientific and Industrial Research
IC	Institute of Chemistry
ICI	Imperial Chemical Industries Ltd.
ICLA	Imperial College, London Archives
JCS	Journal of the Chemical Society
JSA	Journal of the Society of Arts
(J)PIC	(Journal and) Proceedings of the Institute of Chemistry
JSCI	Journal of the Society of Chemical Industry
LCC	London County Council
MBMB	Managing Directors' Minute Books (Brunner, Mond)
NAPT(S)E	National Association for the Promotion of Technical (and Secondary) Education
NST	Natural Science Tripos
PP	Parliamentary Papers
RCS	Royal College of Science
RCSI	Royal Commission on Scientific Instruction
RCTI	Royal Commission on Technical Instruction
SCI	Society of Chemical Industry
SCSI	Select Committee on Scientific Instruction
UAC	United Alkali Co. Ltd.
UCL	University College, London
UGC	University Grants Committee
UMIST	University of Manchester Institute of Science and Technology

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Chapter 1. Introduction

In February 1915 the House of Commons debated the promotion by the Government of a dyestuffs firm which was to address the crisis brought about by the absence of German dyes ("piece-meal plastic socialism", as one member described it). During the debate Alfred Mond, son of the chemical manufacturer Ludwig Mond, told the House, apparently without intending irony: "(y)ou can pick out from the universities today, if you like to pay for it, very able men, and there is no longer any necessity to go to Germany for chemists in order to run a chemical works in Britain". Philip Magnus argued that German prowess in industrial chemistry was "in no way due to any superiority ...as regards education": that country's success stemmed rather from "organisation (in) military, municipal, scientific and industrial work". Walter Runciman, President of the Board of Trade, remarked "...(i)t is the business of the Government, as in all technical education, to increase the amount of training and instruction for the production of a larger number of chemists of the second grade".[1]

Within this debate on public intervention in industry, speakers returned frequently to a governmental role which was evidently much less controversial: the production of manpower for private industry. Their comments signal explicitly some of the themes with which this thesis will be concerned: the role of foreign chemists; the orientation towards collective rather than individual activity; and the notion of a hierarchy among institutions and the students which they produced. However, some of the underpinning messages are equally significant, notably Runciman's identification of technical education with the production of chemists (though of the "second grade") and Mond's vision of university chemists running chemical works. To what extent, it might be asked, was a chemical training "technical", or a university chemist competent to run chemical works? Such questions reflect the fact that for chemistry, and for most of the physical sciences during the period with which this thesis is concerned, the underpinning assumption of a more or less direct industrial relevance was never far from the surface. The main theme of the thesis derives from this situation. It is concerned with the emergence of chemical components of the curriculum of higher and technical education within the tension between academic independence and industrial relevance.

Accounts of the relations between education and industry in Britain have tended to focus on the foresight of academics and a small number of industrialists, the 'failures' of government and industry to heed their warnings and the absence of educational provision and industrial demand. Those with a particular interest in this field have, in some cases, seen lack of scientific and technological education as a key factor influencing British economic performance. Unfortunately a feature of much of this work is the absence of an adequate investigation of the cognitive, ideological and institutional framework within which the relations between education and industry in Britain were constructed. Often this has been coupled with a tendency to take at face value the public statements of interested contemporaries. Indeed some modern accounts constitute little more than prolonged laments on putative British poor economic performance.[2]

Some recent work has begun to fill this gap, and to re-examine the basis of Cardwell's early synoptic account.[3] Bud and Roberts have undertaken detailed explorations of the key institutions of the mid-century.[4] The 'official' history of the Royal Institute of Chemistry was a major contribution to the social history of British chemistry.[5] MacLeod and Moseley, and other scholars, have investigated the significance of the Natural Science Tripos.[6] Sanderson, though covering a very wide front, has provided a detailed account of relations between the universities and industry.[7] The industrial perspective is less well-served. Work such as that of Reader on the history of ICI has had a largely commercial and financial orientation. By contrast that of Chandler on the USA and Kocka on Germany has a wider reference.[8]

The decades around the turn of the century are of central interest for the issues under discussion here. At this time in both education and industry new, if embryonic, institutional forms had replaced those of the early nineteenth century. A situation was being created which was at least recognizable in terms of the categories of a modern industrial society. The present study is an attempt to contribute to the process of gaining a better-grounded understanding of the historical relationship between academic activity and the so-called 'science-based' industries during this period. The chemical field was chosen because chemistry was the contemporary academic domain in which the greatest claims were made for industrial relevance in the nineteenth century. Until the emergence of the electrical industries at the close of the nineteenth century these claims were, at least relative to other disciplines, well-founded. It was also the chemical sector in which some of the earliest use was made of academically trained men, and which therefore seemed likely to have developed some of the earliest examples of bureaucracies and functional specialism involving such men.

The present account does not cover all possible aspects of the field uniformly. It has focused particularly on the definition and institutionalization of curricula, and on the recruitment and role of trained personnel. It gives relatively little attention to technique itself: only so much as was thought necessary to make sense of the areas just referred to. In these circumstances it may be appropriate to give a brief statement of the author's underpinning view on relevant historiograpical matters. Examination of the relations between science and technique is generating a substantial literature, though relatively little of it has focused on the chemical industry.[9] It may be that this is a consequence of the fact that the reality of industrial practice and its relations to academic science are particularly difficult to establish in the chemical field. Much of the work which has been done needed to confront the paradigm of technique (technology) as 'applied science' (in the sense of 'application of "pure" science'). In recent years new conceptualizations have been developed and explored. The modes of interaction between science and technique are seen as multifaceted, and it has become clear that these relations cannot be defined merely at the cognitive level. Each is a social activity. There are social influences on the cognitive development of each. The relations of the two activities (even the question of when they can be separately conceptualized) depend on the institutional framework in play. The present study has been based on the working assumption that the main arenas involved (academic science, industrial technique and academic technology) have no necessary cognitive relations. Such relations are open to empirical investigation. Moreover any findings will apply only within a specific period and for a specific industrial and technological field.

Returning to the thesis itself, an attempt has been made to undertake a systematic and representative study of curricular development and employment. Nevertheless it has been necessary to be very selective. Information on firms and educational activity which were judged similar to those discussed here have not been utilized, and in a number of cases these firms have not been fully investigated. A variety of constraints made it necessary to take decisions about when such an exploration would have yielded nothing qualitatively new. The dangers of this are obvious. Nevertheless it is hoped that the material which has been used is representative. The limitations which have been imposed will be indicated in a moment. More important has been the need to limit the study to certain industrial and academic domains.

It is not proposed to discuss in detail here the meanings of the terms 'chemical industry' or 'chemical process industries'. The first is taken to refer to industries which manufactured products for sale whose function was based on their chemical characteristics rather than physical structure. 'Chemical process industries' is taken to refer to industries involving the manipulation of other products in which chemical processes had a central role. It can be illustrated by the dyeing industry. The standard histories of the chemical industry discuss the issues involved in distinguishing these sectors.[10] One reason for not focusing strongly on this question is that, during most of the period with which this study is concerned, discussion of the industrial role of science and education involved very little differentiation between industrial sectors at any level. Moreover, in attempting to understand relationships such as that at Manchester between the Technical School and Owens College (treated in chapter 4), the position of textile-related fields such as dyeing and dyestuff manufacture cannot be disentangled. However, where the term 'the chemical industry' is used it is intended to refer specifically to manufacturing chemistry. In general this means the synthesis, not extraction, of well-defined inorganic chemicals (notably acids and alkalis) and organic chemicals (notably dyestuffs and to a lesser extent explosives). This applies especially to chapter 8. Little reference is made to electrochemical firms. The information on this area suggests that they differ from those discussed here mainly in physical/electrical aspects: following these aspects through would lead into the academic fields of physics and electrical engineering. The most advanced firm, the Castner-Kellner Alkali Co. Ltd., had strong relations with Brunner, Mond.[11]

There is an issue of definition in the academic sector, involving technological curricula, which parallels that just discussed. During the early part of the period to which this study refers courses relating to industries involving chemical manipulation usually encompassed both manufacturing chemistry and some of the chemical process industries. However, by the turn of the century, technological curricula orientated towards fields such as dyeing, brewing, ceramics, leather and food were relatively well-developed. In this study therefore the account of the earlier period deals with general courses. However later treatment of technological curricula has been limited to that which was most clearly orientated towards manufacturing chemistry proper: that of chemical engineering. Indeed the tension between more specific courses and chemical engineering, caused by claims that the latter constituted the 'primary technology' of industrial chemical manipulations, occupies an important place in chapter 7. The term 'chemical education' used in the title of the thesis has thus been interpreted flexibly though, it is hoped, appropriately.

A number of other definitional matters require attention. When used here the term 'technique' is intended to refer to the complex of knowledge and materials (machinery and chemical substances) which was operated within a particular industrial activity. 'Technology' is used so far as possible in its older sense of a body of organized and explicit knowledge of technical matters and not in the sense of industrial hardware. 'Technology' is therefore usually taken to be an academic category. The title refers to "England", though there is a detailed account of one initiative in Scotland and, where it seemed justified, statements have been made referring to the United Kingdom as a whole. It is nevertheless felt that the limitation in the overall title is appropriate. The term 'class' is used on occasions, because it is impossible to treat the subject matter of this thesis without drawing on the stratification both of society as a whole and of industrial personnel. An attempt has been made to use the term in a pragmatic and limited sense. An effort further to clarify its usage would have meant writing a different thesis. The role of women in chemical manufacturing during this period was negligible, and therefore women students have not been included in the statistical data in chapter 5.

Chapter 2 broadly surveys the issues involved in the period from the late eighteenth to the mid-nineteenth century. It looks briefly at representation, at the institutions present and at industrial activity in two fields: the Leblanc alkali industry and calico-printing. The general argument in the first two areas is that categories such as 'pure' and 'applied' science, especially if understood hierarchically, give little purchase on the ways in which contemporaries represented the relations between science and industrial technique. It is suggested that this is largely because of the absence of an institutional underpinning. In the account of industrial activity itself the complex of informal relations and other routes through which analytical and descriptive chemistry was involved with, rather than brought to bear on, industrial technique is discussed.

Chapter 3 turns to the period of the thesis proper. It explores the ways in which the embryonic body of academic chemists took the initiative in redefining the notion of chemical practice and setting up a dichotomized relationship between this practice and industrial activity. It argues that many of the characteristics of this approach were grounded in the ideological imperatives of the new 'professional' academic activity. It gives an account of the ways in which this approach was developed within the context of the governmental commissions and other enquiries of the 1860s to the 1880s, and the response of men from industrial backgrounds. The complexity of the situation by the turn of the century is surveyed, as new formulations of technological curricula and of the role of trained men in industry were developed. It is argued that the new curricula occupied a problematic position at the focus of the interests of an increasing diversity of groups, while a new hierarchical distinction between technical and university education can be discerned.

Chapter 4 returns to the mid-nineteenth century and looks at one level of institutional response to the academics' programme. Other groups and individuals appropriated that element of the programme which saw public educational activity as the means of training the industrial workforce. The chapter surveys the main attempts to establish curricula or forms of certification in "chemical technology" or "technical chemistry": at the "Andersonian" in Glasgow; at Owens College, Manchester and the Manchester Technical School; and at University College, London. It also examines the chemical element of the Technological Examinations of the City and Guilds of London Institute and the examination in Technological Chemistry of the Institute of Chemistry. It argues that much of this activity was located in institutions in which the influence of industrial capitalists was strong. In other institutions 'technical' curricula were introduced as a response to a perceived threat from such initiatives elsewhere. It concludes that such curricula in technical chemistry were usually relative failures, explores the reasons for this, and analyses the constraints and other determinants of their curricular basis.

Chapter 5 turns back to the chemistry curriculum proper, and surveys the occupational destinations and other characteristics of students at a range of institutions. The main institutions surveyed are: the Royal School of Mines (and associated institutions); the Society of Arts examinations; Owens College; University College, London; the City and Guilds Central Institution; and Cambridge University. This chapter is focused particularly on Cardwell's argument that the recruitment of academically-trained men by industrial firms around the turn of the century had only a peripheral influence on the growth of higher scientific education, and that such employment was effectively a by-product of the growth of educational provision. It takes up a substantially different position.

Chapter 6 looks at the situation within the chemical industry itself. It gives an account of the employment of trained men at a number of chemical firms: the Leblanc alkali firms of Gaskell, Deacon, James Muspratt & Co., the Runcorn Soap & Alkali Co. Ltd. and the United Alkali Co. Ltd.; the ammonia soda firm of Brunner, Mond & Co.; a number of synthetic dyestuff firms, especially Levinstein and Read Holliday;

and, more briefly, the explosives firm founded by Nobel. These are intended to be representative of the industry as delimited earlier in this introduction. The chapter discusses, so far as possible, the educational background of employees, the work which they undertook, their career trajectories and the relations between recruitment, organizational change and the growth of functional specialism within firms.

Chapter 7 is concerned with the growth of chemical engineering. The chapter carries forward the arguments of chapters 3 and 4 to the early 1920s on a narrower front. It discusses the origins of the term chemical engineering and its increasing conceptualization by means of prototype 'unit operations'. It surveys the early attempts to establish chemical engineering curricula, focusing on those at the City and Guilds Central Institution and at Imperial College, London. It looks at the institutional relations of this activity to 'pure' chemistry. Tensions between chemical engineering and courses based on specific technologies are considered. The chapter also discusses the conflicts between formulations of chemical engineering based on a dichotomized view (i.e. as an amalgam of chemistry and mechanical engineering) and those which emphasized its novel integrated character. It explores the ambivalent relationship of industrialists to curricular innovation. Finally an account is given of the origins of the Institution of Chemical Engineers, which is seen as convening a diverse set of interests.

Chapter 8 draws together some of the more important strands of the previous chapters. It focuses particularly on the structural and curricular changes within which formal education became central to the process of defining and creating the industrial workforce.

Notes to Chapter 1

1 Hansard, 1915, lxx, 15 February, col. 110-11, 75-6, 99, 150. In general the use of double quotation marks in the text indicates a direct quotation or contemporary usage. Single quotes indicate consciousness of a problematic or tendentious phrase.

2 The classic workers in this genre are G. Roderick and M. Stephens, Education and Industry in the Nineteenth Century. The English Disease? (1978); Where Did We Go Wrong? Industrial Performance, Education and the Economy in Victorian Britain, ed. G. Roderick and M. Stephens, (Barcombe, 1981). The standard works on technical education are: M. Argles, South Kensington to Robbins. An Account of English Technical and Scientific Education since 1851 (1964); S.F. Cotgrove, Technical Education and Social Change (1958). On the varying emphasis given by economic historians to the role of technical and scientific education in economic development see The Development of British Industry and Foreign Competition, 1875-1914, ed.D.H. Aldcroft (1968); D. Landes, The Unbound Prometheus. Technological Change and Industrial Development in Western Europe from 1750 to the Present (Cambridge, 1969); H.J. Habakkuk, American and British Technology in the Nineteenth Century (Cambridge, 1967); W.W. Rostow, British Economy of the Nineteenth Century (Oxford, 1948).

3 D.L.S. Cardwell, The Organisation of Science in England (1972).

4 R.F. Bud and G.K. Roberts, Science versus Practice. Chemistry in Victorian Britain (Manchester, 1984).

5 C.A. Russell, N.G. Coley and G.K. Roberts, Chemists by Profession. The Origins and Rise of the Royal Institute of Chemistry (1977).

6 R. MacLeod and R. Moseley, 'The "Naturals" and Victorian Cambridge: Reflections on the Anatomy of an Elite 1815-1914', Oxford Review of Education vi (1980), pp.177-95. G.K. Roberts, 'The Liberally-Educated Chemist: Chemistry in the Natural Science Tripos, 1851-1914', Historical Studies in the Physical Sciences xi (1980), pp.157-83.

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Science-Technology Relationship as a Historiographic Problem', ibid., xvii (1976), pp.663--72. E.T. Layton, 'Mirror-Image Twins. The Comunities of Science and Technology in Nineteenth Century America', ibid., xii (1971), pp.562-80. Finalization in Science. The Social Orientation of Scientific Progress ed. W. Schafer, (Dordrecht, 1983). Science, Technology and Society. A Cross-Disciplinary Perspective, ed. I. Spiegel-Rosing and D. De Solla Price (1977). B. Hindle, Emulation and Invention (New York, 1981). The Nature of Technological Knowledge. Are Models of Scientific Change Relevant? ed. R. Laudan (Dordrecht, 1984).

10 D.W.F. Hardie and J.D. Pratt, A History of the Modern British Chemical Industry (Oxford, 1966). L.F. Haber, The Chemical Industry during the Nineteenth Century (Oxford, 1958). Idem., The Chemical Industry 1900-1930. International Growth and Technological Change (Oxford, 1971). P.M. Hohenberg, Chemicals in Western Europe, 1850-1914. An Economic Study of Technical Change (Chicago, 1967).

11 Fifty Years of Progress. The Story of the Castner-Kellner Alkali Co. (I.C.I., 1945?).

Chapter 2. The Background: Aspects of the Relationship between Science and Industrial Technique in the First Half of the Nineteenth Century

A. The institutional and ideological framework

The relationship referred to in the title has received particular attention for the late eighteenth and early nineteenth centuries.[1] Yet, because of the diverse meanings which can be attributed to the terms, and particularly to 'science', the argument is prone to problems of closure or circularity. If science is interpreted as the intellectual products of a modern academic practice, with its attendant social apparatus, there is little 'science' to be connected with technique in that period. If it is identified with a 'rational' manipulative methodology, then the title 'science' can be applied to most technical and commercial activity.

It is useful first to indicate how contemporaries expressed this complex of issues. In 1781 Thomas Henry addressed the newly-established Manchester Philosophical and Literary Society "On the advantages of Literature and Philosophy in General, and especially on the consistency of Literary and Philosophical with Commercial Pursuits".[2] Henry can reasonably be seen as representative of the late eighteenth century "philosophical" manufacturer, as well as illustrating the lack of institutionalization of this position. He had trained in pharmacy, then moved into various manufacturing interests, as well as being active in educational and scientific activity in Manchester.[3] In his address he noted of chemistry that it "may be, not improperly, called the corner stone of the arts. They not only are supported by her, but many of them derive their very existence from this source..."[4] The sense in which Henry appears to use the term 'chemistry' in this address is rather as the manipulation of materials than as a field of study.[5] The limited occupational basis of the polarization which he presents is made clear a few lines later, when he comments that "the chemist is often prevented from availing himself of the results of his experiments, by the want of opportunities for repeating them at large". Here is no independent scholar dispensing scientific largesse to an economic world. The limited differentiation implied by Henry's comments is reflected in his own scientific and commercial activity: distinctions of motivation and conceptual structure can be made, but individuals often embodied a practical integration.

In 1799 Thomas Henry's son, the more famous William, introduced a series of lectures in Manchester "on the nature and objects of chemistry" with praise for Watt and Wedgwood, "not less benefactors of philosophy, than eminent in practical skill".[6] In reference to the advantages and attractions of the first of these activities he went on to note that "though love of speculative refinement has withdrawn (some) men entirely from the straight path of useful industry" it would be "unfair to deduce a general condemnation of theoretical knowledge". It is difficult to assimilate comments of this kind to any clear differentiation of science and technique, particularly in view of Henry's own theoretical activity. Moving forward to 1817 one finds William Brande praising the Royal Institution, at which he was Professor of Chemistry, for that "intercourse which has been facilitated in her apartments, between patrons of science, scientific men, and the promoters of manufacturers and arts (which) has tended to inspire that activity and energy which springs most luxuriantly from the free interchange of opinion."[7] Here there is evidence of a more heterogeneous tone, as might be expected given the conflicts which had been focused on the Royal Institution, and its establishment of a small number of 'professional' scientific posts. Nevertheless the dominant tone is one of integration, of commonality of interest directly understood (i.e. without the differentiations associated with academic practice which are a key element in the late nineteenth century) and of absence of a cognitive hierarchy.

Moving forward again, to 1833, one finds the calico-printer James Thomson commenting to the Select Committee on Manufactures, Commerce and Shipping that "the application of science to calico-printing has attracted the attention of some of the leading manufacturers of this country, and very successfully." Later he agreed that there were "several great manufactories in England carried on by gentlemen perfectly understanding chemistry".[8] Thomson and the calico-printing industry are both significant examples of the integration of scientific knowledge and technical activity during the first half of the nineteenth century, and both will be referred to later in this chapter. For the present it is again sufficient to note that the relationship was not presented as problematic (institutionally or in the sense of a critical national deficiency) or highly differentiated during this period. Thomson's (and Brande's) relaxed approach contrast strongly with the tone which would be used a few decades later.

If the notion of a distinct 'science' impacting on technique is to have any generalized meaning it seems necessary to be able systematically to identify institutions which both define it and differentiate it from technical interests. The contexts of scientific activity in the period can be broadly divided into three:

-as a component of general cultural production,

-as a professional activity,

-as a component of formal education.

It has been argued that the first of these was at its maximum significance at this time, though Shapin and Thackray have suggested that the place of science as "a fundamental component of popular culture" was not lost until the period 1870-1900.[9] The activity has received a good deal of attention, and can be approached along various dimensions. A loosely class-based approach would distinguish at least three levels: firstly the "aristocratic hegemony" identified by Berman as having a key role in the Royal Society and other locations for scientific "polite culture"[10]; secondly the activities dominated by the emergent capitalistic manufacturers and their associated intellectuals (physicians, clergy etc), and most obviously illustrated by the provincial 'Lit and Phils' at Manchester, Derby, Newcastle etc[11]; thirdly, the complex of activity associated with the upper reaches of the working classes in mutual improvement societies, discussion groups etc.[12] An organizational approach might distinguish the informal, private activities of the Lunar Society and the network of personal relationships, from the formal public institutions of the Royal Society, Lit and Phils and Royal Institution, and the network of commercial activity (lectures, journals and books) which was growing rapidly at this period.[13] However these do not seem to help in the identification of a social practice of abstract science systematically distinguishable from technical activity.

Further sub-division, identifying even the motivations of individuals and activities of individual institutions, is possible. However, the work of men like the Henrys above, Josiah Wedgwood and even Joseph Priestley, figures central to the scientific 'community' of the late eighteenth century, and Humphry Davy and John Dalton of the early nineteenth century, often resists any simple classification.[14] More importantly, the problem is carried over into institutions. It is difficult to locate examples even of the emphases of particular pieces of work the function of which was simply 'scientific' or technical/commercial. The tendency to study relatively simple phenomena, the properties of which were more tractable than those of much technical activity, is evident. However the limitation to knowledge 'for its own sake' was not a distinguishing characteristic of any institutions among those mentioned previously, except possibly the higher reaches of the Royal Society. Whether indicated by the interests of the membership (collectively and individually) or papers produced the distinctions are usually partial and temporary. More typical is the approach represented by the comment of Martin Wall (Praelector in Chemistry at Oxford University) when giving a paper to the Manchester Literary and Philosophical Society in 1785.

> My hopes will be fully answered, if...the qualities and preparation of articles so important may be more perfectly investigated...and the great expence...of preparing and importing them diminished.[15]

A similar position can be detected in a paper given by John Dalton to the Society nearly 40 years later and entitled "On the nature and properties of indigo; with directions for the evaluation of different samples".[16] The matching of regions of 'pure' science with technical areas (as, for example, acid-base chemistry with the alkali industry, chlorine chemistry with the bleaching industry or thermodynamics with heat engine technique) does not license the conclusion that the one was pursued in any formal and systematic isolation from the other.[17]

The references to the papers of Wall and Dalton in the previous paragraphs can be extended to much of the periodical literature of the time. The turn of the 18th century saw the establishment of a number of commercial scientific journals such as Nicholson's Journal of Natural Philosophy (1797), Tilloch's Philosophical Magazine (1798) and Thomas Thomson's Annals of Philosophy (1813).[18] Their content showed no systematic distinction between 'philosophical' and 'technical' orientations, and these often mingled in the same paper. This characteristic would continue well into the ninteenth century, extending to journals such as the Watts' The Chemist (1840), and even the early volumes of the Memoirs and Quarterly Journal of the Chemical Society (1841 and 1847).

The absence of institutionally-defined activity in 'pure' science renders the professional aspect of the science of the period difficult to define. There was a growing body of men whose livelihood involved deploying a conceptually distinct scientific knowledge. Bud and Roberts, in their social history of nineteenth-century chemistry, have termed this activity 'professional', rejecting what they see as retrospective projections of professionalism.[19] Certainly the two key forms of professional scientific activity in the twentieth century (academic and salaried industrial employment) cannot be identified on a significant scale at the turn of the eighteenth century or for some years afterwards. The 'professionals' were, in any case, associated with activities and institutions defined primarily in terms of their connections with the broader social position of science, as Brande, Davy and Faraday at the Royal Institution, or such extrinsic activity as the expanding chemical lectures for medical students. Outside these more prestigious and stable activities the major areas open to 'professionals' were such activities as delivering commercial lectures, writing textbooks or popularizations (the distinction was not obvious at this time), delivering 'expert' legal testimony for fees, acting as industrial consultants and exploiting novel materials and processes. By these means it was possible to earn a comfortable living, if one having an uncomfortable status.

No systematic work appears to have been done on the extent or effectiveness of the industrial consultancy undertaken at the period, though Fullmer has given some indication of the body of men available in one technical field.[20] With the tools available it seems unlikely that men of science demonstrated any generalized effectiveness beyond that of a (potentially) systematic, well-operationalized analysis of the materials and phenomena involved.[21] It has been suggested that Andrew Ure was the first to earn his living entirely by analytical consultancy, when he moved to London, and this was not until the 1830s.[22] Some indication of the position may be gained by Ure's own comment in 1827 that "most of the improvements in the science of chemistry consist in bringing the art of analysis nearer to perfection".[23] He noted elsewhere that by the use of his alkalimeter "chemical analysis, the highest and most intricate part of the science, may, I apprehend, be, in many cases, brought within the reach of the busy manufacturer".[24] In any case the extent to which contemporary industrial practice involved systematic experimentation should not be ignored. Samuel Gray, in his account of manufacturing chemistry, gives some indication of the approach used.[25] Davy's work on tanning was evidently constrained within an analytical framework, and Berman has given some indication of the ideological rather than technical significance which it possessed.[26]

The failure to establish separate institutional forms for chemical activity can also be noted. Thus the limited evidence of such activity (the early Chemical Society of the first decade of the century, the short-lived and low status Society established by Thomas Hodgkin during the second decade and the related and equally short-lived journal The Chemist) drew less on the embryonic 'professionals' than, respectively, amateur and artisan enthusiasts.[27]

These activities possessed only a very limited independent institutional structure or ideology compared to that which would be associated with academics and independent consultants later in the century. The dichotomies of subject matter and motivation referred to earlier were not developed by the men involved. This can be attributed to various causes: the absence of a clearly delimited model of their practice; the low status which they enjoyed, either as mere employees (their status in the Royal Institution), as equivalent to artisans (in the court ruling referred to by Fullmer), or as commercialized money-grubbers; and the doubtful origins and prospects of the men themselves.[28] Chemists were often of lowly origins in comparison with such groups as astronomers, geologists and botanists during this period.

As the 'professionals' just referred to cannot easily be disentangled from the generalist cultural institutions, neither can they be distinguished from the educational activity undertaken during the period. According to Hans the scientific element in the traditional grammar school-university system (in England) was steadily decreasing during the eighteenth century.[29] From before the turn of the century the activities of the Professors of Chemistry at Cambridge University (William Farish 1794-1813, Smithson Tennant 1813-1815 and

James Cumming 1815-61) were limited in comparison with German or Scottish contemporaries such as Black, Thomson and Liebig. The nadir, so far as teaching is concerned, appears to have been reached during the 1830s.[30] However, Hans identified a wide range of alternative activity. This ranged over the entire spectrum from ephemeral self-help and other organizations in the cities (e.g. the Birmingham Sunday Society) through academies supplying a kind of secondary education up to the Dissenting Academies proper. Hans estimated that there were 200 academies of various types by 1790, and singled out that at Hackney, which lasted till 1820. The scientific content of the curriculum of these instituions was often substantial. It overlapped with the commercial lecturing circuit referred to earlier.[31]

Differentiation between the curricular aims of this activity was made, but it was rarely institutionalized. One of the highest level initiatives was the School of Practical Chemistry established at Soho by Bryan Higgins in 1774, and advertised as a "Course of Philosophical, Pharmaceutical and Technical Chemistry" for "the patrons of natural philosophy and the useful arts".[32] In Manchester Thomas Barnes supported the establishment of the New College of Science and Art (1783) with the argument that its main aim would be that of "connecting together, liberal science and commercial industry."[33] Again chemistry was given a particularly economic emphasis and a course of its own on the grounds of its "reference to so many of the arts, on which our manufactures depend."[34] Brande, writing of the chemical lectures at the Royal Institution in 1817, where "the application of Chemistry to the Arts and Manufactures" formed a large component, nevertheless noted that "(i)t is here that men of every profession obtain the rudiments of a branch of liberal education, of which the general opinion renders it almost disgraceful for any to be ignorant".[35] An important turning point in higher education was the introduction of the requirement of a chemical certificate for medical practice after 1815, though this also gives some indication of the lack of separate institutionalization of chemistry as a teaching subject. The classes at the Royal Institution and later at University College London were dominated by medical students.[36] Even in 1850 the calico printer Walter Crum commented to Lyon Playfair in connection with a proposed chemical school at Glasgow that "we can scarcely have a flourishing school of chemistry without such an adjunct" (i.e. a sympathetic medical school).[37] At Edinburgh the Chair of Chemistry was not formally distinguished from Medicine till 1844.

It is perhaps in the mechanics' institutes that the clearest formulation of the industrial aspect of science education might be anticipated. The institutes had many precursors, notably Birkbeck's own activities at Glasgow, but also in diverse organizations such as that at Birmingham referred to above and others in the emergent industrial towns of Liverpool, Manchester and Leeds.[38] They nevertheless represented the most large scale attempt up to that time to establish a widespread formal education with a science content.[39] They were undoubtedly heterogeneous, and any understanding of their industrial reference is made more complex by their class dimension. The latter generated some of the most overt disagreement over the aims and organization of the institutes, and some, such as the first Bradford institute (1825), were viewed with hostility by local clergy and manufacturers.[40] This may account for the divergence of modern commentators on the institutes. Shapin and Barnes maintain that the technically utilitarian aspect was a mere gloss on an attempt to establish a kind of epistemological hegemony over the intellectual activity of artisans.[41] Simon, from a more orthodox stance, sees the institutes as an attempt to exploit the inventiveness of the artisan workforce.[42] Given the hetereogeneity referred to above it is likely that even such diverse views will find supporting evidence.

If one turns to the contemporary representation of the supposed industrial role of the science purveyed by the institutes, two models are available. In the first case science was to be an important supplement to the improvement of skill (broadly understood: artisans were frequently in direct control of manufacturing plant). The aims of the Edinburgh Institute were expressed as being to supply "instruction in the various branches of Science which are of practical application to mechanics in their several trades, so that they may the better comprehend the reason for each individual occupation that passes through their hands, and have more certain rules to follow".[43] Two aspects of this formulation can be noted. Firstly, it sets up an even-handed relationship in which science is presented as ancillary to rather than subsuming industrial practice. Secondly it offers no explicit class analysis of the nature or relevance of the science to be taught. The language is, in fact, little different than that of William

Henry addressing the Manchester Lit & Phil thirty years earlier. Referring to the use of the term science in contexts such as these C.C. Gillispie has suggested that it was intended to signify a kind of 'natural history of industry' (meaning some kind of systematized account of industrial practice), rather than a conceptually and motivationally distinct field.[44] However, such an interpretation appears to run counter to the internal evidence of the meaning and is still further contradicted, in the mechanics' institutes and elsewhere, by the courses in chemistry, heat, light, mechanics etc. which were offered.

The second model of the industrial role of science which was offered was related to innovation. Here, specific dicoveries and inventions were the key: thus in the chemical sector the discovery of a new substance or interaction between substances could allow radical innovations. This is supposedly illustrated by chlorine bleaching. Widespread scientific education would multiply the chances of the recognition of such phenomena. Accounts of this view did not generally extend to indicating the mechanisms for their development. An example of this approach, in heroic mode, can be found in the comment of the Rev. James Acworth to the assembled Bradford Institute that

> some happy thought, suggesting itself to the mind of an hitherto obscure member of a Mechanics' Institute, may pave the way to results, far surpassing those ... of a Watt, a Boulton or an Arkwright.[45]

The main representation of science's industrial role within the mechanics' institute movement is encompassed by these two models. The institutes were not associated with new accounts of the relations between scientific and technical knowledges, between science education and industrial activity or of the mechanism by which industrial personnel would use scientific knowledge. The language of the supporters of the mechanics' institutes was not different in this respect from that in which the activities of institutions of higher status were claimed to be of economic significance: as an amateur adjunct to innovation and process control. However it is essential, as Shapin and Barnes have reminded us, not to exaggerate the technically utilitarian aspect of the institutes. Indeed it is only from this perspective that the evident failure to confront the conflicts inherent in the programmes outlined above can be understood.

It was well understood that the immediate interests of masters in 'science-based' and other forms of innovation most frequently ran counter to those of artisans. This was frequently stated publicly during the period, the most famous example being the comment of Andrew Ure that "when capital enlists science to her aid, the refractory hand of labour will always be taught docility".[46] Yet, as if to bring out the contradiction Ure commented elsewhere in the same book that machinery could give workers time to study science itself.[47] As contemporaries must have been well aware, even the most direct examples of the utilization of independent scientific knowledge (as in the use of chlorine for bleaching) were highly mediated. Musson and Robinson's work on chlorine bleaching serves mainly to show the large amount of 'empirical' development work required for the solution of essentially technical problems, with chemical knowledge supplying mainly an analytical framework.[48] The need for access to the time, finance and other resources for such work on the part of artisans would either integrate them into the entrepreneurial role or help in a simple appropriation of their inventiveness.

It is not necessary to rely on the disingenuousness which Shapin and Barnes seem to attribute to entrepreneurs to resolve the class-based contradictions of the institutes. The wider aims of the promoters of the mechanics' institutes are quite compatible with an ingenuous belief in scientific knowledge, and its methodology, as symbol of rational instrumentality. Brougham himself was to offer as a barely-concealed criticism of the Edinburgh School of Arts that its name was "quite at variance with the fundamental principle of our Southern neighbours, that mere science -- the mere pleasures of speculation, are fit mental food for the whole people."[49] The notion of science in its technical aspect was embedded within a much larger understanding of rational education.

This last comment, derived as it is from the views of the most articulate supporters of the institute movement, leads also into a fundamental sense in which scientific and technical activity can be seen as integrated. Running through both were methods of analysis and manipulation, integrated through the predictability of the results of such manipulation: an 'operational concept of truth'.[50] These characteristics extended into approaches to social and economic phenomena. Despite his emphasis on social legitimation, this represents one of the key aspects of Thackray's account of the position of science in Manchester during this period.[51] The most convincing ideological division was between the individualistic, dynamic, instrumental perspective of the men previously discussed (and the more self-consciously radical approach of the Utilitarians[52]) and ideologies of archaism and romanticism articulated by such figures as the young Wordsworth and Carlyle.[53] The first grouping extended into the rationalistic religious tradition within nonconformity, the programme represented by the mechanics' institutes, the Sunday school movement and the Society for the Diffusion of Useful Knowledge together with the growth of 'rational' methods of control within the new large-scale places of work.[54] Whatever the divisions among these activities, they represent a broad unifying framework, in which "natural philosophy" was the standard of social, technical and intellectual rationality.

It has been argued here that the informally-institutionalized 'science' of the early nineteenth century was separated from technical activity in ways which were patchy, individualistic and subsumed within more general differences. Important shifts in the institutional aspect of this situation occurred around the mid-century. However, before developing this, the availability and use of scientific knowledge in two concrete industrial sectors will be considered. The two sectors to be discussed are calico-printing and alkali manufacture. The former can be represented as the first industry in which independent chemical knowledge had a generally important role, and the latter as illustrative of the chemical industry narrowly understood.

B. Chemistry in calico-printing and alkali manufacture

The susceptibility of dyeing and calico-printing to improvement by relatively elementary chemical knowledge is reflected in its personnel during the early nineteenth century. Calico printers constituted the largest single group of men from the process industries involved in the Chemical Society.[55] The reasons for this are not mainly concerned with theoretical knowledge of the dyestuffs themselves, which were mainly natural products, or the dynamics of the dyeing process itself, which was a total mystery. The dyeing process was however very sensitive to conditions which could be controlled through the new metrics of chemistry and physics. Moreover many of the substances used as adjuncts to dyeing (sours, mordants etc.) were relatively simple materials which could be controlled and systematically varied for different effects. Finally, the body of chemicals used directly and indirectly during the processes were in many cases synthesized on the spot. The sequence of contemporary works on dyeing, such as Partridge's Practical Treatise on Dying (1823) and Smith's Dyer's Instructor (1850) indicates the variety and sensitivity of dyeing techniques and material substrates.[56] No other industry had this diverse set of connections with analytical and descriptive chemistry, and to this was added the intrinsic dynamism of patterned textile production.

As early as 1806 the Norwich firm of Sims and Pitchford employed a young chemist of unknown education called William Stark (1788-1863). Stark subsequently found employment as a consultant.[57] However, the most important centre for calico printing was industrial Lancashire, particularly the area around Accrington. The families of Hargreaves, Lightfoot, Mercer and Thomson indicate the complex network of chemical knowledge overlaid on family and financial connections which characterized the industry.[58] John Lighfoot (1774-1820) was apparently educated by private tutor, eventually becoming an exciseman and possessing substantial chemical knowledge. This he passed on to his son John Emanuel Lightfoot (1802-93) and to the young John Mercer

(1791-1866) (later F.R.S.), the well-known dyeing chemist and inventor of "mercerising".[59] Lighfoot senior also attended the home of the local calico-printing family, the Hargreaves as chemical tutor to the sons. The father, Thomas Hargreaves (1771-1822), owned the largest local works in partnership with a designer, Adam Dugdale. In 1818 Hargreaves employed an emigrant French chemist, Frederick Steiner, at his Broad Oak works. Hargreaves' clearly had some interest in using chemical knowledge in his works, and it may have been this which caused him to send his sons to John Dalton for tuition. One at least, William Hargreaves (1815-74), also attended Cambridge University. Two of his sons, Robert (1808-54) and John junior (1797-1873) are recorded as having carried out investigatory chemical work with J.E. Lighfoot and John Mercer. The younger Lighfoot, having also received tuition from the eldest of Hargreaves' sons and Steiner, had become chemist, manager and eventually (1840) partner in the Broad Oak works. His younger brother Thomas (1811-66) succeeded him as manager. Another brother, Peter (1806-65) also carried out work at the plant, and both had patents to their names. One of the sons of Thomas was John Lighfoot (1832-72) the inventor of aniline black, who again was educated privately by other members of the family before joining the Hargreaves firm.

John Mercer, after an apprenticeship at the Oakenshaw works of John Fort, and considerable self-tuition, was employed there about 1818 as "experimental chemist", becoming a partner in 1825. His son John (1825-79) was sent to Edinburgh University before joining his father. A third large firm employing men in a chemical capacity about 1818 was that of James Thomson F.R.S. (1779-1850). Thomson owned the Primrose works at Clitheroe, and had himself been educated at Glasgow under Andrew Ure. He employed Lyon Playfair, a Swiss chemist called Hummel (the father of J.J. Hummel, later a Professor at the Yorkshire College) and various other chemists. He sent his son, Thomas Thomson (1811-48), to University College London.[60] The works referred to so far were the largest in the area in 1840.[61] The Mayfield works of Thos. Hoyle and Sons was smaller, but employed at various times John Graham (1812-69), the brother of Thomas Graham, Professor of Chemistry at University College London, and John Thom (1817-91), both of whom had been educated at the Andersonian.[62] Both eventually left to set up their own firms. Thomas Hoyle himself was active in the Manchester

Mechanics' Institute and the Lit and Phil, presenting a paper on potassium chlorate ("Oxygenated Muriate of Potash") in 1798. The firm eventually passed into the hands of the Neild family, who again were active in scientific and cultural activity, the son Archibald Neild undertaking much personal activity in chemistry.[63]

In 1853 John Mercer, giving evidence to the Society of Arts Committee on Industrial Instruction, summarized the situation as follows:

> Many of the higher print houses and manufacturing chemists have from time to time, supplied themselves with young men to superintend the chemical and colouring departments of their works, from the chemical schools of Scotland-- a few from London, but most from abroad.[64]

He noted about 21 such men employed within local firms. It is doubtful whether any other industrial sector had such a record during the period under consideration, with the possible exception of metal extraction. Even here the situation for iron and steel appears to have been very different from that with the more valuable metals.[65]

Several comments can be made on the situation. The absence of the exhortation so characteristic of later in the century can first be noted, together with few expressions of the absence of a supply of suitable men. The comments of James Thomson to the 1833 Select Committee which were quoted earlier illustrate this. In 1854 Edmund Potter noted that "there are an abundance of really practically educated chemists connected with the trade". Potter was a successful calico-printer, as well as being active in cultural and scientific activity in Manchester, and would be noticeably hostile to the claims of the academic chemists when a member of the 1868 Select Committee on Scientific Instruction.[66] Thus the existing mechanisms for the transmission and utilization of scientific knowledge were evidently perceived as adequate to the needs of this sector, with its relatively well-established modes for the utilization of the descriptive and analytical chemistry of the period. It is perhaps no coincidence that the academics of the second half of the century used carefully disparaging language in reference to the efforts of men like Mercer and Thomson.[67]

A second aspect which can be noted is the tendency for the deployment of chemical knowledge to lead towards an entrepreneurial role either through partnership (Mercer, Lightfoot), the establishment of new firms (Thom, Steiner) or both (Graham). Only towards the end of the period does this appear to become less significant, and Mercer's 1853 list evidently contains many individuals who were likely to remain as employees. Finally, the strict integration with practical requirements can be observed. Richard Fort, himself educated at Eton and Oxford University and a partner of John Mercer told the Society of Arts in 1853 that

> (t)he practical man of active empirical habits, his attention confined to a few objects and whetted by cupidity (sic) and competition, would produce better work than pedantic universalists.[68]

There are anticipations here of some of the arguments in the later part of the century. It is evident, from the comments of men like Fort, Mercer, Potter and Thomson, that the idea of an 'abstract science' which was elevated over the practice of their industry had little meaning.

Alkali manufacture might be anticipated to be the archetypal industry with a strong relationship to independent scientific knowledge. Its major products were chemically simple, and increasingly thought of as defined by the theoretical and analytical knowledge of chemistry (though analytical data continued to be rejected in favour of traditional criteria: both James Muspratt and Ludwig Mond experienced this kind of resistance to their novel products). The production of synthetic alkali became an important ancillary of the textile industry as the latter expanded, and this was supplemented by its use in the manufacture of glass, soap and other basic materials. Though many synthetic routes were explored during the late eighteenth century, that of Leblanc, with its requirement only for the fairly common raw materials of limestone, rock salt and coal (together with sulphuric acid), became dominant during the early nineteenth century. The question of the date of its introduction into the Britain has been variously answered.[69] The consensus appears to favour the firm established by John and William Losh on Tyneside at the turn of the century, which was said to have been routinely producing Leblanc soda at the Walker Alkali Works about 1816.

In any event, by the late 1820s the process, with the associated manufacture of lead chamber sulphuric acid, was well-established on Tyneside, Merseyside and Clydeside. Material, technical and economic conditions in this industry were very different from that in calico-printing. It was more inherently stable, change being brought about by pressures for recycling raw materials and improvements in large-scale plant. The industry tended to figure in encyclopaedias, rather than having textbooks devoted to it, until the late nineteenth century.[70] This is probably a reflection of these characteristics. The normal mode of non-routine activity was that of repeated attack on intractable large-scale problems. The innovative relevance of analytical and descriptive chemistry was less than in dyeing and printing, as was the possibility of innovation through the use of new materials. The major role of analytical activity was in the monitoring of overall efficiency of material transfer, the quality of products and intermediates and the exchange value of commodities. As suggested above, such uses were not automatically acceptable. James Muspratt was required to demonstrate the superior quality of his Leblanc soda in technical rather than theoretical-chemical terms, by giving it away for use rather than by quoting analytical data.[71]

A key technical problem (which remained with the industry for much of the century) was the need to recover the chlorine lost during the initial acidification of common salt. The physical manifestation of this was the cloud of damp hydrogen chloride produced during the process, and later the large quantities of "condensed" acid requiring disposal. The second major problem was to reclaim the sulphur lost as a complex of sulphur-bearing compounds known in Widnes as "galligu". The central engineering problems involved the control of the Glover condensing towers (especially after the passing of the first Alkali Act in 1863), control of the furnaces where saltcake was produced and subsequently converted to "black ash" by a manual process and control of the lixiviating tanks where the black ash balls were extracted with water. The lead chamber process involved a separate complex of problems. These gross, intractable and often unpleasant activities made alkali manufacture very different from calico-printing and most other process industries outside gas works.[72] Dingle has given an account of the industry's external relations, showing the consciousness of alkali manufacturers of their 'marginal' industrial position and their concern to enter the mainstream of acceptable activity.[73]

The early personnel of the industry exhibit parallels and contrasts with calico-printing. William Losh (1770-1861) manager of the Walker Alkali Works till 1831 was educated in Sweden and Germany and is said to have studied under Lavoisier. He retained his scientific contacts with continental Europe, as well as visiting Leblanc plants there. He was replaced by W. Septimus Losh "who had been specially educated to the work".[74] Little is known of many of the early Tyneside manufacturers. John Allen (1791-1860) is said to have been apprenticed as a pharmacist, and Isaac Cookson (1776-1851) was educated at Warrington Academy during the period of Priestley's appointment there.[75] Thomas Bell (1774-1845), who entered into partnership with William Losh and Thomas Wilson at the Walker Ironworks carried out experimental activity and took out patents on the Leblanc process, but his education during his early years in Cumbria is unknown.[76] The other partner in the firm, Thomas Wilson (1773-1858) began life as a miner, moving on to become a schoolteacher, clerk and poet.[77] Thomas Bell's son, Isaac Lowthian Bell (1816-1904), is a familiar figure in the late nineteenth century technical education movement. He studied at Edinburgh University and the Sorbonne, and was very active technically in the manufacture of chemicals and iron and steel.[78] Many years later he told the Society of Chemical Industry: "I recollect my disappointment in travelling among the furnaces and mills at home and abroad to hear so little importance attached to the studies to which I had been applying myself in Edinburgh and Paris."[79] William Losh's brother James also sent his sons to Paris, one of them lodging with a Professor of chemistry, despite the fact that his father's intention appears to have been that his son's career should be be commercial rather than technical.[80]

Isaac Lowthian Bell married a daughter of Hugh Lee Pattinson, who was a partner in another important firm, John Lee and Co., owners of the Felling Chemical Works. Pattinson was essentially a self-taught chemist, though he had been a clerk with another early Tyneside alkali manufacturer and soap boiler, Anthony Clapham.[81] Nothing is known of Lee, except that he was evidently related to the Pattinson family by marriage. The other partner, George Burnett, was actively involved in the scientific work of the Newcastle Lit and Phil.[82] Anthony Clapham, who owned the Friar's Goose works in Gateshead (1827), had originally been a chemist and druggist, and the well-known Warrington soap and chemical manufacturer Joseph Crosfield served an apprenticeship with him in this capacity.[83] Both Clapham and another early manufacturer, Charles Attwood (1791-1875), illustrate the tendency for glass and soap manufacturers to diversify into alkali production during the 1820s, so that many of the skills involved in alkali manufacture had their origins in the more traditional area.[84] Attwood's works was purchased by the wide-ranging Newcastle entrepreneur Christian Allhusen (1806-90), and was to form the core of the important Newcastle Chemical Co. later in the the century.[85] Allhusen's partner in this concern was Wilton Turner, a Giessen-trained chemist and brother of Edward Turner, professor of chemistry at University College London. Allhusen's view of Turner's innovative activity does not appear to have been altogether enthusiastic.[86] In contrast to some of these men another early manufacturer, Thomas Doubleday is known to have had little scientific interest, and it may be relevant that his firm (originally involved in soap boiling) failed.[87]

Another important centre for the industry was Merseyside and south Lancashire. The pacemaker here was James Muspratt (1793-1886), who had served an apprenticeship as a druggist.[88] After a heterogeneous career Muspratt began manufacturing alkali by the Leblanc process at Liverpool about 1823. In 1828 he entered into a partnership at St. Helen's with Josias Gamble (1776-1848), a Presbyterian minister turned bleaching powder manufacturer.[89] Gamble had attended Robert Cleghorn's chemical lectures while at Glasgow University. The partnership lasted for two years, before Muspratt continued alone and Gamble embarked on a separate partnership with the two soap-makers Joseph and James Crosfield. Gamble was later to employ and enter into a partnership with James Shanks (1800-67), a medically-trained Scot who had moved into engineering.[90] Other important works at this time included that of Andreas Kurtz (1781-1840), who had trained in France before establishing a chemical works in St. Helen's.[91] The most significant individual in the Widnes Leblanc industry, John Hutchinson (1825-65), did not establish his business there until 1847. He had been trained in chemistry in Paris and there met the son of Andreas Kurtz. He arrived in St. Helen's in 1845 in order to work for Kurtz, before moving to Widnes.[92] Other firms in the area such as Hazlehurst's and T. & J. Johnson in Runcorn were originally soap-makers.

The final important centre was the Tennant works in Glasgow. Charles Tennant (1768-1838) first developed the production and use of bleaching powder, and subsequently moved into alkali manufacture. The development of bleaching powder, which had been the foundation of the works' success, was said to be due mainly to another partner, Charles

Macintosh. Macintosh had been a student of Joseph Black, and is well known for other manufacturing activity in chemistry-related fields.[93] His son John (1796-1878) was a student of Thomas Thomson at Glasgow University. Another active technical partner was Alexander Dunlop, one of whose nephews (also a relative of Tennant's by marriage) was Charles Tennant Dunlop (1821-57). The latter became chief chemist and generated innovations in hydrochloric acid and manganese recovery.[94] Another technical manager at the works was John Tennent (sic) (1813-67) who became a partner in 1847.[95] He had served an apprenticeship, as well as studying under Thomas Thomson for some time. Such high level education was not essential, however, and another chemist at the works, Thomas Clark (1801-67), had begun work there as a clerk at the age of 15. He stayed there from 1816 to 1826 before moving into educational activity.[96] Charles Tennant's grandson, also called Charles (1823-1906) appears to have received no academic training beyond the secondary level. He and his brother John, who died young, served a commercial apprenticeship at the firm's Liverpool sales office, though this may have been connected with the presence of the technically-orientated Tennent and Dunlop.[97]

The similarities and contrasts between the two industries can be summarized briefly. The first fall under four headings:

a) the utilization of chemical knowledge beyond the most routine was associated with owners and their close associates. This was, it seems, a characteristic of industries involving chemical transformation. E.K. Muspratt told the Select Committee on Patents in 1872 that he knew of no case of a working man initiating a chemical (as opposed to mechanical) innovation, or taking out a chemical patent.[98] There appear to be very few examples of working men utilizing a knowledge of chemistry to progress through firms to senior positions. Men like John Mercer and John Lighfoot had an early and quite intimate involvement with entrepreneurs well before their technical role became important. Others, like John Graham and John Thom in calico-printing and James Shanks and John Tennent in alkali manufacture, who appear to have moved into the industries without such early connections, were certainly not of working class origin and occupied responsible positions from the first. This is not to say that chemical knowledge did not constitute an asset to such men. The position of more routine process monitoring is more doubtful. There is evidence that, before the turn of the half-century, routine testing of the materials at each point in the process of alkali manufacture was commonplace.[99] Some of the earliest volumetric methods appear to have developed in connection with the related process of bleaching. Guyton de Morveau gave some indication of the thrust of this activity when he wrote in 1782

> il faut sur-tout pouvoir arriver à cette connoissance par des moyons simples, expéditifs, qui en peu de jours deviennent une routine aveugle mais sur dans la main des Ouvriers les moins intelligens.[100]

However, the meaning of routine analytical information within a commercial plant, and its implications for action in processes operated by artizans, were problematic. Activities within plants seem likely to have been heterogeneous. This leads to the second similarity across the sectors.

b) in neither case did chemical knowledge allow the development of a theoretical model of the processes involved which could be deployed to practical effect. It is difficult to see how the problems of chlorine or manganese recovery, or systematic study of dyeing technnique could be even conceptualized as problems without the use of chemical knowledge as a basic analytical tool. Nevertheless, the relevance of the knowledge was at the level of macro-control of variables rather than useful micro-theories of fundamental processes.

c) 'abstract' chemical knowledge was to varying extents subordinate to (certainly never dominant over) technological knowledge. The practitioners in each field generally had a long involvement with the practical operations required and there is no evidence of either activity being revolutionized by abstract scientific knowledge. In calico-printing gradualist change and development was the norm. In the Leblanc industry the central process remained unchanged and the ancillary processes relatively intractable for much of the century.

d) finally, it can be noted that both sectors exhibited diversity and informality in the mechanisms by which chemical knowledge was assimilated. Three broad mechanisms are distinguishable. Firstly men might serve a relevant apprenticeship, often with a pharmacist, and supplement this by autodidactic activities (Crosfield, Pattinson, Mercer, Allen). Self-tuition alone appears not have been sufficient. Secondly, they might be educated by chemically knowledgeable men formally or informally connected with the industry: this seems more evident in calico printing (Lighfoot, Hargreaves). Thirdly they might have received some formal academic education. This seems to have been the largest group, and the only one with any possibility of breaking into the industry without related experience or family contact (Thom, J. Graham, Young, Thomson, W. Losh, Wilton Turner, Hutchinson).

The contrasts between the fields are twofold. Firstly descriptive and analytical chemistry provided a much more innovatively useful tool in calico-printing. Secondly, and perhaps in consequence of this, the role of the specialist chemically-trained employee developed more quickly in calico-printing than in alkali manufacture. By 1850 there were significant numbers of well-trained employees in calico-printing. In contrast, a man like James Young (1811-83), trained as assistant to Graham at the Andersonian and University College London, and employed by James Muspratt (1839-44) and Tennant, Clow & Co. (1843-52) in their Lancashire alkali works is a conspicuous but exceptional counter-example.[101]

Both industries drew on diverse available sources of chemical knowledge in a relatively unstructured fashion, to an extent and in forms determined mainly by the specific instrumentality of that knowledge within the field. The knowledge itself constituted a valuable, but fundamentally subordinate, tool for innovation and control. It neither undermined nor revolutionized the existing knowledge or organizational structure within either industry. These points, perhaps truism in themselves, are significant when set against the language which will be discussed in the following chapter.

C. The changing institutional basis of chemistry

The mid-century saw the beginning of the construction of a new basis for chemistry as a social practice. The origins of this practice have been carefully surveyed for chemistry by Bud and Roberts.[102] In the period from 1841 onwards a series of new institutions was founded and these would constitute important locations for the reconstruction of the process by which chemical knowledge was created and transmitted. Chief among these were the London Chemical Society (1841),[103] the Royal

College of Chemistry (1845),[104] the government-funded School of Mines (1851)[105] and Owens College (1851).[106] In addition, these institutions triggered changes in University and King's Colleges and elsewhere. Their origins were diverse, drawing on a body of activity in which chemical knowledge occupied a subordinate position rather than being supported by independent institutions. They themselves were dynamic during their first years. Much of the chemical activity undertaken within them was grounded in the increasingly well-established procedures of analytical chemistry, though reflecting the influence of manufacturing and other 'practical' interests. These changes were merely one strand in the wider-ranging process of specialization and occupational and institutional change within scientific activity which occurred from the mid-nineteenth century onwards. This can be placed under the rubric of 'professionalization', without implying that it was a unitary or homogeneous process.[107]

The emergence of a standardized methodology of qualititative and quantitative analysis was central to the changes in chemistry's position. The idea that materials could be routinely analysed into components provided a key heuristic for its uses as a component of commercial activity, especially that involving exchange of simple materials, as a progressive research programme of knowledge generation and as a tool in such fields as medicine, agriculture and the chemical process industries. The importance and sufficiency of the role of analysis would later become a contentious issue. The extent to which it was offered as a generalized methodology in these early days can be judged from the comments of August Hofmann, the German Professor at the Royal College of Chemistry, in one of his addresses to the College about 1847. "Medicine", he claimed, "no longer draws the veil of vitality over processes, the mystery of which may be unlocked by the key of analysis...".[108] Moreover, the techniques of analysis were straightforward and "when carried out in the proper manner are sure to lead to the correct results."

The seedbed of science as a progressive activity institutionalized in an academic environment was the German university system. The change which this system underwent during the late eighteenth and early nineteenth century has undergone considerable study.[109] Hufbauer has demonstrated the shift of chemistry from a field having doubtful associations with alchemy to one with a status at once utilitarian and fundamental during the late eighteenth century. Gustin has accounted for the emergence of a fully-institutionalized chemical activity in terms of a gradual shift from pharmacy and other secondary functions to academic independence through the medium of educational activity. Morrell has studied the growth of Liebig's laboratory as a research centre, while R.S. Turner has founded his account of the growth of formal academic research in Prussia on the specificities of the relationship between academics and state bureaucracies. Other aspects of the Prussian state in its industrial-educational involvement have been focussed on by Henderson. The social significance of the German universities, contrasting with both ancient and nineteenth-century foundations in England and Scotland, has been clearly brought out by Ringer.[110]

The sum of these and other studies has been to indicate the status of Germany as prototype, but also to demonstrate its contrasts with Britain. In particular, the wide-ranging social and political significance of the intellectual, licensed through the universities, was greater and more thoroughgoing than anything observable in Britain. It is not surprising that men of an intellectual bent were attracted to the high scholarship of the German universities, especially in science and theology, but the migration appears to have had a greater and more systematic significance. Ashby has estimated that 9,000 students from Britain attended German universities before 1914.[111] No study of this substantial social phenomenon appears to have been undertaken.[112] What cannot be doubted is the great, if specialized, influence of the men who returned, with or without doctorates. This extended well beyond the end of the century, but considering only the key chemical posts at about 1850 one finds Hofmann at the Royal College of Chemistry, Williamson newly-appointed to the Chair of Practical Chemistry at University College, Frankland about to be appointed at Owens College, Lyon Playfair at the Museum of Economic Geology, shortly to give birth to the Government School of Mines, and Miller at King's College, London. All possessed German doctorates. Kargon has indicated the German impact on the city of Manchester during the 1840s, though he has tended to present this as an outflowing of the view of the social and economic significance of science personally developed by Liebig.[113]

All of the institutions referred to above, and to a lesser extent the Chemical Society, were more or less orientated towards educational aims. However the transmission of chemical knowledge, once institutionalized as an independent body of curricular material, began to take on a distinct significance from those fields which it serviced. The concrete manifestation of this was the existence of an identifiable, if still embryonic, career in teaching. Though it is well known that Hofmann could earn large sums through consultancy and related activity, the fact that his central role was that of teacher was not in question.[114] In this he can be contrasted with, say, Brande at the Royal Institution twenty years earlier. The 'uncoupling' of chemistry from particular sectors, and its appropriation by specialist academics, was reinforced by the generalized nature of analytical chemistry referred to above. This contrasted with the specificity of the descriptive chemistry which dominated the earlier non-practical courses before that of Hofmann. Courses in quantitative or qualitative analysis claimed to offer a standardized method appropriate to handling any given starting material. The early coupling of chemistry teaching with medicine, most clearly manifested at University College, was under threat, as the Royal College of Chemistry explicitly aimed at diverse sectors.

The element of routine progression which the analytical techniques favoured, and which led to a fairly straightforward induction into what would eventually be called 'research', also had a part to play. The existence of a body of men with such experience was connected with shifting criteria for the appointment and continued efficiency of specialist chemistry teachers. That the best chemistry teachers would contribute to and be up to date with the latest developments was not quite axiomatic, but it had begun to characterize the novel set of skills associated with chemistry as an independent practice in the sphere of higher education. Demonstrated experience in the expansion of chemical knowledge has been shown to become explicitly incorporated into the criteria for high level academic appointment at this period.[115] The existing institutional forms for validating such new knowledge in Germany were matched in Britain, illustrated by the shifting emphasis of the Chemical Society's <u>Journal</u> to a more application-free orientation.

Thus the development of a new kind of chemical practice was focused on the new educational institutions during the mid-century, and involved chemistry as an embryonic, independent, progressive field offering generally applicable knowledge, transmitted and created by specialists. Bud and Roberts have demonstrated in prosopographic terms the increasingly important role within these institutions taken by the new 'professional' academics, and their position as the creators and validators both of new chemical expertise and new chemical knowledge. This body of activity and personnel represents a radical shift from that found in the earlier period. The location of chemical practitioners became more clearly defined during the remainder of the century, though not without fissures and conflicts. The most obvious of these during the latter part of the century was in the three-way tension between academic chemists, analysts/consultants and pharmaceutical chemists.[116] However it was the academics who occupied the dominant position so far as public representation was concerned. Perhaps the single most important element in this representation was the relationship between the 'abstract' chemistry appropriated by academics and the 'practical' chemistry of technical fields involving chemical transformations. The developments in this and related issues are explored in the following chapter.

Notes to Chapter 2

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Chapter 3. Representations of the Relations between Science, Education and Industry

A. Abstract science and industry, 1850-1867.

In 1855 a Regius Chair of Technology was established at Edinburgh University. The circumstances of this Chair can be used to illustrate a central conflict in the industrial aspect of education during the second half of the 19th century. The Chair was occupied by George Wilson (1818-59).[1] Wilson had been trained as a doctor of medicine, but he attempted to combine this with an encyclopaedic knowledge of industrial activity. In his inaugural address he claimed that the term "technology" was no "barbarism", but had a respectable ancestry: it referred to the "science, or doctrine, or Philosophy, or Theory of the Arts".[2] The idea of technology expressed in this address is of an independent body of knowledge, sustainable as an academic discipline. Elsewhere, however, Wilson indicated that, instead of technology constituting an independent study, it was derivative: "the Physical Sciences...form the basis of technology".[3]

During the following year the Principal of Owens College made an unmistakeable attack on Wilson, while defending the failure of the College to run a course of applied chemistry because of lack of students. "We have not here", he wrote, "yet given into the prevailing absurdity of teaching applied Science when there is no Science to apply; any more than into the other absurdity of making one man Professor of Technology in general..."[4] Wilson's Chair died with him in 1859 because, according to Lyon Playfair, "the university had larger and broader views of technical instruction...".[5] According to a near-contemporary these "larger and broader views" amounted mainly to self-interested opposition from other Professors, of which Playfair was one.[6] Men like Playfair used the term "technology", in Wilson's earlier sense, rarely. It is indeed in 1859 that the OED first records "technology" as referring to "practical arts" themselves rather than as a "discourse or treatise" on them. The notion of the practical arts as derivative of "pure" science, and particularly of that science as created and transmitted in an academic environment, was by contrast one of their recurring themes.

The aim of this chapter is to draw out the main structure of the representation of science's industrial relevance, particularly in its curricular aspect, from the mid-nineteenth century until the first decade of the twentieth. Though it focuses on public discourse, in advance of the more concrete subject matter of recruitment, syllabuses, employment and other institutional changes, this is not because the former is considered to dominate the latter. However, the view of the situation offered by early academic scientists has until recently dominated the historiography of the field, rather as it did much public discourse at the time.[7] An exploration of these and other representations is, therefore, a necessary prelude to the examination of more concrete areas, if only to rehabilitate the latter as other than mere symptoms of failures in political and entrepreneurial consciousness. In this discussion only limited attention will be given to accounts of the industrial situation itself, except where they drew more general conclusions about the role of science or education. Such accounts will be surveyed in chapter 6.

Among the institutions which constituted the growth points in this field it was perhaps the new university colleges which were in the most exposed position. Of these Owens College in Manchester was the archetype. Some indication that it faced problems in this respect has already been given. The Manchester businessman John Owens (1790-1846) stipulated in his will that the college was to offer instruction in "such branches of learning as are now and may hereafter be taught in the English universities".[8] The trustees envisaged a professoriate based on that of the ancient universities, but it is said to have been the appointment to the Chair of Chemistry which was anticipated with greatest interest in the town, on the grounds that "in no other department could Owens College so immediately justify its existence".[9] The essentially industrial understanding of this justification is clear, yet it is of interest that both of the early appointments to the

Chair went to candidates whose industrial interests were circumscribed. Edward Frankland was preferred to John Stenhouse, Robert Angus Smith and Frederick Penny in 1850, and Henry Roscoe again to Smith and Frederick Crace Calvert in 1857.[10] Equally significant was the fact that all six men had spent some time in Continental universities, four of them in Germany. Though the interests of the individuals concerned are not easy to establish, it seems that records of research activity were more significant in both apppointments than orientations towards industry.[11]

Frankland delivered his inaugural lecture in March 1851, and showed an ambivalent approach to the industrial significance of his field. "I am", he said, "far from coinciding with those persons who would urge upon you the study of chemistry merely on the grounds of its numerous applications to the arts and manufactures".[12] The tactic of erecting utilitarian straw men was a commonplace of later years. Here Frankland almost reversed the ploy, for he went on to devote almost his entire lecture to the uses of chemistry in fuel economy, metal extraction, medicine and agriculture. The course itself was entitled "Chemistry, and its Applications to the Arts, etc." In addition a course in "Technological Chemistry" was offered.[13]

It is of interest to compare here the comment of Scott, the first Principal of Owens, in his Annual Report that "(f)ew are aware how novel is the experiment here making of a College entirely unprofessional in its provision..."[14] Such differences in emphasis were neither merely personal nor without effect. The College suffered in its early years from an inability to weld diverging tendencies and construct for itself a stable position in the perceptions of its potential local clients: class sizes declined, as did the reputation of the College. In his report for 1856 the Principal considered "whether Manchester has had cause to be disappointed in Owens College, or Owens College in Manchester."[15] By 1858 the Manchester Guardian could describe the College as a "mortifying failure" which "supplies a kind of education which is not wanted; and, secondly,...does not supply the education which is wanted."[16] It referred particularly to the chemistry department as one which had been given insufficient prominence. Frankland himself would later comment that the natural sciences were held in "comparative disfavour" by the College authorities in relation to the classics and mathematics.[17] Speaking to the Devonshire Commission in 1871 the second Principal, J. G. Greenwood observed disingenuously that the chemistry and natural philosophy chairs had grown in importance through "no conscious effort on the part of the Trustees or the Professors". The latter "were determined at the same time to maintain the thoroughly liberal aspect of those studies; to treat them, that is, in a rigidly scientific manner, and not...with a direct regard to their industrial and mercantile applications."[18]

There were other tensions. Frankland did not confine his activities during his time in Manchester to academic work, and undertook consultancy for at least two firms: the Hydro-Carbon Gas Co., of Salford, and the large alum works of Peter Spence.[19] However, when Spence was prosecuted in 1857 on the grounds that his works was a public nuisance, Frankland gave evidence for the prosecution. The defence accused him of betraying Spence's trust, and the prosecuting counsel found himself hoping optimistically that "the character of the doctor would stand as well in Manchester as it had done before the trial".[20] Frankland left Manchester later in the year. Other factors apart, his was scarcely a tenable position for someone likely to be dependent in various ways on the goodwill of the owners of chemistry-related industrial firms. His successor, Henry Roscoe, handled the relations of the chemistry department with local industry more skilfully, despite acting as an Inspector for the local Board of Health.[21] While this issue is not of immediate curricular significance, it indicates some of the wider pressures on academic practitioners in chemistry, stemming from relationships with private industry.

Inevitably a new college in a provincial industrial town had difficulty in establishing itself as fulfilling a coherent local role. Owens' claims to provide a traditional university education, and the local response to it, was a key element in this. The central educational challenge was in its departments of physical science, particularly chemistry, and this can evidently be resolved into a tension between the claims of a chemical curriculum to be the medium for a liberal or university education, and its need to provide curricula perceived as directly relevant to students intending to enter manufacturing industry. The difficulties in this were greater than mere curricular definition. Nevertheless, under Roscoe the chemical department engaged more enthusiastically with its potential industrial supporters, attempting to become what he christened later a "University of the Busy".[22] The tensions were a locally-conditioned example of a national process.

The suggestion that studies in physical science could form the basis of a "liberal education" was the key tactic of those aiming to increase the time and resources given to those studies in older institutions, though it was easily taken over in other contexts. The efforts of J.M. Wilson, science master at Rugby, in the well-known book edited by F.W. Farrar, of Farrar himself (e.g. his talks to the Royal Institution) and of Charles Daubeny all fall into this category.[23] The flexibility of the term "liberal education" has allowed it to have a role in a variety of prescriptive theories of the curriculum.[24] The men of science gave their own gloss to the term. Rothblatt has pointed out the industrial imagery used by Huxley, and, in general, the conception of a mental discipline, mechanistically understood, was the formulation most favoured. This was especially true when the term was used in conjunction with the highly routinized procedures of analytical chemistry. The two were unwittingly juxtaposed by Hofmann in 1849, when he praised the study of natural science as "a means of mental training, more effectual perhaps than any other discipline", and, a few pages later, noted that the student of chemistry learnt "to avail himself of processes, which have been approved by experience, and which, when carried out in the proper manner are sure to lead to correct results."[25]

In general, however, the use of the term 'liberal education' itself was not favoured by the new professional academics such as Hofmann, Roscoe and Frankland. Its association with the classical languages was perhaps too strong: the idea of mental discipline and gymnastic imagery was a two-edged weapon. Such language was potentially independent of subject matter, and this, alternating with claims about the doubtful role of science in a humane education made by figures such as J.P. Norris and Frederick Temple, could work against science in the curriculum.[26] It was at this time associated rather with men like Farrar in bolstering the physical sciences in their emergence from comparative neglect at the ancient universities and the public schools. The two Royal Commissions had shown this neglect clearly, with Cummings at Cambridge suggesting that they had been actively discouraged as inappropriate to true "academical studies".[27] There is an evident parallel with the early days at Owens College. The establishment of the Natural Science Tripos at Cambridge (1851) and Final School in Natural Science at Oxford (1850) were the central elements in the changes in this situation. A course given by a local surgeon at Rugby about 1850 was one of the earlier attempts to teach physical science systematically in one of the great public schools, and was followed in 1859 by the appointment of J.M. Wilson to organize its teaching.[28]

The curricular issue overlaps that of the role of the university and its teachers in the expansion of knowledge. For Newman and the older tradition, the idea that educational institutions should adopt such a role was incorrect and could be harmful. The activity was more appropriately located in "academies".[29] The origins of such a view in a university curriculum dominated by the crystallized knowledge of the classics, a teaching body dominated by clergymen and a student body dominated by "pollmen" are not far to seek. Men from the older universities such as Whewell and Pattison could in varying degrees oppose this view. However the major opposition stemmed from academic men of science within a new institutional framework into which was integrated a dynamic understanding of knowledge.[30] There was thus little attempt to appropriate and reconstruct older views. Playfair certainly preferred a direct, robust attack: "How", he asked in 1852, "is it possible that dead literature can be the parent of living Science and of active industry?"[31]

The bracketing of "living science" and "active industry" was of course intended by Playfair to suggest more than a metaphorical connection of life and dynamism between "science" and industry. It was perhaps inevitable that claims for government and other forms of "public" support for educational institutions later in the century were grounded in suggestions of general, and particularly industrial, utility. Both the Oxford and Cambridge commissions in the 50s took up this point.[32] Though "utility" was explored with ever widening meanings, directly economic significance lent itself most readily to a populist propaganda message and, if less sharply, to the recruitment of students. Yet this emphasis, despite its attractions, posed a threat to the independence of the new academic practice. Thus the period from 1850 saw an increasingly explicit representation of an academic activity in science (both research and teaching) as one in which economic significance could increase even as immediate industrial connection decreased. The polarization which this implied was most clearly expressed by Playfair in 1852: "It is abstract and not practical Science that is the life and soul of industry..."[33]

It is dangerous to use Playfair to exemplify any position, moreso when the subject matter is one to which he returned frequently. His career is well-known.[34] He moved through a more diverse set of activities than men like Roscoe or Huxley: chemist to the calico-printer James Thomson, teacher at the School of Mines, civil servant, academic and, finally, politician. His personal commitment to the role of academic was limited, though he was said by Dewar to have come to regret leaving academic life.[35] His emergence as a public figure was connected with his work for the Prince Consort during the Great Exhibition. He occupied a leading position as an ideologue for science's industrial role, the first clearly and vigorously to articulate a model of that role which reflected the views of the new academic men of science.[36]

It is necessary to formulate this model in some detail. The following quotations, though originating across a wide time scale nevertheless represent a relatively coherent view. In the first place, it drew a sharp distinction between "abstract science" or "science pursued for its own sake" and other related activities, the latter being variously described as "practical science", or with more obvious tendentiousness "applied science". These phrases must be treated with some care: they were rarely defined except within such usage. "Abstract science" was the ideological focus of the position, and its concrete institutional location was comparatively visible. In public discourse, however, it was usually identified in terms of motivation and absence of constraints. It was a science "too lofty for measurement by the yard of utility;-- too inestimable for expression by a money standard."[37] "The discoverer of abstract laws, however apparently remote from practice, is the real benefactor of his kind.."[38] The man who would pursue "abstract discovery" must "study science, and, if he can, advance it for its own sake and not for its application."[39] The appropriation of the word "abstract" and ejection of "practice" in this context were each significant: immediate industrial activity, then, was not to be understood abstractly, and the pursuit of "abstract" science was not itself a practice but had some higher status.

In 1896 Playfair quietly rewrote history, suggesting that the central aim in setting up the Royal College of Chemistry had been "to found an institute apart from professional requirements, in which chemistry would be studied for its own sake, with the expectation that many students might follow it as the occupation of their lives, and have an ambition to widen the boundaries by research."[40] This statement is one of the rare examples of Playfair making any concrete reference to the origins of the "abstract science" which is otherwise so prominent in his comments. Another example of this, equally significant, occurs in his 1852 speech to the Society of Arts. There, after advocating the establishment of "Industrial Colleges" he noted that they would "materially aid the progress of Science by creating positions for its professors and for those who would willingly cultivate Science, but are scared from it by the difficulties they have to encounter in its prosecution."[41] This comment is doubly significant, as giving insight into the curricular emphases of the proposed colleges, and into one of the major motivations for their establishment.

The division which has been referred to was by no means presented as one of equality in intellectual significance. Industrial practice was presented as "merely" the application or utilization of abstract science. A favourite metaphor of Playfair's was of industry as the "overflowings" of science, and others were common.[42] He could express it more straighforwardly: "The rapid development of industry in modern days depends on the applications of scientific knowledge..."[43]

Abstract science was presented as the basis of industrial activity in regard to invention and development, and for the understanding and control of existing processes. Thus, to paraphrase Playfair, all future industrial competition would be simply a competition in the creation and dissemination of scientific knowledge: an "intellectual" competition. The latter addition implicitly defined abstract science (and not the practice of industry) as the appropriate subject matter of "intellect". It also neatly assimilated intellectual activity to an ideology of competition. Yet European countries were ahead in this competition because "their governments have adopted it as a principle of state".[44] The correct response was to set up educational institutions of various types, but most importantly "Industrial Universities".

At this point, and in general as Playfair moves away from a discussing "abstract" science, the detail of the activity becomes more difficult to follow. The question of the curriculum of the new institutions appears to be answered variously. Playfair's own activities at Edinburgh during the 1860s appear not to have departed from the mainstream of academic activity.[45] In the 1852 he expressed the aim of the activity as being to train "a race of men to translate ...abstractions in to worldly utilities",[46] Such men would be taught "how to use the alphabet of Science in reading Manufactures aright".[47] Speaking to the assembled Yorkshire College of Science in 1875 a somewhat different curriculum appears to be recommended, when he observed that, even in a technical college it was necessary only to "(t)each science well to the scholars and they will make the applications for themselves..."[48] It can be noted here that the College, with its proposed Textile Department, represented a movement away from science alone and towards technological education. This was the most fundamental threat to the industrial rhetoric of science education. It had been crudely foreshadowed by Wilson's Chair, and the explicit threat may have been sufficient to remove some of the ambiguities often present in Playfair's language.

The views which have been outlined were not, of course, unique to Playfair. Hofmann can be found taking a very similar position at about the same period. In an address to the Royal College of Chemistry he identified natural science as "the mainspring both of individual and national prosperity". Supposedly perfect "arts and manufactures" had been "entirely superseded by the discovery of new principles".[49] Henry Roscoe, in his inaugural address at Owens College observed of "steam ships, railways, telegraphs, reaping machines, steam ploughs, cotton mills..." that "it is to (Physical Science) that we owe all these inestimable benefits".[50] It is no coincidence that these men should exhibit this similarity. Elements of the position they took up would become characteristic of the growing body of men who earned their living as academics and thus confronted directly the tension identified earlier. It could be flexible, as will be discussed below. The group referred to (led by Williamson, Frankland, and above all Roscoe) were fundamentally pragmatic in their approach, as befitted men holding a somewhat precarious new position within the interstices of Victorian commercial and public activity. The attribution of a dominant industrial role to science was however a most important component in the ideology of this group, using 'ideology' to mean not merely a deliberate construction of perceived self-interest, but a reflected form of the 'lived' relation between these men and their world.[51] It will be argued in other chapters that the extent to which this formulation of the industrial curriculum was dominant was determined also (though in a negative sense) by difficulties in constructing curricula embodying industrial knowledge directly.

In the period from 1853 to the mid-1860s the relations of scientific activity and industry received comparatively little attention as 'matters of public concern'. There occurred a limited growth in educational activity under the auspices of the Department of Science and Art and the Society of Arts, and in the institutions of university rank. The period, perhaps because of its marked economic expansion, did not lend itself to exploitation in the manner of the later nineteenth century.[52] The framework of public intervention in education was still in a rudimentary form. The field under discussion was addressed only intermittently, as for example in Robert Angus Smith's address to the first Social Science Congress in 1857 on "Science and Social Progress".[53] However the appearance, during the late 50s, of the first synthetic dyes from coal-tar derivatives provided a useful propaganda vehicle for the representation referred to above, and its treatment illustrates the use made of such opportunities.

The main points of Perkin's discovery of mauve are well-established.[54] He was working as a student at the Royal College of Chemistry under Hofmann, and possessed a small laboratory at home. He had been one of many pupils of Thomas Hall at the City of London School to have been encouraged to study chemistry. While Perkin was undoubtedly working within an explicit theoretical model derived from contemporary organic chemistry, his motivation was scarcely one of the pursuit of 'abstract truth'. In fact, during Easter of 1856 he was attempting to oxidize toluidine to quinine guided by empirical formulae. He tried the same process with the homologue aniline and obtained the first sample of the crude, unpromising-looking aniline dye. Showing considerable commercial acumen and tenacity, he established its potential value as a dyestuff and told Hofmann that he intended to produce it commercially. Hofmann was, it seems, "much annoyed and spoke in a very discouraging manner."[55] Perkin later gave an account of the numerous technical and commercial difficulties which had to be overcome to bring the Greenford Green works into production, and later scholars have suggested that his major achievements were largely in these fields.[56] The years immediately following his success were marked by a scramble to oxidize aniline and other aromatic bases with various reagents in the hope of striking it rich. This activity was undertaken by men like John Simpson, George Maule, and Henry Medlock.[57] Litigation over patents was rife. Some indication of the atmosphere of the time is given by the situation in Huddersfield, where the dyestuff manufacturer Dan Dawson was manufacturing magenta secretly in his kitchen while awaiting the outcome of litigation between Read Holliday and Simpson, Maule and Nicholson.[58] Perkin himself was later critical of the activities undertaken at this time, as was at least one other contemporary.[59]

Both Hofmann and Playfair referred to this activity when constructing of a particular image of the industrial impact of "academic" science. Playfair, speaking to the Royal Institution in 1862 described Perkin's activity as follows:

> Mr. Perkin had seen and admired the tinctorial power of aniline, and he had an ambition to render this fugitive colour permanent, and to introduce it into the arts as a dye, and he succeeded admirably.[60]

The reference to the "tinctorial power of aniline" appears to be to Runge's blue, produced in the 1830s by treating aniline with bleaching powder. If so, Playfair's statement was a distortion on at least two counts: as crediting both intentionality, and success in that intention (since the colours are not the same).[61] The aim is clear: to elevate the instrumentality of purely laboratory-derived knowledge, and to remove the element of serendipity which surrounded the whole affair. Hofmann repeated the claim on at least two occasions. Speaking to the Royal Institution in April 1862 he suggested that Perkin had been attempting to produce Runge's blue "in a form permanent and applicable for the purposes of the dyer."[62] Such benefits occurred, he suggested, from "the pursuit of truth...pure and simple", and in the case of mauve,

> (t)he scientific foundation having been laid, the time of application had arrived, and by one bound, as it were, these substances, hitherto exclusively the property of the philosopher, appear in the market-place of life.

He went further in his Report on Class IIA of the 1862 Exhibition. Perkin's attention had been drawn to Runge's blue "and he for the first time separated the substance which produces it...".[63] Going on to discuss the other dyestuffs being produced, he stated that the industrial chemist

> can now at his choice pour from the tar-barrel a hundred different dyes...The transition is not a mere scientific dream; nor is it only a chemical prevision based on correct theoretical results; it is something more, it is already in some cases an accomplished fact.

In view of Perkin's own account of the period, and despite Hofmann's own formidable work on the nature of rosaniline, it is at least a somewhat rosy picture of industrial practice based on "correct theoretical results". With the exception of Hofmann's work, Perkin was dismissive of claims for any systematic understanding of dyestuffs.[64]

These expressions of view have been quoted at some length as indicating the steps taken to emphasize the power and effectiveness of "abstract science". Discoveries in this field would provide the material substrate for innovation, tools for the conversion of any suggestive discoveries into commercial products, and for the extension of such innovation in any desired direction. Earlier technical knowledge, or the hard-earned techniques generated during development, received no attention: the "philosophical" substance becomes the "commercial" substance "by one bound". The synthetic dyestuff industry provided a useful and increasingly sophisticated illustration of the possible interaction between knowledge generated in the course of academic activity and industrial practice. Yet, in addition to the other distortions noted above, it can be observed that its distance from matters of technical and commercial interest was not very great during the mid-century. This is indicated by the work of men like Runge, John Leigh, Charles Mansfield and Perkin himself. Mansfield, for example, acted as a consultant for the firm of Read Holliday in the field of coal-tar distillation.[65] It constituted the major example of such an interaction between academic science and industry well into the twentieth century, yet the efforts of Playfair and Hofmann indicate that this status was achieved at some cost to the truth.[66]

Nor was it entirely without opposition. Henry Cole, a man occupying a related but subtly different position from the academics, illustrated the gulf in a parallel address to that of Playfair to the Society of Arts. Here he displayed a healthy willingness to risk any dominance of abstract science over industrial practice. "...if we supply the practical execution, and our neighbours the philosophical theory, it may after all, be only a proper division of labour between friends".[67] The Society of Arts itself undertook a survey of views in its <u>Report on Industrial Instruction</u> in 1853. The calico printer John Mercer took a robust line.[68]

> I do not understand abstract chemistry; many of the richest things in the arts will no doubt be brought from the discoveries in it; but the young man's time is limited; he must be instructed in such knowledge as he can apply at once...

The Committee itself, while accepting the importance of natural science and advocating "the necessity of teaching the principles of science in connexion with the arts", noted that it "laid a basis upon which may be raised with advantage further industrial instruction in the workshop or factory."[69] The differences in emphasis here are important: between physical science as a systematic cognitive adjunct to industrial activity and as "the life and soul of industry".

Others were more forthright in their hostility to attempts to create an 'atmosphere' of scientific dominance. The first number of William Crooke s' Chemical News in 1859 contained a letter from "Philo-technology" (the name is significant) which noted the sometimes "mistaken views" of scientific men: "...we can scarcely be surprised at finding the experienced manufacturer very cautious in adopting opinions which do not appear to be borne out in practice..."[70]. The author went on to stress mutuality and partnership in the relations of academic science and technique.

B The language of "technical education" 1867 to 1900.

It is perhaps no coincidence that the more vigorous and productive propaganda effort after 1867, triggered by Playfair's well-known letter to Granville published in The Times, coincided in its origins with a trade depression in the UK.[71] It seems that the 1867 Exhibition offered an easily-digestible statistical gloss for feelings of disquiet. The expanding output of students from institutions of higher education, and their teachers, provided a distinct and articulate interest group to help sustain propagandist activity, and to these could be added the growing body of educational administrators, and students and examiners of the Science and Art Department. The 1862 Exhibition, with its triumphal focus on the Bessemer process and the evident British dominance in synthetic dyestuffs, had generated a much less favourable environment. Even Playfair had found little on which to focus.[72] The period of the 1867 Exhibition however was full of rumblings about British failure. John Fowler, President of the Institution of Civil Engineers, and Lord Granville had each voiced doubts about the British performance, both making educational references, before Playfair and Taunton's famous initiative.[73]

The exposure of Playfair's letter in The Times provoked limited and heterogeneous reaction there, but in certain circles an extended effort was made to examine the questions which he raised. The extent of this activity ought not to be exaggerated, nor its practical impact outside these quite limited circles. When Disraeli referred to the matter later in the year, it formed a limited part of a speech on franchise reform, and the tone was essentially complacent. The same could be said of Gladstone's public comments on the issue in 1867.[74] In 1872, Gladstone, speaking to the Institution of Civil Engineers on the question derided "the growing tendency to commit to the patronage and tutelage of the Government many of the enterprises formerly the offspring of private enterprise". The Times took the opportunity to comment that if "the State 'does nothing for science'...it need not be much lamented, considering how very little science stands in need of its aid."[75] Nevertheless, the years following Playfair's letter saw an enormous number of speeches, articles, books and enquiries, centred on the three great governmental enquiries.[76] The Schools Inquiry Commission undertook a special enquiry in 1867, as did the Society of Arts and the Royal Scottish Society of Arts in 1868. In the chemical field the two enquiries show something of the incestuous atmosphere surrounding this activity.[77] The Society of Arts invited Edward Frankland, David Price and Alexander Williamson to recommend a 3 year syllabus for future chemical manufacturers, while the Schools Inquiry Commission invited evidence on the chemical sector from Frankland, Price and James Young. Williamson and Young were quite closely associated, and Williamson held shares in Young's paraffin manufacturing company.[78]

From 1867 onward the large amount of attention which the question of what was increasingly termed "technical education" received was dominated by two issues: firstly, the "need" to define an industrially-relevant curriculum, and, secondly, the social class of its students or, more exactly, the mapping of curricula against class. The question of the reality and details of the supposed Continental advances, and the extent and impact of educational activity there, quickly fell from sight except when pressed by manufacturers themselves. Indeed, after the limited correspondence in The Times which followed Granville's letter showed signs of addressing the substantive question of relative performance in iron and steel manufacture, Charles Merrifield, Principal of the Royal School of Naval Architecture, wrote to say that this was not the important issue. What was important was the fact of Continental educational activity and the need for a British response.[79] Of the two questions referred to above, the second was more novel. The absence of class-based differentiation at the cognitive level was characteristic of the language of the the first half of the nineteenth century. Indeed the establishment of the Society of Arts examinations was explicitly identified as aiming to reduce class differences.[80] Playfair's comments in 1867 were, however, unambiguous. The British failure was due to the lack of "good systems of industrial education for the masters and managers". In a less emphasized part of the letter he referred also to the effect of "numerous strikes" on industrial performance.

The chemical witnesses who gave written evidence to the Schools Inquiry Commission followed Playfair's lead. Frankland and Price stressed that scientific education was needed for masters and managers, and James Young emphasized his own movement from artisan to entrepreneur. This differentiation between classes became a component of most discussions. The Samuelson Committee was appointed in March 1868, its terms of reference to investigate "the provisions for giving instruction in theoretical and applied science to the industrial classes."[81] Its report began with a move to consider the subject under the three headings of:

> the foremen and workmen engaged in manufactures,
> the smaller manufacturers and managers,
> the proprietors and managers-in-chief of large industrial undertakings.

This approach was reflected in the questioning of the witnesses. Typical of this was the question from Lord Frederick Cavendish to A.J. Mundella:[82]

> Do you think it is necessary, in order to enable us to maintain competition with other countries, that all persons employed in our manufactures should have some scientific education, or that such education is chiefly necessary for manufacturers, managers and foremen?—I think it is necessary simply for manufacturers, managers and foremen.

Mundella's response was equally typical. Gordon Lennox, Chairman of the Society of Arts at this time, commented that it was necessary to look for "the first and chief results in a higher class of foremen and directors of industry". This emphasis was not without its critics, but direct criticism, such as the comments of George Howell, onetime secretary to the Parliamentary Committee of the TUC, was limited.[83] Fleeming Jenkin, then Professor of Engineering at Edinburgh University, speaking of process control within the dyeing industry, put the position in its most abrasive form, and told the Samuelson Committee that such elementary "knowledge of the theory of chemistry" as artisans could gain would be "objectionable" if it was to be used to "alter or modify the process in any way."[84] Jenkin would later tell the Devonshire Commission that in purely wealth-creating terms the men should be treated as "the merest possible machines", provoking a sharp exchange with James Kay-Shuttleworth.[85] It is of interest to contrast the former comment with William Crookes' view that "we have at present no theory of dyeing worthy of the name", a statement true, it can be presumed, of the chemical knowledge available to all classes.[86]

The dominance of the class perspective is indicated by the structuring of two other activities which took place during the following years. In 1873, the Society of Arts initiated its so-called "Technological" examinations, shortly after its abandonment of the scientific component of its own examinations in favour of those of the D.S.A. The Committee which recommended the establishment of the examinations suggested that they be offered in three grades[87]

> according to the proficiency of the candidate:-
> 1) The elementary grade, or what may be termed the "workman's" certificate.
> 2) The advanced, answering to the "foreman's" certificate.
> 3) Honours, answering to the manager's certificate.

The Royal Commission on Technical Instruction, in its first main report, adopted a similar structure to that of 1868 Select Committee.[88] This assimilation of "proficiency" to industrial categories by the Society of Arts indicates that its examination was dominated by such categories. Yet it appears that the knowledges thought to be appropriate to each were still in some sense of the same kind--they occupied the same spectrum. Thus class stratification did not automatically lead to the assertion of radical differences in curricula. The situation changed in a gradual manner, and increasing stress would be laid on such differences.

Artisans and other manual workers were not, therefore, ignored in the educational propaganda after 1867. There was in any case a tradition of support for working class science education, independent of directly industrial concerns, which had preceded the attenuation caused by the 1862 Revised Code.[89] Advocates of such education in the later period drew on this tradition, as the supposed instrumental role of science in industry became focused on the higher levels of industrial personnel. Science education was represented as having significance for the artisan workforce in two ways. On the one hand, if it was undertaken at evening classes, it would provide a pool of men qualified for promotion to foreman and junior managers by their evident enthusiasm for "getting on".[90] In addition, the concept of the "intelligent workman" was increasingly invoked. This figure drew to some extent on some semi-technical knowledge acquired in formal education— notably skill in engineering drawing—but was anticipated also to display qualities beyond this. These qualities were only loosely "technical", and are illustrated by the list suggested by William Richardson of Platt Brothers to the Devonshire Commission.[91] The "intelligent workman" would, among other things, accept change more readily, be willing to direct others and accept direction, be able to shift from one industry to another, and to communicate more effectively. This amounted to a description of men who would fit more amenably into the workplace hierarchy and the industrial economy. The thrust of this approach was towards general education within a practical and scientific curriculum rather than industrial education in any narrow sense. This widening of reference for "technical education" would become for a time entangled with general secondary education.

Though the intended focus in this account is on the chemical industry, one of the characteristics of the period before 1900 was precisely not to disaggregate industrial sectors in any systematic manner. This general approach is particularly clear in the suggestions made to the Society of Arts by the Committee (referred to above) charged with producing a curriculum suitable for chemical manufacturers and other groups.[92] The curricula in chemically-related areas make very few concessions to the specific technical knowledge of the various occupations covered (including gardening). The emphasis is rather on straightforward analytical and descriptive chemical knowledge, with, for the would-be chemical manufacturers, a minimum of lectures on the vaguely-titled "Technical Chemistry" in the final year. It is noticeable that the architectural and engineering courses suggested by John Scott Russell were considerably more technological in orientation, and explicitly interpreted "applied sciences" as independent fields. However, the thrust of the Committee's report was to limit the transmission of such knowledge to the domain of pupilage.

A more adversarial, and thus developed, view of the positions adopted at this time can be obtained by considering the evidence of academics and chemical manufactures to the Samuelson Committee. The Committee received evidence from W.A. Miller, Playfair, Henry Roscoe and Edward Frankland: the senior chemical professoriate in Britain at the time. It is noticeable that chemists were more widely represented in this respect than less institutionally mature or industrially significant sciences. Miller appeared as the less forceful academic: though senior in years and appointment, he had, significantly, a background in medicine.[93] Playfair's was undoubtedly the dominant voice, and he presented his evidence early, in conjunction with Donnelly and Cole of the Science and Art Department. Chemical manufacturers were represented by Robert Rumney of Manchester, James Chance of Birmingham and Robert Calvert Clapham of Newcastle. A few others appeared from related sectors, such as the ironmaster and engineer James Kitson and the worsted dyer Henry Ripley.

The academics presented an essentially unified picture. The first element in this position amounted to asserting and elaborating the view which was associated earlier with Hofmann, Roscoe and Playfair: the conceptual dominance of abstract science, which in concrete terms meant that science generated and transmitted in institutions of formal education. Playfair suggested that superiority in academic activity was directly responsible for Continental improvements in iron manufacture, and implied that young graduates could go into senior technical positions immediately, and be effective there.[94] Such men, he claimed, could earn a starting salary of £300 to £400.[95] Frankland claimed that the chemical manufactures of the Manchester region were "founded on scientific principles and laws".[96] Only in those fields where men possessing chemical knowledge had worked had improvements been made: others which he had visited were "in exactly the same form" as 10 years previously.[97] Williamson took the claims one stage further, deriding the competence of manufacturers contrasted with the academics:

> It is well known that one of the great obstacles to successful invention on the part of men of science who are outside manufactures, consists in the impossibility of getting their processes fairly carried out in the chemical manufactories. If they themselves turn manufacturers there is little difficulty...[98]

Such claims were supported by references to the roles of past students employed in industry, though these references were carefully worded. Roscoe provides the best illustration. Referring to the local alkali industry he noted the new sulphur-recovery process (evidently that of Ludwig Mond). He pointed to the unnamed patentee's scientific education in Germany, but made no reference, despite quite hostile questioning, to his practical works experience in developing the process.[99] In fact Roscoe evidently knew little of Mond's academic career. Mond had left Heidelberg University without taking a degree, and spent 5 years in various plants before beginning to develop his process in 1861. He had perfected the process over several years at John Hutchinson's Widnes works. One contemporary suggested that Mond's academic activities were very undistinguished, and implied that Mond's subsequent interest in "pure" science had developed during his industrial career.[100] Similarly, in reference to Roscoe's own students who "occupied positions of trust" or were "chemists" in works, the precise nature of their work was not made clear.[101] The implication was that they were acting as works managers or research consultants, but the reality was somewhat different, as will be seen. A routine analytical chemist was, after all, still in a position of trust.

The committee had considerable difficulty in accepting that young inexperienced men were employed in positions of responsibility for the operation of the works. In response to sceptical questioning from Edmund Potter Roscoe was compelled to admit that such men were not uniquely relevant to manufacturing activity, but similar to others possessing "knowledge of all kinds that has a commercial value."[102] It was noted in the previous chapter that Potter, who had a background in calico-printing, was likely to have had few illusions about the industrial uses of contemporary scientific knowledge, or the realities of employment of chemistry students.[103] In practice, it is clear from the scattered comments even of academic witnesses that the main openings into responsible industrial positions were for the sons and relatives of principals and partners.[104] The precise location of other trained men within plants remained unexplored, the "chemists" being subtly transformed into managers and partners.

A further aspect of the evidence was the wide-ranging claims made by the academics for their syllabuses, and, by implication, for their own competence to prepare students for diverse industrial activities. Roscoe, after making a fairly standard complaint about a father asking for instruction in a particular industry, and an equally standard response about the need to teach chemistry as a whole first, went on "afterwards...they must work out their own particular subject with me."[105] Miller, referring to his own applied science course, claimed to teach "the principles of chemistry (illustrated) by their application to the arts".[106] Frankland noted that the course at the Royal School of Mines was diversified to include "those specialities of science which have a direct bearing on (the students') own pursuits".[107] The questions implicit in the above comments were never developed. In what sense could the specialist science appropriate to particular industries be taught by a professor and one or two assistants? Why was such knowledge appropriate while not being part of the practice of the particular industries? Why did the generalized power presented elsewhere as implicit in "abstract" science require such mediation?

The evidence of manufacturers is more ambivalent. James Chance, of the Midlands alkali and glass firm, was enthusiastic about the general value of education, particularly referring to senior workers.[108] However, he expressed disagreement with academics on two counts. Firstly, he found that the existing system of science education was adequate for managers to obtain "such scientific education as is necessary for their position".[109] Secondly, he made clear that this knowledge was subordinate to technical knowledge: "...taking theoretical chemists of the highest character...I have found them incompetent to deal with conditions of which they are naturally enough ignorant". Given the alternatives only, he claimed that he would prefer practically- to academically-trained men.[110] Nor could Chance be presented as an ignorant or prejudiced manufacturer. He had studied science at University College London and graduated 7th wrangler in the Mathematics Tripos of 1838 at Cambridge University. He employed onetime senior wrangler John Hopkinson in his glass manufacturing firm. Hopkinson's work on optical glass constituted one of the more striking examples of the attempt to transfer academic knowledge into industry during the late nineteenth century.[111]

Further evidence came from the Manchester murexide manufacturer Robert Rumney. Rumney was also an enthusiast about the benefits of increased science education: he was President of the Lancashire and Cheshire Association of Mechanics' Institutes and a Governor of Owens College, to which he left a bequest for an artizan scholarship. He was, however, sceptical about the immediate impact of such knowledge on the works, going so far as to deny the purely scientific bases of the work of James Young and Perkin.[112] He commented that "(i)t is possible to have scientific men who are utterly incompetent to manage works", agreed with a committee member that "mere sciences would not constitute a foreman", and distinguished the varying susceptibilities of industrial sectors to the influence of scientific knowledge.[113] At one point, when he had commented that scientific education of the working class would not directly benefit local industry, an evidently surprised Parliamentarian asked "(t)hen why do you promote it?"[114] Robert Calvert Clapham, the remaining witness from the chemical industry proper, did not enter explicitly into the impact of chemical knowledge, though he did discuss the origins and activities of men trained in chemistry. There is some confusion in these comments, with Clapham evidently referring to analytical chemists and the committee members (perhaps after the ambiguous comments of Roscoe) discussing process managers.[115]

Interesting comments can be found in the evidence of witnesses from chemistry-related industries, especially the Bradford dyer Henry Ripley. Ripley had no doubts about the direct value of scientific education, having had students sent to be trained at Owens College and one of the London colleges. One of the resulting "chemists" was brought back into the works and presented to one of the foreman dyers (the key process workers) with the comment that "he will help you and point out the reasons of your difficulties". The dyer objected and subsequently left. The fact that this was not mere prejudice, which Ripley suggested, is indicated by his somewhat contradictory comment that the chemist "did not prove himself at all equal to the position".[116] The situation of the other trainee (who may have been the successful dyeing chemist Thorp Whittaker) was not recorded, but Ripley was apparently unabashed. He had his own son specially taught chemistry at Cheltenham College, and was now introducing him into the works hoping

> to see results which I have not seen before, in connection with scientific knowledge being brought to bear on practice in my establishment.
> Your son is still young of course?—He is 19 years old.[117]

A still more optimistic example of this type of approach is provided by the Nottinghamshire lace manufacturer Thomas Birkin, who suggested that silk-dyeing was done by guesswork, "instead of coming directly to the result, as the men would do if they had a good chemical education".[118] This kind of expectation, at least in part attributable to the propaganda effort of the academics, would generate hostility among a younger generation of teachers. In 1885 Watson Smith, then teaching "Technological Chemistry" at Owens College, commented

> There is no outlay of proportionately meagre amounts in any commercial branch, for which such, I would almost say, outrageously large and quick returns are demanded as Chemical Education in this country.[119]

He did not make any reference to the origins of these expectations. By the turn of the century comments on the failure of academically-trained employees were not uncommon.

It should be evident from the previous account that the members of the Select Committee were sceptical about the claims of the academics. This was reflected in the Report itself, which stated simply that scientific education was worthwhile but could not be claimed to be the basis of any British economic failures. It is ironic, but significant, that the proposals for the extension of general scientific education which were made differed only in scale and enthusiasm from what would have satisfied the scientific lobbyists. This was a result partly of the effective closure of the debate within constraints set by the academics, and, it will be argued later, partly by the wider constraint of what constituted a competent field and curriculum for public education. During this early period these two were mutually reinforcing, but even at this stage the exploration of alternatives was in progress.

At the Royal Scottish Society of Arts conference on technical education in 1868, one speaker, R.W. Thomson, called for the teaching of "technical knowledge", which he contrasted with "abstract science".[120] The President of the Society, the civil engineer George Robertson, noted in his Presidential Address of that year: "Every branch of learning, every species of knowledge, every kind of trade, has a science in it, and may be technically taught...".[121] Comments of this kind developed the tension noted earlier in George Wilson's representation of "technology". The idea that it was possible to define a curriculum of the "principles" of technical activities which was not merely "abstract science" or some selection thereof was in some respects well-established. Oxford University had had its Professorship of Rural Economy since 1796, and more recently the teaching of mining at the Government School of Mines legitimized such activity. At the School of Mines the Granville Committee had defended this role in preference to more general teaching.[122] The idea can be found most vividly expressed at this time in John Scott Russell's Systematic Technical Education for the English People, published in 1869. Noting the inclination of "members of the higher and modern professions" to keep secret the mysteries of their craft, he claimed that on the Continent there were "public institutions in which all these mysteries were unveiled, all this secret knowledge made public property."[123]

In a scheme which appears to have been a precursor of the activities of the City and Guilds later in the decade, a group of men with City connections, but few to the new academics, attempted to establish a National Technical University in 1870-1.[124] The scheme, to be based in the Greenwich Hospital, was to be orientated to "the practical (and) the useful; and its object the successful cultivation of every art, science, profession, trade and occupation...".[125] The proposal was received in silence by the scientific community. Finally the language surrounding the establishment of the Royal School of Naval

Architecture can be noted. It was to be, according to the Admiralty, for "the general study of the science of ship-building and naval engineering."[126] This development, which preceded the events of 1867, was described by its Principal in the correspondence following Granville's original letter to The Times as giving both "special acquaintance with the particular art" and "general instruction in the mechanism and combination of materials".[127] Such formulations of what could be understood as "technical education" differed from those of the academics in that they were underpinned by few institutions or curricula.

The next major vehicle for public presentation of science's industrial role was the Royal Commission on Scientific Instruction, which sat from 1870 to 1875.[128] Its terms of reference were "to make Inquiry with regard to Scientific Instruction and the Advancement of Science and to Inquire what aid thereto is derived from Grants voted by Parliament or from Endowments". Thus it has been fitted rather within the sequence of events known as the endowment of research movement than the movement for activity of immediate industrial significance.[129] Many figures involved in science, such as Frankland, William Crookes, Ivan Levinstein and even William Odling at various times indicated only qualified approval for the "endowment" approach.[130] Crookes noted in Chemical News that such endowment which "as an abstract proposition ...appears reasonable enough" would not attract "the really earnest workers in science, but the scientific Micawbers."[131] Ivan Levinstein, a chemical manufacturer and editor of Chemical Review, suggested that it would encourage merely "fashionable men" and greater bureaucracy in "South Kensington".[132]

Despite its terms of reference, the Commission could not avoid a fairly close examination of the directly industrial significance of scientific education. The evidence of the witnesses and the close questioning by the Commissioners indicates already more developed and self-conscious views than those of a few years earlier. Thus Williamson showed a tendency to bridle at the mention of technical education, and was given a repeatedly close questioning by the Commissioners.[133] Once it was established that forms of economically significant educational activity in the public sphere could exist, the curricular basis of this activity became highly exposed. Williamson appears insufficiently sensitive to the shifts of language needed, in contrast to Roscoe or Playfair. Such tensions were the harbinger of an increasing complexity within public discourse.

It was during the 1870s that the first curricular shifts towards technological teaching occurred, in institutions such as the Yorkshire College, or encouraged by the Society of Arts Technological examinations. The Chemical Review commented

> until the Yorkshire College, none of the seats of higher education ventured upon boldly associating instruction in those practical arts which have made our country rich with a knowledge of pure and applied science.[134]

During the preparatory work undertaken by the City and Guilds of London in the late 1870s a reconnoitring of the balance between 'true' technical education and mere "trade teaching" occurred in the reports which were commissioned from J.F.D. Donnelly, G.C.T. Bartley, T.H. Huxley and others. This was, however, in many respects merely a trial run for the much greater enterprise of the Royal Commission on Technical Instruction which sat from 1881 to 1884.[135]

It is a mistake to place too much emphasis on the title of this Royal Commission: this title nevertheless gives some indication of shifting assumptions and pressures. The Owens College Extension Committee, when approaching the Society of Arts for support in 1869, could routinely refer to "the extension of technical education, or, more properly, scientific instruction".[136] Earlier it was suggested that an important aspect of the 'technical education movement' was its association with that for general secondary education, nowhere more clearly expressed than in Huxley's famous comment in 1877 that "your 'technical education' is simply a good education".[137] By the time of the Samuelson Commission there is evidence of resistance to this view. C.T. Millis, of the City and Guilds Technical College at Finsbury argued in 1884 that

> instruction, in no way differing from what was formerly given as scientific, is now termed technical; to which appellation it has no title whatsoever.[138]

The Commissioners' examination of witnesses on the subject of education provides an insight into the basis of new curricular activity. Charles Graham gave evidence as Professor of Chemical

Technology at University College, and was subjected to some close, not to say hostile, questioning from Roscoe for his evident belief that fairly limited chemical knowledge was adequate to prepare for the study of technical aspects of brewing.[139] Graham was able to remain within the pale by his agreement that he did not "attempt to teach processes", though he had earlier stated that he was able "to develope (students') knowledge of their own technical processes".[140] Samuelson came close to the crux of the questioning when he offered this summary

> you consider that valuable knowledge, knowledge which would not be acquired in the brewery or in the dyehouse, can be given by you (that knowledge not being simply a knowledge of pure chemistry).[141]

This careful description of the curriculum was no mere pedantry, but an attempt to locate a key boundary. The most usual compromise term for the legitimate preserve of the industrial curriculum was "principles". Long, convoluted discussions could occur over the meaning of the term in relation to particular sectors, as for example in the questioning of C.W. Siemens by the Samuelson Commissioners, where everyone involved appears to have become rather irritated.[142] The identification of the "principles" with abstract science, a commonplace of ten years earlier, was less evident.

The underlying pressure was tacitly acknowledged during the questioning of T.H. Huxley, where he noted increased specialization or, as he put it,

> special classes set up to grind young fellows, without any knowledge of principles, in that which would be no better than a rule of thumb learning of the present practice of their business...instruction in special subjects in cases where preliminary instruction in general physical science is ignored.[143]

The structure of this answer is revealing. The latter part in effect licensed what the earlier part had condemned, provided that it was preceded by instruction in pure science, and that this science was identified with industrial principles. Yet the connection between the two fields is left vague, as is the relationship between the "grinding" and the (apparently) legitimate technical education which would follow instruction in general physical science. A further implication was that physical science is a more effective preparation for future industrial activity than knowledge of current practice. John Donnelly somewhat undermined these messages in his statement that what the Department of Science and Art would allow as "technical" was "all a matter of expediency".[144] He was referring here to the relationship between the Department and the City and Guilds Technological Examinations. This was supposed to institutionalize the cognitive relationship which Huxley was exploring. The Samuelson Commissioners later found themselves in difficulties when dealing with the City and Guilds' activities.

The City and Guilds Institute sent four witnesses to the Samuelson Commission who, while willing to adopt the linguistic conventions of the time, were unwilling to give ground on their judgement of what curricular content might be appropriate.[145] Roscoe asked Sydney Waterlow at some length about the problem of teaching "brewing, calico printing, or dyeing", not failing to point out that German polytechnics did no such thing. Waterlow made clear that the proposed Central Institution would allow

> practical experiments, either in connection with brewing or calico-printing or dyeing...enabling the professors to see whether the students have really grasped their subject practically.[146]

Earlier, Owen Roberts had been equally firm in telling Roscoe that the instruction would be more specialized than that at Owens College.[147] Samuelson questioned Roberts about the Institution's technological examinations, remarking that competent people had expressed the view that a written examination would not be suitable for the assessment of "technical arts". The word "arts" here may indicate that Samuelson felt the examinations were extending beyond acceptable boundaries, but Roberts replied simply by agreeing, and stating that the City and Guilds were intending to conduct supplementary practical examinations. Roberts made clear that the City Guilds would not accept restraints and criticisms which stemmed from an alternative view of technical education, and indicated also the context in which their activity was perceived as important:

> We read in trade journals criticisms directed from a manufacturer's point of view, and we endeavour to improve our system in accordance with the suggestions we find in those journals.[148]

Some indication of the Commissioners' approach to industrial personnel has already been given. Further insight, in the context of the chemical industry proper, can be obtained from their examination of the main witness with experience in that sector, W.H. Perkin.[149] Perkin stressed the importance of research training for "chemists intended for industry". The Commissioners accepted this point, but in their report it was emphasized in connection with manufacturers themselves, seen as industrial "leaders". A long sequence of questions was devoted to the appropriate technical training for an industrial manager in a synthetic dyestuff factory.[150] Perkin's awkward final answer appears to undermine the entire thrust of the questioning, and again suggested that he was focusing on a distinction between chemist and manager which the Commissioners were not addressing: "German chemists", he noted, "as a rule, who go into works of this nature as chemists, do not go to a technical school." The Commissioners' account of the Swiss dyestuff firm of Bindschedler and Busch also shows this tendency to assimilate scientific knowledge and personnel directly to the authority structure of the firm. They wrote:

> the scientific director...is a thoroughly educated chemist...Under him are the three scientific chemists...Each of these head chemists has several assistant chemists placed under him...An important part of the system has now to be noticed, viz., that directly under these scientific assistants come the common workmen, who have, of course, no knowledge whatever of scientific principles, and who are, in fact, simple machines, acting under the will of a superior intelligence. The many and great advantages of this system are patent to all.[151]

It is evident from other parts of the report that this plant undertook considerable research activity (it possessed 10 laboratories), but the focus of the Commissioners' comments is on the production hierarchy. It is not intended to suggest that this was either a conscious distortion or exhaustive of their perception of the role of trained men in the chemical industry. However, they did not appear see it as necessary to attempt a systematic, functionally differentiated account of the most developed plant which they visited.

The Commissioners' commentary on the existing and required system of technical education is difficult to summarize coherently. It begins with an affirmation of the fact that "our managers, our foremen, and our workmen, should, in the degrees compatible with their circumstances, combine theoretical instruction with their acknowledged practical skill", and an account of existing facilities. Here, "theoretical instruction" is identified, for example, with preparation for the science examinations of the Department of Science and Art, and natural science instruction in the universities and university colleges.[152] Included in this is criticism of the continuation of the education of "those intended to become proprietors or managers of industrial works" in "a Polytechnic school" as a general policy. Moving on to consider this group in more detail, the Commissioners sub-divided them into

> capitalists who will take the general, as distinguished from the technical, direction of large establishments; and those at the head of small undertakings, or the persons more especially charged with the technical details of either.[153]

For the latter the key requirement was "sound knowledge of scientific principles" before entering the plant. They discriminated hesitantly between industrial sectors, itself a novel element, but only in terms of varying the time spent studying abstract science. Approval was expressed for curricula including the use of "machine and hand tools" for "familiarizing students with their use". There follows a diversion into art education, treated a good deal more robustly than science. ("Large grants of public money for teaching art to artizans in such classes can scarcely be justified on any other ground than its industrial utility.") Returning to science, the Commissioners allowed themselves to criticise "workmen (who) attach too little value to the importance of acquiring a knowledge of the principles of science", before, remarkably, presenting the City and Guilds practical classes as "a mode of instruction in which the direct application of scientific principles is the means by which a knowledge of these principles is conveyed".[154] A description of manual instruction in elementary schools follows, and then a return to science, with an emphatic statement that

> no portion of the national expenditure on education is of greater importance than that employed in the scientific culture of the leaders of industry.

This was associated with an emphasis on "investigations...the practical bearings of which were not at the outset apparent" (pace artists). Immediately afterwards the Commissioners praise weaving and dyeing schools, whose aim was to instruct in "the processes of the manufacture of goods". After discussing several other topics they return to the City and Guilds, praising trade schools and the technological examinations, characterized simply as as "more specialised, according to the requirements of persons engaged in different industries" than those of the Science and Art Department.[155]

Turning to the Commissioners recommendations one finds a basic orientation to science at various levels: in elementary schools, under the Science and Art Department, in teacher training colleges, for "secondary and technical instruction" (specified as including "natural science, drawing, mathematics, and modern languages") together with some comments on public libraries and museums. These are followed by some general recommendations for tuition in "science and art" after starting work, on the payment of science teachers and the grouping of "cognate science subjects", on scholarships for elementary school children, on agricultural education and a pious hope that the City and Guilds Central Institution would be properly funded (the Technological Examinations, it seemed, would have to look after themselves).[156] It had been a commonplace of the 1860s and early 1870s that curricula based on specific technical knowledges were impossible or worthless.[157] The shift in what was considered an acceptable position is evident from the content of the Samuelson Commission evidence, but the thrust of the recommendations continued to draw on a model of the industrial role of public education where "abstract science" was central. Roscoe himself stated the position uncompromisingly in 1884, when he told the Society of Chemical Industry that "for technologists the three great requirements are science-science-science."[158]

This account of the governmental enquiries has indicated some of the other elements in the view which had dominated public discourse during the period. Before making a final comment on the Samuelson Commission, it is appropriate to summarize that position.

The key component was the directly instrumental character of scientific knowledge, defined in terms of those knowledges associated with early academic practice. It was axiomatic that this knowledge represented a necessary, and sometimes a sufficient, basis for control and innovation in industrial technique. This represented the radical element in the position taken up by the academics. At its crudest, it can be seen as an ideological construction based on the need to define potential societal benefits of the new academic practice. The academics' position was, however, in many respects conservative in outlook. This is most clearly the case in its analysis of the men who were to wield the powerful new knowledge. They tended, as has been seen, to be assimilated directly into the existing personnel structure of industrial firms. "Managers", "foremen" and, most optimistically, "leaders of industry" were the appropriate recipients of scientific knowledge. There was a connection between the supposedly unmediated utility of this knowledge and this position. It drew directly for its model on the type of activity which had been undertaken in the chemical and calico-printing industries for many years. Ideas of functional specialists and differentiation between routine analytical activity, research and development work etc. were not articulated. Even when they were sketched or hinted at, their mapping against class of worker within a decision-making hierarchy was immediate. Thus in the 1884 speech quoted above Henry Roscoe distinguished "the rank and file of our young technologists" from those

> who look forward to becoming our leaders in industry, who are determined to push beyond the routine of the present, to initiate new processes.[159]

Specification of the actual contemporary position of men specially trained in science was rarely precise and sometimes appears disingenuous (compare Roscoe above on "men in positions of trust"). The implication that they were, when not the sons of owners, candidates for partnerships was commonplace. Representation of the men active in the movement for increased technical education as radical or anticipating later developments is quite simply incorrect. As has been seen for the Samuelson Commissioners in relation to Bindschedler and Busch and Perkin their response to early manifestations of more developed structures was ambivalent. It can be argued that elements of structural differentiation within industrial firms preceded its recognition in public forums. The position adopted by the new academic chemists represented a radical shift from the situation described in the last chapter only in aspects limited and determined by the practice which they themselves were developing. This practice institutionalized the transmission and creation of an "abstract knowledge" characterized and limited by its generalized and public character. The academics reinterpreted the cognitive base of industrial activity in terms of this knowledge. But on aspects of industrial structure, which extended outside this ideological framework, they drew on older models. It will be suggested later that shifts from this position were constructed within the industrial sector itself. Something similar will be argued for technological curricula.

There are ancillary aspects to the adoption of a conservative view of the organizational implications of science. The idea that such a powerful industrial tool should be placed in the hands of artisans was unlikely to prove popular among the owners of capital, even if it could be sensibly argued within increasingly centralized, integrated and large-scale industrial plants. In addition, the type of science education requiring support was of a high level, if it was to sustain an academic practice at the boundaries of knowledge. It is necessary to note also the shifting cultural position of scientific activity. The expropriation of the amateurs of 50 years previously, as documented by Kargon for Manchester and as shown in the shifting emphasis in the Chemical Society, can be seen as a kind of marginalization.[160] Even a sympathetic observer such as Michael Foster noted in a Quarterly Review article that the men of science were "isolated", "dogmatic" and aggressive.[161] The effect of a functionally-specialized industrial work organization would have been to reinforce this process. Thus the response of the early academics can be interpreted as an attempt to minimize this, and to define a scientific-industrial culture sustaining professionalized academic activity within a high-level 'generalist' educational practice.

One final characteristic of the early view which must be noted was its undifferentiated character with respect to industrial sectors. Analytical chemistry was marked out from the first by its potential to service diverse sectors. This formed the basis for the generalized claims of "abstract" chemistry, and there was an inevitable tendency to minimize the significance of specific industrial practices. This was characterized as "mere empiricism" and, by a frequent slippage of meaning, as associated with handicraft skills.[162] The knowledges or technologies (properly so called) of these practices were equally downgraded in such terms as "rule of thumb", if they were allowed as existing at all. In the first instance the idea that such knowledges could be transformed into the bases or key components of curricula was summarily dismissed. A related possibility, and one which becomes increasingly difficult to disentangle from discussion of technological activity proper, was that of dividing chemical curricula according to the material substrate of particular sectors. Even within the analytical field the pressure for such specialization was considerable from an early stage. The response that chemical knowledge could not be sub-divided seems to have provided a valuable tactic for the academics who were, after all, the experts in handling and transmitting such knowledge. Nevertheless the more specialist position did provide them with a valuable strategy in responding to pressure for directly relevant curricula without licensing technology. Playfair seemed content to accept the possibility of specialization in the early 1850s, and this appears to be the meaning of Roscoe's comment to the Devonshire Commission in 1871 that

> ...the first thing is to secure a proper foundation of sound scientific principles. This is, I believe, our first duty, and then it is easy to add such knowledge of those portions of science which bear upon manufactures as may be of importance and value to the student[163]

The status of the view, or sequence of views, just presented must be treated carefully. It constituted a model which provides a useful benchmark against which particular statements can be judged, without being intended as a concrete description of the position of any individual or group. In part, as has just been seen, it represented also a kind of buffer, by the shifting of which curricular pressures could be, at least for a time, neutralized at the level of discourse. If technological courses must be set up, then attendance of 'pure' science could be made an institutional prerequisite. The dynamic of the shifting institutional and ideological position in the closing decades of the nineteenth century can be interpreted as a piecemeal shifting in the various components of the position.

The Samuelson Commission was the last great set-piece public enquiry on this area in the nineteenth century. Novel yet conflicting views were apparent in the evidence. The Report itself, particularly the part summarized above, is noticeable mainly as a remarkable hotch-potch on which it is difficult to impose any order. This can in part be interpreted as the result of the pressure of numerous practical initiatives, especially those of the City and Guilds, which could not be assimilated into the older view, but merely praised unilaterally and surreptitiously corrected. The Commissioners did not construct any typology of activity either in education or industry. Their view was closer to that of Roscoe and A.H.D. Acland in 1889 arguing on behalf of the National Association for the Promotion of Technical Education for a programme of general education: " (w)hat is now wanted is not to define more clearly, but to get the thing done".[164]

The recommendations of the Commission drew heavily on the model which has been described, though they also strongly refracted industrial arguments into a pressure for increased general education. The Commissioners unofficial efforts later crystallized around the National Association for the Promotion of Technical Education, established in 1887. The orientation of this group to general secondary education was clear from its propaganda output, as in the Contemporary Review article by the Marquis of Hartington and other supporters. It was formally recognized in 1890 when the Association changed its name to refer to "Technical and Secondary Education".[165] However, on all three main fronts (the question of the expansion of general secondary education, the possibility of an authentically technological curriculum and the concrete role of science in industry) the period from the mid-1880s saw an increasing diversity of expressed views.

The comments of "Philo-technology" in 1859, and some of those previously noted in the evidence to the governmental inquiries, indicate this process at an early stage. In a review of the 1867 Exhibition, a correspondent of Chemical News noted that German plants

> are always able to obtain the services of men who, having received their chemical education in laboratories directed by high-class men, are able to derive new processes, improve those already existing, and, especially, to adopt, simplify, and cheapen methods invented in this country.[166]

The concept of the specialist employee is expressed here more clearly than almost anywhere in the literature of the movement for scientific education, though the idea of the conceptual dominance of academic chemistry is clearly present. Fleeming Jenkin, writing in the Fortnightly Review in 1868, also expressed the position more coherently than was common:

> the usefulness of science is overrated...the manufacturer or manager will seldom have the best special knowledge of the kind he requires...The manager of a factory is essentially an admininistrative officer,— not a professional man, but able to superintend professional men.[167]

Both the curricular and the industrial practice aspects of the academic position were perceived as vulnerable during Roscoe's evidence to the Devonshire Commission:

> You would not transfer (a student of chemistry) at once from his theoretic studies to the superintendence of a lot of uninstructed artizans in a colour shop, without some intermediate step?-- I have no doubt that an intermediate stage would be very beneficial...but I cannot form to myself at the present moment an exact idea of how that is to be accomplished...[168]

By the time of the Samuelson Commission active attempts were being made to formulate curricula having an intermediate (and sometimes alternative) character. The innovations themselves are the subject matter of other chapters. As is clear from the comments of Millis earlier, such attempts were leading to public challenges to 'scientific' dominance and these were stated with some confidence during the 1880s.

In 1888 the Quarterly Review made a very effective analysis of the technical education "movement" for its failure to disaggregate industries, and its wide-ranging claims for education, ending with a jibe that

> (w)e are not sure whether there is not an element of self-interest, or at least strong bias with many of the advocates of technical education...[169]

The most famous of the challenges to the movement during this period was that from W.G. Armstrong (Lord Armstrong) of the Tyneside engineering firm. His comments were direct, hostile and based on wide industrial experience. He argued that the immediate functions of abstract science in industrial activity were limited and heterogeneous across sectors. In particular "...only in pursuit of research and discovery (was) highly advanced scientific knowledge" required.[170] In a second article he noted that the main location for "talented specialists" was in certain areas of the chemical industry, while in many other sectors the scientific basis was not "tangible".[171] Playfair attempted a response to Armstrong's comments, but was compelled to meet his specificities with a generalized advocacy of the need to "teach working men to observe, to appreciate and to think", and essentially to allow Armstrong to renew his claim that the true aim of the advocates of technical education was general secondary education.[172]

Even a sympathetic commentator such as Henry Armstrong, Professor of Chemistry at the City and Guilds Central Institution said of the promoters of the Technical Instruction Bill of 1889 that they were "availing themselves of the term 'technical education' because they knew it to be a popular expression". Their real aim must be to support "a wider system of State education".[173] At the same meeting Raphael Meldola, significantly also employed by the City and Guilds, attacked the introduction of chemistry into the elementary curriculum "smuggled in with the much-abused word 'technical' attached to it."[174]

These more abrasive comments are significant in two other respects. They were delivered by men from a new generation of academics, and in a forum (the London Section of the Society of Chemical Industry) which had not existed 10 years earlier. The Society of Chemical Industry (1881) was inevitably a still-fluid organization, but it represented a public arena for men whose 'professional' activity was in manufacturing industry.[175] Other forums potentially available for the expression of alternative views included the Institute of Chemistry (1877) and those industrially-orientated societies which had preceded the SCI: the Lancashire-based Faraday Club (1875) and the two Tyneside-based chemical societies, the Tyne Social Chemical Society (1870) and the Newcastle Chemical Society (1868). In addition, from 1874 to 1886 the Society of Arts operated a Chemical Section which was was held "in some sort of way" to represent technical chemistry.[176] A different type of platform was provided by such periodicals as William Crookes' _Chemical News_ (1859), Ivan Levinstein's _Chemical Review_ (1871) and, more generally, P.L. Simmonds' _Journal of Applied Science_ (1870). Later would come George Davis's _Chemical Trade Journal_ (1887), along with Crookes' publication the longest-lived of these periodicals, and the commercially-orientated Manufacturing Chemist (1892). The significance of these forums is variable, but they indicated the existence of a constituency, inevitably less voluble, less academically orientated and less integrated than the body of academics. It was able to formulate alternative, though not necessarily unconnected, views. The comment of Owen Roberts to the Samuelson Commission on trade journals can be recalled here.

The Chemical Review was particularly robust in its approach. In 1874 it took the still-unfashionable view that chemical training should include

> an insight into actual work, into the planning and arranging manufactories (sic) for different purposes...the construction and use of all the plant...[177]

It manifested an undifferentiated hostility to "South Kensington", especially "the inevitable Sir Henry Cole" and the "little knot of worthies" thrown to prominence by the Great Exhibition.[178] The general editorial position adopted, as in Chemical News and the Chemical Trade Journal, was far from hostile to scientific education, but critical of "official" views of senior academics and pragmatic about the possibilities of more directly industrial curricula. George Davis, himself a significant figure in the emergence of chemical engineering and chemical engineering education, could refer by 1887 to "all this gush" about technical education.[179]

An indication of the vigour with which the public orthodoxies of earlier decades could be attacked came during the establishment of the Society of Chemical Industry. The formal establishment of the Society occurred in April 1881. Much debate took place over its aims and title and D.B. Hewitt, of Brunner, Mond & Co., stated that manufacturers "could obtain plenty of men capable of carrying through processes in a laboratory, but not competent to apply them on a large scale".[180] The evident distancing from the centrality of academic chemistry produced tensions between academics and others. They surfaced in 1883 when the Council at first refused to publish Ivan Levinstein's Chairman's Address to the Manchester Section, partly because of its comments about academic chemistry.[181]

In 1889 the Society gave perhaps its fullest attention to education, on the initiative of the chemical manufacturer Thomas Tyrer, when all of the sections discussed the Technical Instruction Bill.[182] Though diverse points of view were adopted, many of the comments showed hostility to the generalist direction the movement (and the bills) were taking. The comments of Henry Armstrong and Raphael Meldola have already been noted above. Thomas Tyrer recognized pure chemistry, applied chemistry and chemical engineering as appropriate curricular activities.[183] R.J. Friswell explicitly distinguished between the "masters of chemical factories" and the "scientific worker".[184] In Manchester Watson Smith suggested that technical education was made to cover too great a range of activity, and that at "South Kensington" students learnt "to become scientists rather than technologists".[185] At Newcastle P.P. Bedson, supported by H.S. Pattinson, (an academic chemist and a practising analyst respectively) thought that the development of colleges of science was appropriate, whereas at Nottingham the dyer John Ashwell argued that men with successful industrial experience rather than mere academics were required and unlikely to be obtained at current salaries. In contrast to the somewhat hesitant view to be found here, by the turn of the century the President of the Society, George Beilby of the Cassell Cyanide Co., was confidently formulating curricula and expressing views on their relationship to industrial practice. He emphasized that "works operations are not simply laboratory operations writ large". It was practicable, he claimed, for universities to offer curricula to promote the special complex of skills required.[187]

The technical education movement absorbed rather than rejected shifts towards advocacy of more technological curricula. In their account of the situation in 1889 Henry Roscoe and Arthur Acland, on behalf of the NAPTSE, easily turned arguments about specialist requirements into that for a generalist preparation.[188] Tensions did, however, result from the increasingly explicit advocacy of such curricula within institutions. A clear example of this again involved the dyestuff manufacturer Ivan Levinstein. It was noted previously that Levinstein's supposedly anti-academic views drew criticism within the SCI Council. Yet he was active within both the Manchester Technical School and Owens College. In 1890 he told those students studying chemistry-related fields at the former institution that "the teaching of scientific principles, important as it is, is after all only a preparatory course for the study of 'Technology'", which should be "illustrated by appliances as near as possible similar to those in actual use in our works".[189] This drew a letter of support from Henry Roscoe, illustrating his underlying pragmatism.[190] Levinstein was not content to influence the Technical School. In 1892 he attacked the arrogance of academically-trained men, noting that in many cases when transferred to industry "the scholar makes a fool of himself" and arguing again for a more directly technical training. Later he attempted to introduce such activity into the curriculum of Owens College.[191]

Such views and initiatives provoked one academic chemist, Arthur Smithells of the Yorkshire College, to the radical step of criticising Levinstein publicly for the impracticality of his scheme. The training for the chemical industry must be that of "a chemist pure and simple", with no expectation of immediate usefulness from the "expert". It was the demand for immediate utility which was "at the bottom of all these schemes for producing chemical engineers".[192] It is of interest to follow Smithells view through into the twentieth century, located as he was in an institution with a deep-seated technological orientation. In 1894 his comment was caustic:[193]

> it has become implanted in the public mind that in chemistry there is an intermediate realm of knowledge which is free from the abstractions and futilities of pure science; yet in its nature scientific; which has for its apparatus something between the beaker and the boiler; and for its teacher something between the professor and the unpolluted practical man; for its goal pure gold.

However, speaking to the Congress of the Universities of the Empire in 1912, he can be found expressing almost the opposite view in parallel terms:[194]

> (T)he exclusive man of science is being forced to recognize that there is a whole realm of specialized knowledge, lying immediately outside his own domain and in close juxtaposition to the industrial arts, which may fitly engage the highest intellects to explore, to extend, and to impart.

By 1925, when speaking to an Institute of Chemistry conference on applied chemistry in defence of the rights of graduates from chemistry-related technology departments to full Institute of Chemistry privileges, he was sufficiently self-aware to be able to give a description of his own shift of view. He indicated that the shift had been brought about mainly through his being "confronted by demands on the part of industry born of a totally different view of chemical science".[195]

C. Increasing complexity: the turn of the century

The development in Smithells' views reflected a widespread diversification of approach. The first systematic exploration of the position after the Samuelson Commission was in a Sub-Committee of the London County Council Technical Education Board, on the teaching of chemistry, set up in 1896.[196] It was required to establish "in what manner the instruction might be made more thoroughly and better adapted to the needs of London industries". The terms of reference indicate the limited extent to which chemical education had succeeded in divorcing itself from a framework of utility and, as a corollary, the extent to which general scientific education remained under the effective authority of a "technical" administrative body. In this respect the comments of Sydney Webb to the Bryce Commission are relevant: he suggested that the Board covered 90% of the subjects taught in secondary schools, and was the effective authority for secondary education.[197]

The LCC sub-committee took evidence from a limited but well-defined body of men including Raphael Meldola, S.H. Davies (Battersea Polytechnic), Henry Armstrong, William Tilden (Professor of Chemistry at the Royal College of Science) and, perhaps most significant, Ferdinand Hurter. Hurter was the only man from outside London, brought down from the Central Research Laboratory of the United Alkali Company. The fundamental themes of the evidence were similar to those of 15 years earlier: the importance of high-level education, the location and function of chemical knowledge in the works and the value and practicability of specialized technical training. However, the language in which these issues were discussed was altogether more sparing and precise, drawing as it did on established activity at Finsbury, at the Central Institution and at the United Alkali Co. Distinctions between types of student were made positively, as were those between classes of men employed within the UAC identified by Hurter.

The inquiry was the first of a sequence around the turn of the century, coinciding with a period when interest in the industrial aspect of education probably exceeded any which had gone before. The Society of Arts staged the International Congress on Technical Education in June 1897.[198] The London County Council undertook a second inquiry, on the application of science to industry, in 1901.[199] The Board of Education mounted an internal inquiry on technological education in 1900.[200] In addition, the Departmental Committee on the Royal College of Science in 1905 led to the formation of the Imperial College of Science and Technology.[201] The subject matter of Presidential Addresses to the Society of Chemical Industry shifted markedly towards educational topics during this period. In the period 1881 to 1895 two out of 13 addresses were wholly or substantially concerned with this subject, compared with seven out of 14 in the period from 1896 to 1910. Keith Quinton's Science and the Manufacturer, published in 1906 and emphasizing a need for specialists in industrial research laboratories, provides an indication of the increasingly widespread and independent analysis of the situation.[202] In 1910 Raphael Meldola gave a comprehensive survey of the relations of science, education and industry during his Presidential Address to the Society of Chemical Industry. His account contained much that is recognizable in mid-twentieth century terms. By this time then public accounts of the situation had undergone a radical shift from those of a view decades earlier. The remainder of this chapter will attempt to describe the main points of contrast with the older situation, though, as will be seen, without suggesting that there was homogeneity of view during the period.

Differentiation of function was perhaps the key element which had emerged in representations of the industrial role of trained men. Three functions were recognized: servicing analysis; process control;

and research and development. An early outline of this structure was given by William Ramsay in 1904.[203] He took the argument one stage further by suggesting that the appropriate route for an academically-trained chemist was to enter the works as an analyst, before moving into one of the other two fields. This approach was adopted by Meldola in 1909 ("the great thing to consider was whether a man was to be a research chemist, a works chemist, or a departmental manager"[204]) and by others.[205] By 1921 an account by Francis Carr had introduced only one further class of employee, distinguishing troubleshooting from routine process control.[206]

Another characteristic which can be identified was the tendency to downgrade the activity of routine analysis, with explicit reference to the output and curriculum of the chemistry departments of the late nineteenth century. An education officer with the LCC, Robert Blair, told the BAAS Education Section in 1910, "under the name of chemist enough rubbish was supplied to (the chemical manufacturer) to break down his faith in the panacea". The English chemical schools had "turned out only analytical machines" 20 years earlier.[207] In 1913 H.B. Dixon suggested to the Institute of Chemistry that claims that manufacturers no longer looked merely for "testers" were mistaken, and research experience was now in demand.[208] However Meldola suggested that many manufacturers still treated chemists as "human testing machines", and Walter Reid took a similar position in 1911.[209]

Another significant development was the increasing tendency to present the role of individuals as merely part of a wider structure. From an early date the metaphor of an industrial army had been regularly used. Indeed in 1868 a writer in Chemical News had used it with explicit reference to Germany.[210] Playfair had applied it to the organization of science as a whole in his Presidential Address to the BAAS in 1884, while E.C.C. Stanford applied it to the wider organization of the industrial workforce in 1884.[211] After the turn of the century it was a commonplace, often involving a direct comparison with Germany.[212] Some part of this can be related to the wider imperialist and militarist approach, which some men of science adopted.[213] However, claims that a more general model for organization was being developed within the large scale capitalist enterprise itself were not uncommon. A vigorous statement of this view was offered by J.A. Hobson in 1906. For Hobson the commercial and technical organization of a modern firm represented

> an application of science as important and as progressive as any of the contributions of the physical sciences...modern capitalism is the concrete industrial expression and embodiment of science, organised mentality applied to the production of wealth.[214]

J.A. Fleming, Professor of Electrical Engineering at University College London, told the LCC Sub-Committee in 1902 that capital, labour and scientific knowledge were all of less significance than "commercial organizing power...which puts the other three in their right relations."[215] These comments were made in connection with the ambiguity of the phrase "leaders of industry", itself a noticeable shift from the time when this phrase was inserted almost automatically into accounts of the industrial role of scientific education. One of the clearest expressions of view came in 1908 from an individual with concrete industrial experience: Max Muspratt.[216] This must have drawn on his experiences as a young man with technical training working in the environment of the United Alkali Co., though his approach was considerably more developed than anything which can be discerned in that company. James Dewar, speaking before hostility to things German had fully gathered momentum, indicated in 1902 the extent to which the heroic language of 20 years earlier was being replaced by a more bureaucratic account even of scientific activity itself. In his Presidential Address to the British Association he claimed that

> It is in the abundance of men of ordinary plodding ability, thoroughly trained and methodically directed, that Germany at present has so commanding an advantage.[217]

Frequently public discussion on the issue slipped into a conflict between such expertise and that of commercial men. Looking back at organic chemical industry (which had for a long time been constituted as a paradigm of UK decline in so-called 'science-based' industries) the firm of Brooke Simpson & Spiller was singled out by A.G. Green as dominated by men with largely commercial instincts who had "condemned their firm to continued decadence and ultimate extinction".[218] The question surfaced most vigorously and concretely in 1915 during the formation of British Dyes Ltd. The announcement of the directorate of the government-financed firm provoked Meldola, the Chairman of its Advisory Council, to protest in a letter to The Times that it asserted

> that principle which has wrecked many of our industries in the past...the subordination of science to 'business' in an industry in which science should govern the Directorate.[219]

The letter was supported by others from Henry Armstrong, William Ramsay and Edward Thorpe.[220]

The burgeoning public discussion of industrial aspects of public education, the examination of the German 'model' for such activity, and the shifting emphasis reflected by new forums such as the British Science Guild, could make this field a study in itself. It was marked particularly by an underlying acceptance of the place of public education as an appropriate mechanism for inducting men at all levels within industry. This is a fundamental contrast, probably deeper than curricular and organizational issues, with the later nineteenth century. It cannot merely be attributed to the efforts of the propagandists discussed above, but reflects a deeper renegotiation of the role of the state in many aspects of civil society.[221]

Focusing more narrowly, one of the striking characteristics of the language of academics is that, in general, it reversed one of the central aspects of the situation which was described above. They were, so far as can be judged from the archive evidence, offering an account of industrial organization which anticipated organizational shifts rather than employing a conservative model. Men like Ramsay, Meldola and Dixon appear to have recognized that the utilization of trained men which had been made in industry was dominated by a narrow and routine form of functional specialization in analytical work. This situation was a common cause for complaint from well before this period, and will be discussed further in chapter 6. The older emphasis on "leaders of industry" was manifestly not tenable as a basis for scientific education, and academics appear to have projected and exaggerated the embryonic forms of specialist industrial employment known to exist. "Research" became the central novel element in the career trajectory they promoted. Moreover they formalized the route from the laboratory into process management which did exist into a central and desirable mechanism, drawing on the language of "organization" and "efficiency".

The main curricular shift during the period was that, from the turn of the century, the arguments for more directly technical academic curricula and research were advanced with greater frequency. The position of chemical technology in the curriculum will be examined detail in the following chapter. Here the general situation will be outlined. Some academics in the now well-established pure discipline gave the new fields a cool response. This can be illustrated by FS Kipping at Nottingham and FG Donnan at Liverpool. It may have been impractical for them to deny outright the claims of technological studies, in view of the amount of activity occurring in London and the provincial universities. In any event their position was largely confined to reasserting the more fundamental status of the pure sciences and the need for preliminary courses there. This position is the descendant of the view of men like Roscoe and Williamson. It is typified by Donnan's comment to the Liverpool Section of the Society of Chemical Industry in 1908, where he argued that chemical theory must "rule successful technical practice", and particularly that physical chemistry and the newer chemical theories must first be taught to the intending industrial chemist.[222] Donnan affected to find "amusing" a view attributed to the electrochemical engineer James Swinburne that technical men "refined and finished" the "crude raw material" supplied by the pure sciences. By 1914 Donnan was, if anything, more vigorous, attacking "cheap knowledge...vulgar ambition and...short-sighted utilitarianism".[223] However, as will be seen in chapter 7, Donnan was quick to support the novel discipline of chemical engineering when it was perceived as contributing to the importance of his own special field of physical chemistry.

Kipping, speaking as President of Section B of the BAAS in 1908, attacked the enthusiasm of manufacturers for education on "the practical side", going so far as to single out the activities at institutions in Birmingham, Leeds and Manchester as generating a "poorly trained Jack-of-all-trades".[224] He argued for a five-year academic training for future works chemists, including two years' research. They would then move into the works laboratory "those who proved to be the best research chemists would, of course, remain in the laboratory." Kipping was not, however, averse to gaining resources from industry on his own terms, and went on to suggest that "applied research" (i.e. research on the chemistry of problems of interest to manufacturers) might be undertaken by university departments. Donnan, on the other hand, claimed that undertaking directed research ("closely connected with questions of immediate practical interest" was the phrase used) would involve "so many delicate questions" as to cause problems, and was better carried out by manufacturers themselves. Donnan came from a better endowed institution than did Kipping and his remarks were cautiously expressed. The general position of academic chemists before the First World War was not hostile to obtaining funds in this way provided that what they presented as the integrity of the curriculum was maintained. After the war a more robust conflict came into view, as the universities attempted to exploit the perceived contribution to industrial and military successes in claims for more funding. Henry Armstrong suggested that German universities had been ruined by too great an industrial orientation, and the consequent prevention of open discussion.[225] In 1918 the Scientific Research Association was established "in order that the interests of pure science may not be lost sight of amongst the increased activities of applied science."[226]

Academics in technological fields, exemplified by A.K. Huntington speaking to the Faraday Society in 1917 and A.G. Green speaking to the Institute of Chemistry in 1913, were usually careful in their approach.[227] One of the rare examples of tensions between the claims of industrial and academic knowledge breaking the surface (though not in relation to the curriculum) was the controversy in 1919 between Herbert Levinstein and Green, in the one hand, and William Pope on the other, over the production of mustard gas. Levinstein, managing director of the Manchester dyestuff manufacturers, claimed that[228]

> (o)ur scientific advisers found (the German) process difficult. If they had come straight to our dye industry we could have shown them how to carry out the reaction on a large scale without any difficulty whatsoever.

Pressure for new curricula helped legitimize activity which had already begun to draw the boundaries of new academic fields, such as dyeing, metallurgy and chemical engineering. This applied especially to new institutions (e.g. Leeds University and Manchester Municipal School of Technology, the latter from 1905 as the Faculty of Technology in the Victoria University of Manchester). Such institutions became more securely located in the field of higher education. The process of defining the position of technical studies thus had two elements. On the one hand it involved a differentiation within the many new institutions which had sprung up as municipally-funded technical colleges, polytechnics and potential university colleges. In addition the position of technological disciplines within university institutions was negotiated. The process aided the downgrading of the term "technical" to something which frequently resembled its mid-twentieth century meaning. By 1895 Philip Hartog was complaining that the assumption of equivalence between English technical schools and German Technische Hochschulen was masking the true educational reasons for German success.[229] Speaking in 1903 Meldola claimed that the English use of the term "technical education" was "degraded".[230] In 1915 E.B.R. Prideaux could delineate the education of the "industrial chemist" in terms of "technical" and "university" perspectives. He contrasted the technically-trained man, with a routine knowledge of specific processes, and the university man, with a wide theoretical base and power of investigation, "the officers of the army of production".[231]

Julius Wertheimer, Dean of the Faculty of Engineering at Bristol University, illustrated the ambivalent emotions of men active in the field in his response to the 1903 Consular Report by Frederic Rose on German Technical High Schools. Wertheimer objected to any subordination to established academic activity, but thought that technical institutions "might, however, very well become constituent parts of a university..."[232] The criteria for this were generally formulated as twofold. Firstly there was the requirement of the prosecution of research of a kind suitable for publication. In a careful and concise analysis of the situation in 1904 W.P. Dreaper identified this as a key absence in the work of the technical colleges: "original experimental work" was the best measure of the result of the colleges' activities.[233] The reason for their comparative failure was that the manufacturer "will not see work concerned with his factory routine...publicly carried on", and private professorial work was inappropriate for academic activity.

This method of delineating curricula and institutions pointed to an important problem in the assimilation of technological studies as authentic academic disciplines on the model of the 'pure' sciences. Raphael Meldola, himself a teacher at a what was nominally a technical college, referred to this issue repeatedly. In 1903 at a University Extension Meeting, and again in his 1907 Presidential Address to the Chemical Society, he attributed a key role to technical research in defining the industrial relevance of the universities, and the absence of it as the key failure of the technical colleges.[234] Norman Lockyer, speaking as President of the Association of Technical Institutions felt the need to defend the research output of the technical colleges from the attack by Meldola. He suggested that they did not deal with that particular class of work which would naturally go to the Journal of the Chemical Society.[235]

Meldola was also a most articulate defender of the claims of independent applied science. In the 1903 address previously referred to he distinguished between the physical sciences and the distinct "claims of the applied sciences as subjects worthy of inclusion in (the universities') curriculum".[236] In his 1907 address to the Chemical Society he gave a notable reinterpretation of the Perkin legend. Perkin's "accidental discovery of mauve... was not in itself a very remarkable achievement...". However, Perkin had

> developed a laboratory preparation into a factory product involving the use of raw materials which had never before been made on a large scale...[237]

This had been Perkin's principal achievement. The remainder of Meldola's address was again essentially an appeal for recognition of such "applied research" in factory and academe.

However his most explicit claim for technical curricula was made in his 1909 Presidential Address to the Society of Chemical Industry, previously referred to for its analysis of industrial activity. In the educational field he referred to the "lack of discrimination" which had characterized the late nineteenth-century view, and went on

> Those teachers who are clamouring for the staffing of our factories by scientifically trained chemists, have, if I may say so, damaged their case by leaving out of consideration the expert technologist—the man whose knowledge of technique enables him to translate a new discovery into terms of pounds, shillings, and pence.[238]

He then developed the idea of "technicalising" (the word is Meldola's) academic activity in chemistry-related fields, both in terms of curriculum and research. Meldola indicated explicitly that he was conscious of taking up a new position, although he was to some extent exaggerating its novelty. In the second decade of the century the extension of this view among (then) less prominent figures such as Martin Onslow Foster and Charles Carpenter can be clearly seen.[239] In some cases these men were willing to push the boundaries of their schemes well beyond those which were likely to be compatible with an academic view, the most extreme example being F.H. Carr.[240] Carr's vision of academic institutions producing chemicals for sale is interesting precisely in that, by going beyond the boundaries within which applied science could hope to gain a legitimate place, it illustrated how wide those boundaries had now become. The principle of disciplines drawing directly on industrial knowledges, subject to various, usually implicit, criteria, received in contrast only limited resistance in the twentieth century.[241] The reality was of course complex, requiring to be worked out for each field and to some extent for each institution.

One final group must be noted as taking an identifiable, if limited, part in the public negotiation. These were men employed in industry who had little sympathy with the attempt by new academic groups and others to appropriate the definition and transmission of their particular skills and knowledge. Platforms for such men were limited. However in 1911 there existed for some time an Institution of Chemical Technologists which was, briefly, associated with the periodical <u>Chemical Engineering and the Works Chemist</u>.[242] The organization faced strategic problems in its relations with academic institutions. On the one hand it had no foothold in the educational domain, while on the other it had the avowed aim "(t)o extend the study and practice of Applied Chemistry...". Some indication of the public attitude of the leading members to academic activity can be gained from the sequence of articles on the subject which appeared with noticeable frequency during its first year. They can be illustrated by the views of a Council Member, R.A. Dibdin. As might be expected there were frequent attacks on "knowing things without regard to use".

However support for more "practical" education was tempered. Dibdin expressed the central position as follows.

> The scholastic mind is gradually realising that Technology as a science may exist. It is a new kind of science, and the scholastic mind thinks perhaps it ought to exist. Of course it will not exist until a special University of Technology has been started, with curricula modelled on the lines of pure science teaching.[243]

The Institution will be referred to again in chapter 7.

The preceding discussion does not attempt to present a narrative of the changes in public view which occurred in the early twentieth century. Rather it delineates the main themes and groups which were involved and points up the contrasts with the situation during the later nineteenth century. It has looked particularly at the representation of the position of trained men in industry, and of technical curricula and academic research. In the period from the mid- to the late-nineteenth century public discourse had been dominated effectively by transactions between an emergent body of professional academics in the pure sciences and a loosely structured body of manufacturers and politicians. The influence exerted by the academics was to some extent effective in changing the institutional forms (and perhaps the cultural significance) of science.[244]

The early twentieth century situation involved more classes of protagonist and the complexity of their relationships underpins the views which have been discussed. By this time chemistry had developed most of the institutional apparatus of a mature academic discipline, and sub-disciplines were already well on the way to formation. Though, as this section has indicated, chemistry found itself involved in dealings with emergent technological fields, it operated from a position of strength, having gained a largely hegemonic position in chemistry-related areas. A variety of forces had contributed to this position, some of which have been discussed in this chapter. However attempts had been made from the 1860s to establish curricula or forms of certification in "technical chemistry", of varying degrees of independence, which engaged more directly with industrial practice. The following chapter explores the most important examples of these and the reasons for their weak position.

Notes to Chapter 3

1 J.A. Wilson, Memoir of George Wilson M.D. F.R.S.E., (Edinburgh, 1860).
2 G. Wilson, What is Technology? Inaugural Address at the University of Edinburgh, (Edinburgh, 1855), p.1 and On the Objects of Technology and Industrial Museums: Two Lectures Addressed to the Philosophical Institution, Edinburgh, in February 1865, (Edinburgh, 1856).
3 Idem., 'On the Physical Sciences which Form the Basis of Technology', Edinburgh New Philosophical Journal v (1857), pp.64-101.
4 Owens College, 'Annual Report of the Principal' (1856), p.vi.
5 Report of the Select Committee on Scientific Instruction, P.P. 1867-8, xv, q.1188.
6 "The Professors of Chemistry, Botany, and Natural History, each saw a rival in the Professor of Technology, and they got the Senatus to represent to Government that it would be better, instead of seeking for a new Professor of all the useful Arts, to allow each of the Professors named to lecture separately within the Museum on subjects connected with his own department." A. Grant, The Story of the University of Edinburgh during its First Three Hundred Years (1884), pp.360-1.
7 Compare F.M. Turner, 'Public Science in Britain 1880-1919', Isis lxxi (1980), pp.589-608.
8 E. Fiddes, Chapters in the History of Owens College and of Manchester University 1851-1914, (Manchester, 1937), p.13.
9 Ibid., p.44.
10 "John Owens Esquire, Deceased, Minutes of Trustees, Proceedings etc", 19 December 1850, 7 September 1857.
11 Stenhouse (1809-1880) and Smith (1817-84) studied with Liebig. Frankland and Roscoe were pupils of Bunsen. On Stenhouse see JCS xxix (1880), p.190. and Smith see JSC xlvii (1885), p.335. Crace Calvert (1819-73) studied with Chevreul in Paris. DNB. Penny (1816-69) had studied at Giessen. On Penny see JCS xxiii (1870), p.301.
12 Manchester Guardian, 22 March 1851.
13 Owens College, Prospectus 1852.
14 Owens College, Annual Report 1853.
15 Ibid., 1856, p.vi.
16 Manchester Guardian, 9 July 1858.
17 On see E. Frankland, Sketches from the Life of Sir Edward Frankland, (2nd. ed. 1902), p.135, and C.A. Russell, Lancastrian Chemist: the Early Years of Sir Edward Frankland, (Milton Keynes, 1986). Amongst the Owens Professoriate only those of Classics, Mathematics and Logic and Mental Philosophy were eligible for appointment as Principal. "John Owens Esquire, Deceased, Minutes of Trustees, Proceedings etc", 26 July 1850
18 Evidence to the Royal Commission on Scientific Instruction, P.P. 1871-2, xxv, q.7253.
19 J. Butt, 'Technical Change and the Growth of the British Shale-Oil Industry', Economic History Review xvii (1964-5), pp.511-21.
20 Manchester Guardian, 25 August 1857. The second part of the biography by Russell may cast some light on this episode.
21 Roscoe Letter Books, John Rylands Library, University of Manchester, English MSS CH R107.
22 Roscoe, op. cit. (1906), p.177.

23 Essays on a Liberal Education, ed. F.W. Farrar (1867). F.W. Farrar, 'On Some Defects in Public School Education', Proceedings of the Royal Institution v (1866-9), pp.26-44. Modern Culture: its True Aims and Requirements, ed. E.L. Youmans (1867). C.G.B. Daubeny, Can Physical Science Obtain a Home in an English University?, (Oxford, 1853).

24 R.G. McPherson, Theory of Higher Education in Nineteenth Century England, (Georgia, 1959). S. Rothblatt, Tradition and Change in English Liberal Education: an Essay on History and Culture, (1976). M. Garland, Cambridge before Darwin. The Ideal of a Liberal Education, 1800-1860, (Cambridge, 1980).

25 Hofmann, op. cit., pp.xliii, xlvi.

26 RCSI, q.8531. See Temple's comments to the Clarendon Commission under close questioning from Vaughan and Lord Lyttleton, Report of Her Majesty's Commissioners Appointed to Inquire into the Revenues and Management of Certain Colleges and Schools, P.P. 1864, xx xxi, qq.1037-48. Temple (1821-1902) was Headmaster of Rugby. JP Norris (1823-91) was, among other things, an Inspector of Schools. Both DNB. Some indication of the distance between the older view and that which came naturally to the new academics is given by Newman's comment: "that alone is liberal knowledge which stands on its own pretensions, which is independent of sequel, expects no complement, refuses to be informed (as it is called) by any end, or absorbed into any art...the Baconian philosophy, by using its physical sciences in the service of man, does thereby transfer them from the order of Liberal Pursuits to, I do not say the inferior, but to the distinct class of the Useful'. J.H. Newman, The Idea of a University, (1873 ed.), pp.95-7. For Mill there was 'tolerably general agreement about what an University is not. It is not a place for professional education'. J.S. Mill, Inaugural Address to the University of St. Andrews. February 1st 1867, (1867?).

27 Report of Her Majesty's Commissioners Appointed to Inquire into the State, Discipline, Studies and Revenues of the University and Colleges of Cambridge, P.P. 1852-3, xliv, pp.322-3.

28 On Wilson see DNB. T.W. Bamford, The Rise of the Public Schools. A Study of Boy's Public Boarding Schools in England and Wales from 1837 to the Present Day, (1967), p.111. A.J. Meadows and W.H. Brock, 'Topics Fit for Gentlemen: the Problems of Science in the Public School Curriculum', in The Victorian Public School, ed. B. Simon and I. Bradley (Dublin, 1975), pp.95-114.

29 Newman, op. cit., pp.xxviii-xxxi. For others the idea of the pursuit of experimental science at the ancient univerities was simply impractical. (J.B. Mozley), 'The Oxford Commission', Quarterly Review xciii (1853), pp.152-238.

30 M. Pattison, Suggestions on Academical Organisation, (1868). On Cambridge see R. Svierys, 'The rise of physical science at Victorian Cambridge', Historical Studies in the Physical Sciences ii (1970), pp.127-51.

31 L. Playfair, 'The Chemical Principles Involved in the Manufactures of the Exhibition as Indicating the Necessity of Industrial Instruction', in Society of Arts, Lectures on the Results of the Great Exhibition, (1853), pp.73-96.

32 Report of Her Majesty's Commissioners Appointed to Inquire into the State, Discipline, Studies and Revenues of the University and Colleges of Cambridge, P.P. 1852-3, xliv, p.102. Report of Her Majesty's Commissioners Appointed to Inquire into the State,

Discipline, Studies and Revenues of the University and Colleges of Oxford, P.P. 1852, xxii, pp.107-8. The Oxford Commission was more inclined to lament the threat of the middle and lower classes exceeding the upper classes in knowledge of natural science.

33 Playfair, op. cit., p.88.

34 T. Wemyss Reid, Memoirs and Correspondence of Lyon Playfair, (1899).

35 H.E. Armstrong, James Dewar, 1842-1923, (1924), p.6.

36 Playfair returned to the question of the relation between education and industry many times. An incomplete list of these occasions includes apart, from that already cited: 'The Study of Abstract Science Essential to the Progress of Industry (Being the Introductory Lecture to the Course of Chemistry', Records of the School of Mines and of Science Applied to the Arts i (1851-2), pp.23-48; (Museum of Economic Geology. Government School of Mines and Science Applied to the Arts), Industrial Instruction on the Continent (Being the Introductory Lecture of the Session 1852-1853), (1852). Science in Its Relation to Labour. Being a Speech Delivered at the Anniversary of the People's College, Sheffield, on the 25th October, 1853, (1853); 'Scientific Institutions in Connection with the Department of Science and Art', Introductory Addresses on the Science and Art Deparment and the South Kensington Museum, No.3 (1857); speech to the Yorkshire College, 6 October 1875, Leeds Mercury 7 October 1875; 'Technical Education' in Subjects of Social Welfare, (1889), pp.307-36.

37 Playfair, op. cit. (1851-2), p.27.

38 Playfair, op. cit. (1853), p.88.

39 Playfair, op. cit. (1889), p.261.

40 L. Playfair, 'Personal Reminiscences of Hofmann and of the Conditions which Led to the Establishment of the Royal College of Chemistry', JCS lxix pt.I, (1896), pp.575-9. Compare Roberts' account of the College in Roberts, op. cit. (1973).

41 Playfair, op. cit. (1853), p.95.

42 Playfair, op. cit. (1853), p.13. He used the same metaphor over 30 years later to the BAAS, op. cit. (1889), pp.225-62.

43 Playfair, op. cit. (1889), p.244.

44 Playfair, op. cit. (1853), p.89.

45 SCSI, qq.1032 et seq.

46 Playfair, op. cit. (1852), pp.8-9.

47 Playfair, op. cit. (1853), p.89.

48 Playfair, op. cit. (1875).

49 A.W. Hofmann, 'Remarks on the Importance of Cultivating Experimental Science in a National Point of View', Reports of the Royal College of Chemistry and Researches Conducted in the Laboratories in the Years 1845-47, (1849), pp.xxiii-xliv.

50 H. Roscoe, 'On the Development of Physical Science', Introductory Lectures, (Manchester, 1857).

51 On the "total" conception of ideology see K. Mannheim, Ideology and Utopia. An Introduction to the Sociology of Knowledge, (tr. L. Wirth and E. Shils), (1960), pp.49-53.

52 W.W.Rostow, British Economy of the Nineteenth Century, (Oxford,1948), pp.33-9.

53 R.Angus Smith, 'Science and Social Progress', Transactions of the National Association for the Promotion of Social Science, (1857), pp.517-26.

54 W.H. Perkin, 'The Origin of the Coal-Tar Colour Industry and the Contribution of Hofmann and His Pupils', JCS lxix (1896), pp.596-637.

'The Aniline or Coal-Tar Colours', Journal of the Society of Arts xxii (1868-9), pp.99-105.

55 Perkin, op. cit. (1896), p.605.

56 R. Brightman, 'Perkin and the Dyestuff Industry in Britain', Nature clxxvii (1956), pp.815-21. W.V. Farrar, 'Synthetic Dyestuffs before 1860', Endeavour xxxiii (1974), pp.149-55. Perkin, op. cit. (1868-9).

57 J.J. Beer, The Emergence of the German Dye Industry, (Illinois, 1959), p.27. On the men referred to see chapter 6.

58 JSDC xxiv (1908), pp.8-9.

59 'Notices of Some of the Patents Taken Out for the Preparation and Use of the New Dyes, Generally Known as Fuchsiacine, Violine, Purpurine, Roseine, Magenta &c., with Remarks on Them', CN ii (1860), pp.244-5. The substance of the criticism was that the patents covered materials globally, with no real understanding of the chemical processes involved. See also Perkin op. cit. (1896), p.632-4 and Hofmann op. cit. (1862),

60 L. Playfair, 'On Some of the Chemical Arts, with Reference to Their Progress between the Two Great Exhibitions of 1851 and 1862', CN v (1862), pp.302-6, 327-32. Compare Perkin himself: 'On the Newest Colouring Matters', Notes and Proceedings of the Royal Institution v (1866-9), pp.566-74.

61 On Runge (1794-1867) see B. Anft, 'Friedlieb Ferdinand Runge: a Forgotten Chemist of the Nineteenth Century', Journal of Chemical Education xxxii (1955), pp.566-74. Perkin had tried to prove post hoc that the material was Runge's Blue and failed. Perkin, op. cit. (1868-9).

62 A.W. Hofmann, 'On Mauve and Magenta', Notices of the Proceedings of the Royal Institution iii (1862), pp.468-83.

63 International Exhibition, 1862. Reports by the Juries on the Subjects in the Thirty-Six Classes into Which the Exhibition was Divided, (1863), Class IIA Chemical Products and Processes, p.124.

64 Perkin, op. cit. (1866-9), p.574.

65 Charles Mansfield (1819-54) was working at the Royal College of Chemistry in connection with coal-tar distillation. Obituary: JCS viii (1855), pp.110-12. Letter from Perkin reprinted in 'Zum fünsfigjährigen Jubiläum der Teerfarbenindustrie' in Zeitschrift für Angewandte Chemie xix (1906), p.1281. Perkin had worked initially with anthracene supplied by Samuel Clift of the large distilling plant of John Bethell. Clift himself had obtained the dyestuff "Tar Red", of obscure nature, from coal tar in 1853. W.H. Perkin, 'On the Colouring Matters Obtained from Coal Tar', CN i (1861), pp.346-55.

66 G. Gore, The Scientific Basis of National Progress, Including that of Morality, (1882), pp.9-10. F. Abel, Presidential Address to Section B, Report of the 47th Meeting of the British Association for the Advancement of Science, (1877), pp.43-50. R. Meldola, 'The Relations between Scientific Research and Chemical Industry', Nature lxviii (1903), pp.398-404.

67 H. Cole, 'The International Results of the Exhibition of 1851', in Society of Arts op. cit., p.534.

68 Society of Arts, Middle Class Education and Class Instruction in Mechanics' Institutions, Considered in Two Reports of the Society of Arts, (1857), p.164.

69 Ibid., p.69.

70 CN i (1859), pp.17-18.

71 Rostow, op. cit., pp.33-9.

72 Playfair, op. cit. (1862).
73 Granville was speaking at the London University degree ceremony. The Times, 17 May 1867. Fowler was speaking at the Annual Dinner of the Institution of Civil Engineers, ibid., 9 May 1867. Granville's letter appeared in The Times of 29 May 1867. It was followed by letters from, among others, D.S. Price and Charles Merrifield, ibid., 30 May, 31 May, 4 June, 11 June, 12 June.
74 Ibid., 29 and 30 October and 19 December 1867.
75 Ibid., 25 and 26 April 1872.
76 The best survey of this activity remains D.L.S. Cardwell, The Organisation of Science in England, (1972), chapter 5, but see also J. Blanchet, 'Science, Craft and the State. A Study of English Technical Education and Its Advocates, 1867-1906', unpublished D.Phil, Oxford University, 1953. The Select Committee on Scientific Instruction was referred to above, note 5 It will be abbreviated here as SCSI. The reports and minutes of evidence to the Royal Commission on Scientific Instruction (Devonshire Commission) can be found in P.P. 1872, xxv; 1873, xxviiii, xxii; and 1874, xxviii. They will be abbreviated here as RCSI. The reports and minutes of evidence of the Royal Commission on Technical Instruction (Samuelson Commission) can be found in P.P. 1881, xxvi; 1884, xxix, xxx, xxxi, xxxii. They will be abbreviated here as RCTI. On the background to the reports see R.M. McLeod, 'Education: Scientific and Technical' in Government and Society in Nineteenth-Century Britain: Commentaries on British Parliamentary Papers. Education, ed. G. Sutherland, (Dublin, 1977), pp.196-225.
77 Schools Inquiry Commission, Report Relative to Technical Education, P.P. 1867, xxvi, p.263. Society of Arts, Conference on Technical Education, Journal of the Society of Arts xvi (1868), pp.627-42. This was followed in 1872 by the establishment of a committee to consider the question of technical education, ibid., xx (1872), pp.261-3, 725-35; xxi (1873), pp.21-34. Conference on Technical Education, Transactions of the Royal Scottish Society of Arts vii (1868), pp.395-472.
78 On Frankland (1825-99) see E. Frankland, Sketches from the Life of Sir Edward Frankland, (1902). On Williamson (1829-90) see J.H. Harris and W.H. Brock, 'From Giessen to Gower Street: Towards a Biography of A.W. Williamson', Annals of Science xxxi (1974), pp.95-130. David S. Price (d.1888) was educated at Giessen, worked in the dyestuff and iron industry before eventually becoming Superintendent of the Technological Museum at Crystal Palace. Proceedings of the Institute of Chemistry (1890). On Young see J. Butt, 'James Young, Scottish Industrialist and Philanthropist', Ph.D. thesis, University of Glasgow, 1963.
79 The Times, 11 June 1867.
80 Journal of the Society of Arts iv (1855-6), p.219
81 SCSI, p.i.
82 Ibid., q.4664.
83 G. Howell, 'Trades Unions, Apprentices, and Technical Education', Contemporary Review xxx (1877), pp.833-57. 'On Technical Education', Journal of the Society of Arts xxiv (1875-6), pp.775-7. H. Pelling, A History of British Trade Unionism, (1963), pp.73-6. On Howell (1833-1910) see DNB.
84 SCSI, q.2439. On Jenkin (1833-85) see DNB.
85 RCSI, qq.1703, 1784-5.
86 W. Crookes, A Practical Handbook of Dyeing and Calico-Printing,

(1874), p.2.
87 *Journal of the Society of Arts* xx (1871-2), pp.261-3.
88 *RCTI, First Report*.
89 D. Layton, *Science for the People*, (1973).
90 Lord Armstrong, 'The Vague Cry for Technical Education', *The Nineteenth Century* xxiv (1888), pp.45-52.
91 *RCSI*, q.1808.
92 *Journal of the Society of Arts* xvi (1867-8), pp.633-40.
93 W.A. Miller (1817-70) was Professor of Chemistry at King's College, London. *CN* xxi (1870), pp.177-8. DNB. On Roscoe's low opinion of Miller see R.J. Spring, 'The Development of Chemistry in London in the Nineteenth Century: Studies in the Social History of Chemistry', unpublished Ph.D. thesis London 1978, p.216.
94 *SCSI*, q.1008.
95 Ibid., q.1146.
96 Ibid., q.5509.
97 Ibid., q.8128.
98 Ibid., q.8130.
99 Ibid., qq.5512-4.
100 Letter from W.P. Beale, 19 June 1914, to H.E. Armstrong, apparently in connection with a proposed biography of Mond. Beale was a contemporary of Mond's at university. Armstrong correspondence, ICLA, MS 67. J.M. Cohen, *The Life of Ludwig Mond*, (1956). J.R. Lischka. 'Ludwig Mond and the British Alkali Industry: a Study in the Interrelations of Science, Engineering, Education, Industry and Government', Ph.D. thesis, Duke University, 1970.
101 *SCSI*, q.5515.
102 Ibid., q.5525.
103 See above p.24.
104 W.A. Miller, ibid., q.3340; Frankland, ibid., q.8108.
105 Ibid., q.5747. This story was repeated a number of times, and Meldola referred to it as part of the folklore of technical education in 1909. R. Meldola, 'Education and Research in Applied Chemistry', *JSCI* xxviii (1909), pp.555-77. See also H. Roscoe, *Record of Work Done in the Chemical Department of the Owens College, 1857-1887* (Manchester, 1887), p.9.
106 Ibid., q.3319.
107 Ibid., q.8035. On the curriculum of the Royal School of Mines see chapter 4.
108 Ibid., q.6674. On Chance (1814-1902) see DNB.
109 Ibid., q.6625.
110 Ibid., qq.6692-3.
111 On Hopkinson (1850-99) see *Chemical Trade Journal* xxiv (1899), p.64.
112 Ibid., qq.5988-93. On Rumney (1812-72) see *JCS* xxvi (1873), pp.780-2.
113 Ibid., qq.5999, 6064, 6066.
114 Ibid., qq.6056-6.
115 Ibid., qq.7000-32, especially 7017 and 7019. On Clapham (1823-81) see *JSCI* i (1882), p.19. See chapter 6.
116 Ibid., qq.4047-8. On Ripley (1813-82) see W. Cudworth, *Histories of Bolton and Bowling (Townships of Bradford) Historically and Topographically Treated*, (Bradford, 1881), pp.249-57.
117 Ibid., qq.4048-9. Cheltenham College, established in 1841, was well-established as providing a scientific curriculum, and preparation for a military career. It received the sons of John Brunner and Ludwig Mond also. M.C. Morgan, *Cheltenham College. The First Hundred Years*,

(Chalfont St. Giles, 1968).
118 Ibid., q.4900.
119 W. Smith, 'On a Course of Instruction in Technological Chemistry, and the Difficulties at Present Encountered and to be Overcome in this Country', JSCI iv (1885), pp.84-93. On Smith see chapter 4.
120 Conference on Technical Education, Transactions of the Royal Scottish Society of Arts vii (1868), pp.395-472.
121 G. Robertson, 'The Science Education Movement', ibid., pp.570-96.
122 Department of Science and Art, Tenth Annual Report, P.P. 1863, xvi, Appendix V.
123 J.S. Russell, Systematic Technical Education for the English People, (1869), p.147. Another formulation of technical education as a more specialized but still authentically educational activity was expressed at this time by Alfred Barry, Principal of Cheltenham College and then of King's College London. The Relations of Technical to General Education, (1867).
124 The scheme was first proposed in July 1870: its ultimate fate is obscure. It may have merged with the City and Guilds movement. Journal of the Society of Arts xix (1870-1), pp.76 and 630.
125 Executive Committee of the Proposed National University for Technical and Industrial Training, A National Technical University for Great Britain and Her Colonies; or How to Utilize Greenwich Hospital and the Obsolete Charities, (1871), p.9.
126 Department of Science and Art, 11th Annual Report, P.P. 1864, xix, p.5.
127 The Times, 11 June 1867.
128 See note 76.
129 R.M. McLeod, 'Resources of Science in Victorian England: the Endowment of Science Movement, 1868-1900', in Science and Society 1600-1900, ed. P. Mathias, (1972), pp.111-66.
130 Frankland and Odling (then Professor of Chemistry at Oxford University) were later involved in a brief but bitter skirmish with Norman Lockyer on the issue. Odling was unsympathetic to endowment of research in his 1885 Presidential Address to the Institute of Chemistry. CN lii (1885), pp.243-7; 257-9. Lockyer in turn attacked those whose 'knowledge is merely a stock-in-trade to which they look for their livelihood'. 'The Whole Duty of a Chemist', Nature xxxiii (1885), pp.73-7. Odling replied with a reference to 'the new apostolate of sponging upon others...' Nature xxxiii (1885), p.99. See also Frankland's letter to Chemical News lii (1885), pp.305-6.
131 CN xxviii (1873), p.127.
132 Chemical Review iv (1874), pp.43-4. On Levinstein see chapter 6.
133 RCSI, qq.1173, 1197, 1217-28, 1292-1301, 1344-63.
134 Chemical Review x (1881), p.275.
135 Livery Companies' Committee, 1878. Report on Technical Education, (1878). On the Samuelson Commission see above note 76.
136 Nature i (1870), p.239.
137 T.H. Huxley, Collected Essays, (1895), iii p.411.
138 C.T. Millis, Education for Trades and Industries. A Historical Survey, (1932), p.144.
139 RCTI, qq.1517-21, 1551. On Graham (1836-1909) see JCS xcvii (1910), p.677. See also chapter 4, p.122.
140 Ibid., qq.1520, 1552.
141 Ibid., q.1549.
142 Ibid., qq.1413-71.

143 Ibid., qq.3001-2.
144 Ibid., qq.2866-7.
145 The four were (Sir) John Watney (1834-1923), Sir Sydney Waterlow (1822-1906), (Sir) W.P. Sawyer (1844-1908) and (Sir) Owen Roberts (1835-1915).
146 Ibid., q.4467. The City and Guilds Institute's activities will be discussed in chapters 4 and 7.
147 Ibid., q.4433.
148 Ibid., q.4518.
149 Ibid., qq.151 et seq.
150 Ibid., q.177 et seq.
151 Ibid., Second Report, pp.223-4.
152 Ibid., pp.513-5.
153 Ibid., p.514.
154 Ibid., p.523.
155 Ibid., p.528.
156 RCTI, pp.536-7.
157 Roscoe told the Devonshire Commission: "I deprecate altogether the idea of teaching (as some people seem to think it possible to do) the arts or manufactures themselves." RCSI, q.7367.
158 H. Roscoe, 'Remarks on the Teaching of Chemical Technology', JSCI iii (1884), pp.592-4.
159 Ibid.
160 Kargon, op. cit., pp.147-8.
161 (M. Foster), 'Science in Schools', Quarterly Review cxxiii (1867), pp.464-90. Foster (1836-1907) was Professor of Physiology at Cambridge University. For Ruskin in 1876 the men of science were increasingly objectionable as "the modern scientific mob". Works xxviii, p.532. Compare the comments of Beatrice Webb, note 244 to this chapter.
162 Among the many examples see H. Roscoe, Presidential Address, JSCI i (1882), 250-2 and note 143 above.
163 RCSI, q.7367.
164 Marquis of Hartington et al., 'The Industrial Value of Technical Training', Contemporary Review lv (1889), pp771-97. They were responding to accusations that the 'cry for technical education is vague and ill-defined'. They made no comment on the fact that their plea for "the improvement of elementary education by the encouragement of object lessons, by the extension of drawing teaching, and by the increase of facilities for the teaching of science, and for simple manual training..." had little in common with other contributions. Thus the dyestuff manufacturer Ivan Levinstein wrote: "It is not increased quantity but improved quality which we want." There is ample other evidence of fragmentation within the technical education 'movement' by this time.
165 NAPTSE, Third Annual Report, (1889), p.40.
166 CN xvi (1867), pp.96-7.
167 F. Jenkin, 'Technical Education', Fortnightly Review x (1868), pp.197-228.
168 RCSI, q.7397.
169 (J.G. Horner), 'Technical Education and Foreign Competition', Quarterly Review clxvii (1888), pp.448-60.
170 Lord Armstrong, op. cit., pp.50-1.
171 Idem., 'The Cry for Useless Knowledge', The Nineteenth Century xxiv (1888), pp.653-65.

172 L. Playfair, 'Lord Armstrong and Technical Education', ibid., pp.325-31.
173 JSCI viii (1889), p.331.
174 Ibid., p.334.
175 The Society's first Council of 29 members included 18 principals/partners and 4 academics. There is further discussion of the Society in chapter 6.
176 CN xxxiii (1876), p.250. JSA xxxiv (1886), p.1267.
177 Chemical Review iii (1874), pp.3-4.
178 Ibid., iv (1874), p.43-4; v (1876), p.43; vii (1878), p.304.
179 CTJ i (1887), p.85. On Davis see chapter 7.
180 Chemist and Druggist xxiii (1881), pp.182-4.
181 Society of Chemical Industry, Council Minutes, 21 December 1883.
182 Ibid., 23 November 1888. JSCI viii (1889), pp.325-51.
183 Ibid., p.327. On Tyrer (1892-1918) who was a manufacturing chemist see PIC (April 1918), p.51.
184 Ibid., p.331. On Friswell (1849-1908) who was a director in the dyestuff firm of Brooke, Simpson & Spiller see PIC (April, 1908), p.29.
185 Ibid., p.338. On Smith see chapter 4.
186 Ibid., p.348.
187 G. Beilby, 'The Relations of the Society to Chemical Engineering and to Industrial Research', JSCI xviii (1899), pp.333-40. On Beilby (1850-1924) see DNB.
188 Marquis of Hartington et al., op. cit., pp.793-6.
189 I. Levinstein, Address to the Students of the Chemistry, Dyeing and Printing Departments in Manchester Technical School, Introductory Address on Technical Teaching and Its Application to Trades and Industries, (Manchester, 1890). The lecture was reprinted in Manchester Guardian 20 September 1890.
190 Ibid., 23 September 1890. Contrast note 157 above.
191 JSCI xi (1892), pp.875-8. See chapter 4.
192 JSCI xiii (1894), pp.18-21. On Smithells (1860-1939) see DNB.
193 JSCI.xiii (1894), p.18.
194 A. Smithells, 'The Relation of the Universities to Technical and Professional Education', in Congress of the Universities of the Empire, 1912, Report of the Proceedings, (1912), pp.77-85.
195 Institute of Chemistry, Conference on the Place of Applied Chemistry in the Training of Chemists, (1925), pp.12-13.
196 London County Council, Technical Education Board, Report on the Teaching of Chemistry by a Special Sub-Committee Appointed by the Technical Education Board of the London County Council, (1896)
197 Royal Commission on Secondary Education, Minutes of Evidence, P.P. 1895, xliv, qq.2650 and 2658.
198 Society of Arts. International Congress on Technical Education, Report of the Proceedings of the Fourth Meeting. Held in London, June, 1897, (1897).
199 London County Council, Technical Education Board, Report of Special Sub-Committee on the Application of Science to Industry, (1902).
200 Board of Education, Annual Report, 1901, xix.
201 Departmental Committee on the Royal College of Science (including the Royal School of Mines) and Questions Connected Therewith, Preliminary Report PP 1905, lxi; Final Report I and Final Report II Minutes of Evidence and Appendices 1906, xxxi.
202 K. Quinton, Science and the Manufacturer, (1906).

203 JSCI xxiii (1904), pp.851-7. Ramsay was Professor of Chemistry at University College London. See W.A. Tilden, Sir William Ramsay (1918).
204 R. Meldola, 'Education and Research in Applied Chemistry', JSCI xxviii (1909), pp.555-77.
205 See, for example, H.L. Heathcote, 'The University Training of Industrial Chemists' JSCI xxviii (1909), pp.171-7 and T.H. Gray commenting on R.M. Caven, 'The Chemical Education Question', JSCI xxxv (1916), pp.1195-8.
206 F.H. Carr, 'Post-graduate Training in Industrial Chemistry', JSCI xl (1921), pp.161R-4R.
207 R. Blair, 'The Relations of Science to Industry and Commerce', Nature lxxxiv (1910), pp.345-53.
208 Institute of Chemistry, Conference of Professors of Chemistry, Held at 30 Bloomsbury Square, London, W.C., on Friday, 17th October, 1913, (1913), p.38.
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210 CN xviii (1868), pp.239-40.
211 E.C.C. Stanford, Chairman's Address to the Glasgow and West of Scotland Section, JSCI iii (1884), pp.149-56.
212 See, for example, E.H. Starling, 'The Pressing Need for More Universities', The Nineteenth Century il (1901), pp.1029-37; Blair, op. cit., pp.350-1.
213 R.J.S. Hoffman, Great Britain and the German Trade Rivalry, 1875-1914, (1933). Turner connects it closely with the British Science Guild, op. cit. pp.601-5.
214 J.A. Hobson, 'Science in Industry' in Science and Public Affairs, ed. J.E. Hand, (1906), pp.172-206. This view was also frequent, though with "science" as the model for all forms of organization, in the British Science Guild. See for example the comments of Sir William Mather and R.B. Haldane in British Science Guild, Inaugural Meeting at the Mansion House, October 30th, 1905, (1905), pp.7-9, and Haldane's comments at the 3rd AGM Third Annual Report, (1909), pp.2-3.
215 London County Council, Technical Education Board, op. cit., pp.16-17.
216 M. Muspratt, 'The Individual and the Corporation in the Chemical Industry', JSCI xxvii (1908), pp.1185-7. See also H.S. Garry, 'Works Organisation', JSCI xxvii (1908), pp.605-8.
217 J. Dewar, Report of the 72nd Meeting of the British Association for the Advancement of Science (1902), pp.15-18.
218 A.G. Green, 'Some Notes on the Discovery and Introduction of Primuline', JSDC xxxiii (1917), pp.137-46.
219 The Times, 20 January 1915.
220 Ibid., 20 January, 2 February, 10 March 1915.
221 On the wider context see G.R. Searle, The Quest for National Efficiency. A Study of British Politics and Political Thought, 1899-

1914 (Oxford, 1971).
222 Donnan, op. cit., p.275. The last point is part of the more general attack on merely analytical studies.
223 F.G. Donnan, 'Chemical Education in a Modern English University' in A Miscellany: Addresses Presented to John MacDonald Mackay, (Liverpool, 1914), pp.19-25. On Donnan (1870-1957) see DNB. His view on chemical engineering is discussed in chapter 7.
224 Kipping, op. cit. On Kipping (1863-1949) see DNB.
225 JSCI xxxviii (1919), p.358T.
226 Ibid., pp.26R-27R.
227 'The Training and Work of the Chemical Engineer', Transactions of the Faraday Society xiii (1917-18), pp.61-118. Institute of Chemistry, Conference of Professors of Chemistry, Held at 30 Bloomsbury Square, London, W.C., on Friday, 17th October, 1913, (1913), pp.13-14, 35. Huntington was Professor of Metallurgy at King's College, London. Green was Professor of Tinctorial Chemistry and Dyeing at Leeds University.
228 JSCI xxxviii (1919), pp.249T, 344R, 363R. See also L.F. Haber, The Poisonous Cloud. Chemical Warfare in the First World War (Oxford, 1986), pp.164-5.
229 P.J. Hartog, 'The Owens College, Manchester', The Record of Technical and Secondary Education iv (1895), pp.407-25.
230 R. Meldola, 'The Relations between Scientific Research and Chemical Industry', Nature lxviii (1903), pp.398-404.
231 E.B.R. Prideaux, 'The Education of the Industrial Chemist', JSCI xxxiv (1915), pp.535-6.
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233 W.P. Dreaper, 'Technical Research and the College System', CN xcvix (1904), pp.230-1; c (1904), p.2-3.
234 Meldola, op. cit. (1903) and (1907).
235 Lockyer, op. cit. (1908).
236 Meldola, op. cit. (1903), p.403.
237 Meldola, op. cit. (1907), p.632.
238 Meldola, op. cit. (1909), p.558.
239 C. Carpenter, 'Chemistry and Engineering', JSCI xxxv (1916), pp.1185-91; idem., 'Research in Technology', ibid., xxxiv (1915), pp.763-5. M.O. Forster, 'Research and Chemical Industry', JSCI xxxiv (1915), pp.759-63.
240 F.H. Carr, op. cit., and 'The Post-Graduate Training of the Works Chemist', JSCI xxxviii (1919), p.1013R.
241 The Committee established by the British Science Guild, for example, was quite clear that for high-level men in industry 'whole-time instruction is essential in institutions of advanced type. It is desirable that each institution of this type should add to its curriculum, as far as possible, specialist instruction in a particular subject, or group of subjects, relating to one or more of the principal industries of the district.' British Science Guild, Fifth Annual Report, (1911), Appendix C (Report of the Technical Education Committee), p.56.
242 Chemical Engineering and the Works Chemist i (1911), pp.3-7.
243 R.A. Dibdin, 'The Chemical Technologist', ibid., pp.62-4.
244 Beatrice Webb gives a vivid account in My Apprenticeship of their dominance within the culture of the 1880s, "snubbing the artists, ignoring the poets". p.153.

Chapter 4. Chemical Technology in the Curriculum 1850-1910

A. Introduction

The mainstream chemical curriculum and academic discipline were themselves only just defined (the latter in rudimentary form) at the beginning of the second half of the nineteenth century. The major innovations in science education (some, to be more exact, certification) with a chemical component in the period from 1850 to 1870 were: the Natural Science Tripos and the Science Schools at Cambridge and Oxford Univerities (1850 and 1851); the B.Sc. degree of London University (1858); the Society of Arts examinations (1856); and the Department of Science and Art examination (1859-60).[1] Other examinations, such as the Oxford and and Cambridge Locals, also began to appear. None of these had so explicitly industrial a reference as those which will be discussed in this chapter. The Society of Arts and the Department of Science and Art examinations both generated a considerable amount of industrial rhetoric during their establishment, but the industrial content of the examinations was very slight. Evidence on the extent of the industrial orientation of the examinees will be discussed in chapter 5. Nevertheless all of the activities referred to above had an important role in determining the balance of educational curricula and in the construction of a body of professional academics, both directly and through the provision of teaching posts, examinerships and a demand for teacher training. Courses offering a chemical education were continually appearing. By 1870 the annual survey of chemical education in Chemical News identified 50 chemistry courses in existence, many with more than one teacher.[2]

This chapter will not attempt to follow the process by which the independent disclipinary activity of pure chemistry matured except, as it were, in relief. It will look at changes with a technical orientation in a number of important institutions: the Andersonian in Glasgow, Owens College and the Manchester Technical School, and

University College, London. Some attention will also be given to early events at the Royal School of Mines, to the City and Guilds Technological Examinations and to those of the Institute of Chemistry. The intention is to survey a sufficient range of important institutions to allow some general view to be developed of the characteristics of this type of curricular innovation. Developments at the City and Guilds Central Institution are not included. Although the situation there impinges on those of the institutions to be discussed in this chapter, the chemical curriculum was described at first as "chemical engineering" and will therefore be discussed in chapter 7.

The developments discussed here involved the diversification of curricula into industrially-based knowledges, and can even be seen in some cases as an attempt at discipline formation. They implied a renegotiation of the connection between the "pure" academic discipline of chemistry and industrial activity. The idea that formal education could play a key part in the reproduction of the industrial workforce was taken over from the academics and placed in a different cognitive context. The earliest curricula of the kind with which this chapter is concerned can be found in the 1850s and 1860s at Owens College and the Royal School of Mines.

B. Owens College and the Royal School of Mines, 1851 to 1870

It was observed in the previous chapter that the relationship to industrial activity was a central element in the justification of the chemical curriculum at Owens in the mid-century. Some of the tensions in the position of the chemistry department were also outlined there. In fact the technical claims of the early chemistry courses were considerable. The earliest major course (1852-3), though "complete in one session", was described as embracing "both organic and inorganic Chemistry, their applications to the Arts, Manufactures, Agriculture and Animal Physiology, and the laws of Physical forces".[3] It was accompanied by a course in "Analytical and Practical Chemistry" described as follows:

> The object of this course is to make the Student practically acquainted with Chemical manipulation and analysis, the assaying of Metallic Ores, and the various other Chemical determinations which constantly occur in the Arts, Manufactures and Agriculture.[4]

Moreover, in 1853-4 Frankland was offering a separate course in "Technological Chemistry". This consisted of sections on "Vegetable fuel, Common Salt and its derivatives, Dyeing and calico printing, and the production and value of food". It attracted 7 students.[5]

The relevance of these curricula to the activities occurring within an industrial plant and to the students intending to work there will be discussed below. In any event Frankland's Technological Chemistry course "remained unexecuted" in 1854-5. The Principal commented "(t)here were not students far enough advanced in the science to proceed to its application...".[6] It attracted 5 students the following year, none in 1857-8 and 7 in 1858-9. The main chemistry course also struggled to attract students at this time, reaching a nadir in 1856-7, the year of Frankland's departure, with 33 students. In the years of growth under Roscoe which followed the course in Chemical Technology remained of limited significance. During the 1860s, while numbers of students of all types following the general courses grew steadily, exceeding 100 in 1870, the Technological Course usually had a single figure enrolment. Twice during the period it was not formed.

Its status was equally doubtful. It was listed among the Day Classes in the Calendar, and was indeed timetabled on Wednesday afternoon from 4pm to 5. Yet its numbers, examination papers and prizewinning students were reported under the Evening Classes. There is no indication at this time of the member of staff who delivered the course. None had significant industrial experience. This was in any case of less importance than might be expected, because the course was described as discussing all of "the most important Chemical Manufactures...as far as time will permit". It promised to include the major fuels, water and air "as regards their Sanitary and Technological relations", acid and alkali manufacture, dyeing and calico printing and glass and porcelain manufacture.

As in all institutions, the situation at Owens was partly determined by local conditions. The enthusiasm of the early governing body for a "traditional" university curriculum, under the terms of John Owens' will has already been referred to. Nevertheless the college did not have a unique experience of technical chemistry in England at this time. It can be compared with the Government School of Mines and Science Applied to the Arts. This institution had been founded in 1851, emerging from the Geological Survey, which had incorporated various classes within its Museum of Economic Geology. The first Professor of Chemistry was Lyon Playfair. In 1853 it was partially merged with the privately founded Royal College of Chemistry, and Hofmann became Professor of Chemistry. Playfair moved to an administrative position within the Department of Science and Art. These institutions have been examined by several scholars. Bud and Roberts have documented the generalized claims which were made for the course in analytical chemistry available at the Royal College of Chemistry and the connection of the College with various technical interests, notably agriculture, pharmacy and medicine.[7]

The first Annual Report of the DSA in 1854 described how the School consisted of four divisions, of which Division C, the "Technical Division" was intended "for those who propose to engage in either arts or manufactures, depending either chiefly on chemical or chiefly on mechanical principles".[8] The School had little success in its organized courses for matriculated students. The Granville Committee on the School noted in 1862 that its annual average of matriculated students over the previous 9 years had been only 11, though occasional students had averaged 54.[9] As a result of this committee the School was reorganized so as to focus on mining, though with limited effect. Complaints from the mining regions of its remoteness were voiced to the governmental commissions a few years later, and a large proportion of its activity continued to involve students recruited for short-term, ad hoc courses.[10] Parallels between Owens and the School of Mines included both curricula and the difficulty of attracting students for technical courses. A letter from Frankland to Playfair in 1853 shows that Frankland envisaged a connection based on more than merely parallel curricula.[11]

The prospectuses of the two institutions and their associated examination papers cast some light on the teaching which they undertook, and thus the interpretation placed on the rhetoric of "applied chemistry". Each institution offered as its mainstream academic course a systematic descriptive treatment of the main elements and organic and inorganic compounds, together with a basic introduction to qualitative and some quantitative analysis. The course for matriculated students at the Royal School of Mines was described as follows:[12]

> The fundamental studies in practical chemistry are the same for all pupils, however different the future pursuit may be to which the knowledge obtained will be applied. It is only after having mastered the most important methods of distinguishing, separating, and estimating substances...that the course of each student diverges into some special line.

There followed a list of technical subjects offered, indicating both a discursive and essentially descriptive treatment, and covering the full range of chemical and chemistry-related industries. "Technical chemistry" or "chemical technology" at both Owens and the School of Mines involved two main components: descriptive and analytical information on those substances which could be chemically defined, together with broad-brush descriptions of the processes involved in various industries, interpreted in terms of the former categories and usually encompassing some elementary thermochemistry and stoichiometry.[13] Industrial processes were thus understood in terms of academic practice and its conceptualizations.

Discussion of curricular content leads directly to questions of the workplace competencies which could be engendered and the characteristics of students' anticipated and actual employment. This area will be treated in chapter 6, though it will receive intermittent attention in this chapter. The fundamental competence developed by the courses under discussion was clearly analytical. In 1856 Frankland told his old teacher Bunsen that the students at Owens wished to know only about "the testing of 'Soda-ash' and'Bleaching-powder'".[14] Among the points of interest here is the material specificity of Frankland's comment. The idea that analytical techniques were readily generalized, the result of carefully carrying out a limited number of algorithmic procedures, was often fostered at this time, as has already been indicated. It was, at best, a half-truth, applicable to the estimation of specific chemical species in well-understood starting materials. The reality of successful analytical practice was very different, as the frequent controversies over analytical techniques at the commercial level indicate. For any but the most elementary student standard techniques were not available in any practicable curriculum. Thus when E.K. Muspratt, son of the alkali manufacturer James Muspratt, attended Owens to develop his knowledge of analytical techniques for metals he found that Frankland had little to teach him, and he was left largely to his own devices. He stayed only two months.[15] Furthermore, the instrumental significance of such analytical knowledge in the workplace was limited except in certain industries, of which dyeing may be the best example. In a heavy industry with a chemical orientation the situation was very different, as the famous investigation in 1844 by Bunsen and Playfair of the operation of the blast furnace indicates. It was undertaken under optimum conditions, and thus represents the limit of the application of this type of analytical knowledge. Yet, despite Playfair's claims, the utility of the knowledge obtained appears to have been very limited.[16]

These early examples of 'technical' curricula constrained 'industrial' chemistry within the cognitive boundaries of academic chemistry. The possibility of more independent approaches existed, establishing new contents for the teaching and, eventually, the research aspects of academic practice. In fields not identified with chemical manufacture this type of development is found in the Royal School of Naval Architecture (1864) and the activities leading to the foundation of the Yorkshire College of Science (1874).[17] In the chemical field the first such attempt occurred in the Young Chair of Technical Chemistry at the Andersonian in Glasgow.[18]

C. The Young Chair of Technical Chemistry, 1869

The Andersonian was known during the nineteenth century as Anderson's Institution (1796-1828), Anderson's University (1828-77), Anderson's College (1877-87), the Glasgow and West of Scotland Technical College (1887-94) and the Royal Technical College. It had been founded under the somewhat optimistic terms of the will of a Glasgow academic, John Anderson "for the good of Mankind and the improvement of Science" and had included among its Professors of Chemistry Henry Birkbeck and Andrew Ure.[19] Throughout most of the century it was an underendowed institution offering day and evening classes of a mainly scientific kind, in the shadow of the University proper. It was controlled by a body of Trustees and Managers which had included from 1858 the paraffin manufacturer James Young. Young has been referred to previously as one of the chemical witnesses in the Taunton Commission's inquiry into technical instruction.[20] His earliest employment had been as a carpenter, but he had attended classes at the Glasgow Mechanics' Institute and at the Andersonian. Subsequently he had worked as an assistant to Thomas Graham at Glasgow and at University College, London. In 1839 he had moved to Lancashire, being employed in the alkali works of James Muspratt and Tennant, Clow & Co. Young eventually set up a works manufacturing paraffin at Glasgow, and made a considerable fortune in this field. He had strong connections with Lyon Playfair and Alexander Williamson, both of whom had shares in the limited company he set up in 1865.[21] During 1869, in the aftermath of the controversy over technical education, Young offered conditionally to endow the Andersonian in the sum of 10,000 guineas, the endowment to be used "for the encouragement of practical chemistry".[22]

The proposal was vague in curricular terms and administratively idiosyncratic. Nevertheless the prospect of such a large sum (approximately two thirds of the Andersonian's existing assets) appears to have stirred the Managers to act quickly. A week later a special sub-committee was established to consider the proposal.[23] By August 9 a body of Trustees (not the Andersonian Trustees) had been set up to oversee the fund, and offered what was now referred to as the Young Chair of Technical Chemistry to the organic chemist and dyestuff manufacturer W.H. Perkin.[24] On Perkin's acceptance it was agreed to rent premises within Anderson's College.[25] The Managers of the Andersonian passed the proposal to the institution's Trustees, who agreed to accept the Trust Deed on September 1, despite the protest of one member, John Adams, "against the nomination and appointment of an additional Professor of Chemistry".[26] The entire process had taken less than three months.

It is easy, with hindsight, to see that matters were unlikely to progress without difficulty. The new Chair posed directly the question of the nature of "technical" chemistry. Young's original reference to "practical chemistry" was significant, because this term, rather than the more tendentious "applied" chemistry, was frequently used to signify actual industrial operations of a chemical kind. Moreover, whereas men like Roscoe at Owens College could attempt to define curricular boundaries without an internal academic conflict, the Andersonian already possessed a Chair of Chemistry. The holder of the existing Chair was Frederick Penny. Penny had studied with Brande and Faraday at the Royal Institution, and at Giessen. He had held the Andersonian Chair, in conjuction with a consultancy practice, since 1839.[27] Both Penny and his supporter John Adams published pamphlets objecting to the new Chair. Penny's is the more interesting. Adams confined himself mainly to the administrative arrangements, outlining the damage being done to the interests of the holder of the existing Chair and, in the long term, to the Andersonian itself.[28] He noted also that there was an "undercurrent of gossip" concerning bad relations between Penny and Young. The administration of the Chair was indeed rather odd. It appears to have been designed to retain control in the hands of Young and his nominees, while using the premises and name of the College. Nevertheless Adams' complaint was rather superficial, and in some respects contradicted that of Penny.

Penny directly addressed the question of the nature of "Technical Chemistry" in an educational context. He claimed that the great majority of his students were "either sons of chemical manufacturers or young men following earnestly the study of Chemistry with a view of becoming connected with chemical works." He went on:[29]

> My laboratory is unmistakeably a Technical Laboratory. The instruction given and the processes illustrated have special reference to the industrial arts and to chemical manufactories.

The title "Technical Chemistry", he argued, was both "novel and mysterious" and "imposing and vaunted". It was calculated to convince the Trustees of the Andersonian that they were "to establish something new". Yet he himself had been teaching technical chemistry for many years. He had once worked in the largest "laboratory of manufacture" then existing in the country (probably that at Tennant's St. Rollox chemical works). Perhaps anticipating the argument that he taught mainly analytical chemistry, he went on to claim that, while acting as a consultant he had[30]

> ...acquired a complete and thorough practical knowledge of every essential process and operation of Technical Chemistry, and of the most approved construction of apparatus in use on a large scale.

He claimed to have developed improvements in many fields, and that[31]

> ...I have also been enabled, for many years, to give in my lectures, without violating confidence, extended and accurate descriptions of the various processes of Chemical manufacture.

Penny's pamphlet, particularly the reference to "violating confidence", showed a sensitivity to issues in the definition of a technical chemistry curriculum only rarely exposed at the time. He had expressed some of the cognitive criteria for the shift from academic chemistry and some of the problems of novel curricula in technical chemistry. Public controversy is in this respect more informative than the relatively predictable language and concerns of speeches, articles and apologia for curricula. His major claim was to have run an evening class entitled "Technical Chemistry and Analysis" which had attracted 73 students in the previous year. While it is not possible to identify the content of this course in any detail, it seems likely that analysis and broad descriptive chemistry were predominant. Time and facilities, not to mention the "confidence" which was essential to a man with a substantial consultancy practice, made his wider claims unconvincing.

It is unlikely that these matters carried weight directly with the

Managers. More important for them was Counsel's advice that the establishment of the Chair would probably be found to be outside the terms of John Anderson's will, if brought to court. On September 22 the Managers, and later in the day the Trustees, agreed to rescind the resolution establishing the Chair. In agreeing to this the Managers expressed a series of doubts about the wisdom of the objectors. They noted that many academic chairs, and by implication disciplines, underwent sub-division "as seemed conducive to the public interest". Further it seemed wrong[32]

> to stereotype the requirements of 1796 as answering to those of 1869...or refuse to extend the teaching of their schools...in accordance with the usages of other institutions and the requirements of the times.

The stance adopted by the Managers was pragmatic. Their attitude owed litle to a rhetoric in which "abstract" science stood above a derivative and subordinate "applied" science. It was "the requirements of the times" and "public interest" which were paramount, and the Governors seem not to have accepted Penny's claims for analytical and descriptive accounts of industrial operations.

Frederick Penny died in November 1869, allowing the issue to be reopened. The Young Trustees had meanwhile threatened to found a separate institution.[33] The Managers did not rush to appoint a successor to Penny, and allowed Stevenson Macadam to take over his lectures on a temporary basis while they considered the matter.[34] In January 1870 they heard a paper from James Napier, a Glasgow chemical manufacturer and one of the Trustees appointed by Young. His views may have reflected those of Young himself. Whether Napier, with his active involvement in the Young Chair and the Glasgow Philosophical Society, was representative of general opinion among chemical manufacturers is more doubtful. In the present state of education, he observed, after a man was engaged as a chemist,[35]

> although he may have certificates of proficiency of years of study in the Laboratory, when he enters the factory he has to begin an apprenticeship, and for a year or two is of little use to his employers.

The situation envisaged in the proposal for the Young Chair would involve such a student, after "learning the principles of the Science and Analyses" being able to

> enter on the practical application of these to manufacturing

> purposes...(he) would be asked to watch, if not also to work out, every operation...required for the produce (sic) of the article being manufactured, tracing the chemical changes in every operation, studying the circumstances under which they take place, the Professor pointing out weak parts where loss or waste occurs...

This curriculum would contrast with "the abstract principles and practice of the science". To some extent the meaning of this kind of language is obscure, partly because no courses of the type envisaged were in operation. Yet it is clear that it involved a considerable movement from the curriculum as represented by the academics in the previous chapter. In particular, industrial operations themselves were seen as the legitimate subject matter of the course, and it was identified as replacing an apprenticeship. Napier was prepared to take academic chemists at their word, and assumed that the Professor's "abstract" chemical knowledge (despite the appointment of Perkin, it will be seen that no particular attempt was made to obtain a man with industrial experience) would enable him to have an instrumental insight into works processes. In the period under discussion apprenticeship was accepted as the appropriate institutional location for transmitting the unidentified competencies involved in operating "the processes themselves", and was often explicity contrasted with institutions of technical education.[36] In Napier's account, industrial practice was to be transmitted in the context of public education rather than some form of pupilage, with public institutions represented as directly preparing men for such practice. It was a radical shift, yet one which developed, in part, directly from that of the academic chemists.

The occasional references by academics to an unidentified body of opinion which advocated curricula based on "the arts or manufactures themselves" can be recalled.[37] (The criticism of this approach would often be retrospectively modified as having been towards those advocating knowledge of technical details without "scientific principles".) This and other evidence indicates that the origins of this anonymous pressure was among manufacturers themselves. The point requires some qualification however. The views of less articulate and publicly active manufacturers often seem to have been different, with a greater emphasis on commercial secrecy and a much more ambivalent attitude to education. It is worth recalling here that Young, like many others in the field, was a "radical" in politics. Technical education has been called "the scheme of Liberal Britain".[38]

After Penny's death the chemical staffing at the Andersonian was restructured. The original chemical chair was retitled to refer to "Scientific Chemistry", and Young was requested to renew his offer.[39] Perkin, who had found the affair distasteful, appears to have thought better of accepting the Chair.[40] Events proceeded slowly, with the Managers more wary of the details of the control of the Chair. Eventually a new Trust Deed was drawn up, in which Young retained control of the Chair, and a group of Trustees with chemical connections was appointed.[41] It was not until March 1871 that the Trustees approached the German chemist Gustave Bischof to fill the Chair.[42] T.E. Thorpe occupied the other Chair from 1870 to 1874, and was followed by another German chemist, William Dittmar.[43]

Bischof's time in the Chair was not a happy one. The precise organization of the course is not clear, but it was intended to be complete in one year. It promised to cover most of the major chemical and chemistry-related industries, though varying somewhat randomly from one year to the next.[44] The variation could be interpreted as the experimentation of a man in a novel educational position. Alternatively it may have been an attempt to attract students by finding the most attractive course, or by covering as much of the market as possible over a number of sessions. In any event it seems that Bischof was unsure what a curriculum in technical chemistry was and what its aims ought to be. Not surprisingly he turned to what he knew best, and emphasized that "special reference has been made to the technical analytical examination of the materials employed in the various industries".[45] This was some distance from the activity envisaged by Napier in his paper.

Problems appear to have arisen at other levels. Bischof had language problems, and left most of the teaching to his two assistants William Ramsay and Otto Hehner.[46] Both were young men (aged 19 and 21 respectively) fresh from Germany and with no industrial experience. Hehner commented in his obituary of Ramsay that Bischof's main qualification for the post appeared to be that he could not speak English and knew nothing of technology, and said they were ashamed to be associated with him.[47] Ramsay approached Young to be allowed to give a course in organic chemistry, and was brusquely refused permission. Young told him that the field had nothing to do with industrial chemistry (despite the earlier appointment of Perkin) and would impinge on the area of the other Professor. By October 1873 Bischof was developing a consultancy practice.[48] Student numbers dropped steadily from 14 in 1871-2 to 8 in 1874-5.[49] James Napier complained that it was not possible to obtain students with sufficient chemical knowledge to fill the available Bursaries. This was "a desideratum we never dreamt of".[50] Since nine three-year Bursaries were available and had been filled, it appears that the number of fee-paying students was very small indeed. The Trustees began to emphasize the need to find firms willing to employ ex-students preferentially "to demonstrate the value of technical education".[51] By 1875 they felt that, despite a favourable report on the students from Angus Smith, the success attending the Chair "has proved after four years to have been much less than might have been expected".[52]

The implication of the remark was clear, and Bischof's resignation was accepted at the following meeting.[53] He was replaced in October by E.J. Mills. Mills appears to have had considerable experience in industrial plants.[54] He brought a much more vigorous and outgoing approach to the Chair, visiting works and expanding the student body by encouraging the attendance of part-time and occasional students who were already in employment. His course consisted of 25 lectures on "general principles of technical chemistry", 12 on destructive distillation and 13 devoted to "a survey of the Vitriol, Soda, Bleaching Powder, and Soap Industries".[55] His own speciality was in oil and related areas, for which he would become examiner for the City and Guilds. In 1875-6 the total number of students on the various courses had increased to 25 (9 full-time and 16 occasional and part-time students). In 1877 the Trustees commented on Mills' active attempts to interest manufacturers in the benefits of the course, and again on the need to persuade employers to appoint students preferentially to suitable posts. Nevertheless, with 16 full-time students attending, they considered this year "the most encouraging so far experienced by the Young Chair".[56]

No further details of Mill's course at this time are available. It represented a combination of specific and general elements, the former chosen to bracket Glasgow's major chemical industries. The phrase "general principles of technical chemistry" opens up the possibility that this was a course in something resembling early chemical engineering--if so, the earliest such attempt to codify generalized chemical process knowledge for use in a public educational institution. The phrase may, of course, merely have represented material comparable to that found in 'pure' chemistry courses. Later Calendars refer to early general lectures on chemical and physical laws, after which "(a) particular subject will ... be considered in comparatively minute detail".[57] The ad hoc nature of the latter part of the course is indicated by the College's entry in the "Student's Number" of Chemical News for 1880, which stated that the detailed subject "this session" would be Oils, Paints and Varnishes. A subsidiary and again evidently ad hoc course, to be given by the senior assistant, was "intended for Dyers, Colour Manufacturers, Brewers and Distillers, Tar Rectifiers (and) Drysalters...".[58]

The Young Chair can be considered the first systematic attempt in Britain to develop an academic department in chemical technology identified by personnel and organization as distinct from the mainstream of academic chemistry. The programme described by Napier represented a considerable development of the activity undertaken in the courses at Owens and the Royal School of Mines. Whether or not Mills' activity went very far to fulfilling that programme is more doubtful. There is no evidence that the proponents of the Chair envisaged education in a general technology of chemical processes. Rather they looked for the intervention of the teacher in specific industrial processes: they suggested that the instrumentality promised by academics to inhere in 'pure' chemistry be made the basis of an educational syllabus. Mills' course did indeed treat industrial sectors. Yet it continued to be problematic in various ways. There is no evidence that he was supplied with other than laboratory apparatus. The information which is available indicates that he looked in greater detail than his predecessor at the details of some industrial processes, perhaps in the manner which will be described for Watson Smith below, but that this involved a considerable narrowing of the range of sectors covered.

If student numbers are used as a criterion then the Chair was not a success, even under Mills, during this period. In attempting to push the curriculum into technical areas the protagonists exposed tensions which the previous courses had avoided. Most important among those which apparently surfaced during Bischof's and Mills' period were questions of the coverage of sectors, the competence of academics and the demonstration of industrial faith in the extended competencies supposedly to be found among students. Attracting students continued to be difficult. It is significant also from the perspective of later chapters that the curricular solutions developed under the relatively independent Young Chair showed some evidence of a third strand --of general chemical technology-- as well as the two which have previously been noted at Owens College and the Royal School of Mines. Nevertheless, the two strands of analytical methods and more or less detailed accounts of specific manufacturing processes remained dominant.[59]

These problematic aspects of independent academic activity in chemical technology will receive attention throughout the remainder of this chapter. It is not intended to follow in detail here the subsequent history of the Young Chair, but a brief sketch will be given. Numbers of full-time students began to fall again in the late 1870s. In 1880-1 a course orientated towards the recently-established City and Guilds examination in Iron and Steel was offered. It attracted 39 students, mainly "artizans" according to the Trustees.[60] The institution had already discovered that the courses occurring in the institution could be readily adapted to the City and Guilds Examinations. Such activity recommended itself to the Trustees, and further courses were introduced. Thus in 1882-3 only 12 students were involved with the Day Course, whereas 149 were attending City and Guilds Evening Classes.[61] The shift in emphasis presages the important role that the question of the class of the target student constituency would have in other institutions.

In 1887 the College changed its name to "The Glasgow and West of Scotland Technical College". The early general component of the Technical Chemistry course developed in the late 1880s into a course and diploma entitled "Chemical Engineering". Conflicts over the relationship between the chemically-orientated chairs continued, requiring an internal committee of enquiry in 1890. They led eventually to the appointment of G.G. Henderson (then the Professor of Chemistry) as Senior Professor in 1892.[62] After Mills' departure in 1902 the Diploma in Chemical Engineering was replaced by one in Chemistry.[63] The institution's acceptance of its role as a technical college was always ambiguous, reflecting the more widespread ambiguity of the activities convened under this heading during the period. In 1894 it became the Royal Technical College. In 1912 it was affiliated to Glasgow University and recognized as competent to offer degrees in Applied Chemistry (1914) and eventually the first Bachelor's degrees in Chemical Engineering (1923) in the United Kingdom.

D. Chemical Technology at University College, London, 1879 to 1894

The next major institutional initiative occurred at University College London. University College had a Chair of Chemistry from its establishment as the "University of London" in 1826.[64] The original intention had been to appoint two chemical professors, one with specific responsibility for "the application of chemistry to the arts". The second Chair was not filled, apparently through lack of money. The first Professor was Edward Turner whose work had substantial technical content at the analytical and descriptive level. On Turner's death in 1837 he was replaced by Thomas Graham, an appointment which was said to have been "virtually in the hands of the medical professors".[65] The threat posed by the Royal College of Chemistry, and particularly its provision of practical tuition, appears to have been the motivation for the establishment of a Chair in Practical Chemistry in 1845 and the opening of the Birkbeck teaching laboratory. George Fownes occupied this Chair till 1849, and was followed by A.W. Williamson. When Graham resigned in 1854 the Chairs were merged. The orientation of the work of the Department appears to have remained focused on the preparation of students for London University degrees, on the chemical certification of medical students and on supplying occasional students with an ad hoc knowledge of analytical chemistry.

Williamson's position is not easily defined. It was observed in chapter 3 that he showed considerable hostility to the notion of technical education as involving any studies directly concerned with manufacture. Yet at this period he is also recorded as inaugurating Saturday visits to chemical works by his students.[66] In the years 1875 to 1883 he devoted considerable time and money to attempts at technical innovation, though without the success which would have warranted the tone of his comments to the Devonshire Commission.[67] There is however little contradiction in Williamson's public stance. In 1870 he delivered an Inaugural Lecture to the new Faculty of Science at the College entitled "A Plea for Pure Science", in which he claimed that

> ...the explanation of any chemical or mechanical arrangement or contrivance is supplied by certain simple general principles which are explained and illustrated in the manner most convenient for their easy acquisition and practice in certain departments of science called Chemistry and Mechanics; and those who have been taught to apply those principles to simple examples, are able to understand and direct complicated operations and machines with a facility and accuracy unattainable by others.[68]

Williamson was no Roscoe or Playfair. He never entered Parliament and was apparently unaccustomed to ambiguity. He canvassed here some of the criteria for the technical significance of "abstract" science which they attempted to represent more circumspectly. These are, particularly, its generality, its appropriateness for communication and its ability to confer instrumental competence at the technical level. Elsewhere in the lecture he attacked "pupilage" for its specificity and the obscurity of its methods, and contrasted it with attendance at a college or university.

In 1872 Charles Graham was appointed to a position as "assistant Professor" at the college.[69] Graham was an ex-student of University College. After taking the London University D.Sc. he had held various industrial appointments abroad, before returning to London to set up a consultancy practice, with a laboratory close to the college.[70] Brewing was Graham's speciality and later events suggest that this and other of his food industry interests had a part to play in his appointment. Comments by contemporaries and the data presented in chapter 5 indicate that many students at the college did not follow a course which led to any certification. A demand for courses for *ad hoc* students, often interested in specific industrial sectors, certainly existed.

Whatever may have been the reality of teaching in the college laboratories, it succeeded in attracting 60 to 70 students per year at this period. Williamson, whose active chemical work had ended quite quickly, had found his department increasingly under pressure from the secure, publicly-financed Royal School of Mines. An important question in the arguments being rehearsed in the evidence to the Devonshire Commission during the early 1870s concerned the acceptability of a state-funded institution competing with private institutions such as University and King's colleges.[71] However, during the mid-1870s a new threat began to emerge. In June 1877 a body of representatives of the London Guilds agreed to set up a committee which would aim to establish a "National System of Technical Education".[72] The intention was that one component of this would be an "Industrial Institute or University".

Such an institution, financed by the wealthy City Companies, posed a threat to University College. Indeed, the other components of the scheme, which included a model technical college and a system of technical examinations, were also threatening. As will be seen the educational trajectories of the student bodies of many institutions providing science education were at that time relatively uncrystallized. In January 1878 the Council of the College set up a committee "to consider what steps may with advantage be taken for the purpose of providing further instruction in Applied Science".[73] In March 1878, after consultation with the Senate, the Committee produced a report, recommending the financing of an Engineering Laboratory, a Chair of Mechanical Technology and a Chair of Chemical Technology.[74] The College applied to the City and Guilds Institute for funds, and received a regular annual contribution of about £200 to its upkeep. It is difficult not to see in these proposals a response to the City Companies' own scheme. Charles Graham was appointed to the new Chair without advertisement.[75]

Graham's inaugural lecture in 1879 attempted to define the curricular space which the new Chair would occupy.[76] After praising Williamson's work and suggesting that "the Study of Pure Science" was of key importance to those "professionally engaged in industrial positions where Applied science plays an important role", Graham quickly moved to different ground. Science was essentially a "preliminary education". Parents expected students to be immediately fit for works posts, whereas men of science had attempted to exclude from curricula "facts and processes of (the student's) particular industry". In fact "knowledge of technical processes" could be "rapidly acquired under the direction of a competent teacher". Graham's general conclusion was that it was possible to provide a "professional training in Technology", and this was better undertaken at a general college such as University College than a technically orientated institution. One can contrast these explicit statements with Graham's more circumspect comments when under questioning from the Samuelson Commissioners, and particularly from Henry Roscoe.[77] In some respects they contrasted also with the actual course which he provided. Nevertheless they indicate the way in which new opportunities and newly-defined institutional space allowed a reformulation of the 'principles' of curricular content.

The Calendar for 1878 gave an account of the target population and the content of the course.[78] The aim was to prepare students for "industrial pursuits", for the profession of "Consulting Chemist", for London University degrees and for membership of the Institute of Chemistry. It was intended to occupy three years. The first year was to be a standard chemistry course. The second year was also largely of this type, but included a number of courses on "Applied Chemistry". The third year was mainly devoted to lectures in "Chemical Technology". The relationship between the courses taken in the second and third year was not made clear, and it was stated that a student could take any course individually.[79] A list of courses followed, each occupying one term. In 1878-9 they were to be: "Chemistry of Brewing; Chemistry of the Alkali Trade; Soap Glass, Pottery, Cements; and Agricultural Chemistry." In 1879-80 this became: "Heating and Lighting; Gas, Fuel, Furnaces; Metallurgical Chemistry; Dyeing and Calico Printing; Paints, Oils, Varnishes; and Distilling, Vinegar-making, Bread- and Biscuit-making". This type of apparently random variation from year to year was seen at the Andersonian and other courses discussed in this chapter. In addition students could receive "individual instruction in the Laboratory" in "Photography and Photographic materials, Paper-making, Gas-tar products, the products of the Distillation of Wood, Tanning, and other Chemical industries". In the event of this list not being sufficiently comprehensive, Graham added:[80]

> Should a sufficient number of Students desire a Course of Lectures on some subject of Applied Chemistry other than those above mentioned, the Professor will be glad to give such either in lieu of, or in addition to those mentioned.

The laboratory componentof the courses was to consist of

> the examination and valuation of raw materials used, and of the final products obtained, in various manufacturing industries, and of experimental examination of the processes employed in the arts and manufactures.

The syllabus of the Chemical Technology Department was in fact less a projected course of study than an invitation to anyone with an interest in a chemical process industry to attend University College. Graham eventually employed two assistants, though it is not clear how many were employed initially. Both were or became FIC, indicating that their major competence was probably analytical.[81] There is no record of the college purchasing any apparatus for carrying out manufacturing processes. Originally facilities were shared with the Chemistry Department, but in 1880 Williamson received new laboratories, and chemical technology was located in the laboratory he vacated.[82]

The institutional status of Chemical Technology in the College was ambiguous. It appeared briefly in the Calendar as an independent department, but from 1880 was under the aegis of the Chemistry Department. Its finances did appear separately in the statement of accounts. Graham had been appointed to a full Chair in the same year that William Ramsay replaced Williamson, and the relationship between the two areas was not clarified until after Graham's departure. In purely numerical terms chemical technology at the College was at first quite successful. Aggregate student numbers rose steadily for the first few years, reaching a maximum of 82 in 1884-5.[83] A closer examination of the Fee Books reveals, however, that activities had a very fragmented character. Thus in 1880-1, out of 43 students attending the lecture courses and the laboratory, 22 were following only a single course, 5 were following two courses and 1 three courses. Four students attended the laboratory for the full session, 3 for six months and 11 for three months. Few students appear to have taken both laboratory and lecture courses. Only 3 students were also registered for courses in the Chemistry Department (indicating that they were pursuing an integrated programme of study) though others may have done so in earlier years. Overall the impression gained from the student registers is similar to that from the Calendar: the 'course' appeared to cater for students attempting to gain chemical knowledge (mainly analytical) relevant to specific areas of manufacturing activity. There is no record of the numbers involved in each of the formal courses, or even which of them actually ran. Overall, the evidence available suggests that the "Department" constituted an essentially opportunistic effort to attract students.

Graham's speciality was brewing, and Owen Roberts of the City and Guilds told the Samuelson Commission that the University College department was mainly orientated to this.[84] In 1902 Ramsay suggested that the class had been one in brewing, and that Graham "had trained most of the brewers of his day".[85] Certainly by 1887 the brewing lecture course was equivalent in cost and length to any two others.[86] However, and perhaps in consequence, by this time the department was attracting fewer students. In 1888 only 20 students were registered (though the mainstream chemistry courses had undergone a similar, if less marked, reduction in numbers).[87] The reasons for the fall may have included any or all of such factors as: a shift of interest on the part of Graham, decreasing conviction on the part of students and parents of the value of the courses and increased competition from the various activities associated with the City and Guilds. In particular the latter's Technological Examinations constituted the kind of piecemeal specialized activity apparently being offered at University College. The London County Council Report on technical education in London (1892) reflects the widespread availability of courses of this kind in the capital. They were based on institutions such as the London polytechnics, which had developed during the 1880s.[88] From 1885 the City and Guilds Central Institution began to offer a more co-ordinated course than that available at University College.[89] Moreover the fees at University College were generally reckoned to be high. They were, for example, nearly twice those at the Central Institution.

Whatever may have been the reason for the decline, Graham did not find the future prospects sufficiently attractive to remain, and resigned his Chair in April 1889.[90] The departure was not rancorous, and in June of that year Senate recommended that he should be given the title Emeritus Professor.[91] Meanwhile it gave consideration to the vacant post, and decided in May that the Chair should be suppressed. Instead a Lecturer in Applied Chemistry would be appointed, and Watson Smith was offered the post.[92] Smith was in the process of moving to London from a post at Owens College. According to the Council minutes of the Society of Chemical Industry for June he was to come to London as full-time Editor of the Society's Journal, at a salary of £500, but free to undertake other work subject to Council permission.[93] In the July meeting he asked permission to take the University College post, and this was granted.[94]

It will be seen later that Smith's departure from Owens College appears to have been at least partly motivated by the lack of an independent position for chemical technology there.[95] If he had hoped to occupy an altered position at University College he was quickly disappointed. The absence of a Chair made clear that the position was a subordinate one. The change of title to Applied Chemistry may also have been intentional, indicating the status of the activity as a component of the Chemistry Department. In June, when Smith submitted his intended entry in the Calendar to Senate, it was immediately referred to Ramsay, who was now well-established in the Chair of Chemistry.[96] The Calendar which appeared contained a much-attenuated section on Applied Chemistry, and reflected Smith's particular experience rather than Graham's. It made no attempt to canvass for students in the way which had characterized Graham's entries.[97] Three main lecture courses were offered: "Chemistry of the Alkali Trade", "Fuel and Gas" and "Coal-Tar Products". The first of these promised also that "some of the general principles of Chemical Engineering will be treated of and illustrated". A set of evening lectures was also promised, to be given by "gentlemen particularly qualified by their practical and theoretical acquaintance with special subjects." Even the main courses were timetabled for 5 to 6 pm, which made their status as Day Classes ambiguous, and gives some indication of an attempt to attract students able to get away from work fairly early.

The reorganized provision was far from successful. Only five students registered for the courses.[98] Apparently in an effort to redeem the situation Ramsay proposed in November 1889 that the College should institute a Certificate in Chemical Technology.[99] The Certificate required a minimum of three years' study, drawn largely from the existing chemistry courses. It included all three of the lecture courses referred to above, a fourth entitled "Chemical Technology of Building Materials" and some study of engineering.[100] It is not clear whether this disparate body of activity ever motivated any students to complete the three years and gain the Certificate. The number of students increased to nine and then fell away to six by 1893-4. In May 1892 Ramsay was requested by Senate to make a submission to the London County Council in connection with the special committee referred to above.[101] It recommended that University College be given a grant of £1,700

> to be divided at the discretion of the Council of University College among the departments of chemistry, chemical technology, mechanical engineering, electric technology and architecture.[102]

It is difficult to determine exactly how the grant was distributed by the Council, since no breakdown was given in the accounts. Nevertheless, and despite the emphasis given by the LCC to chemistry, the College appears to have chosen to allocate it to mechanical and electrical engineering. In the previous Annual Report Council had referred to the success of the engineering departments.[103] The mechanical engineering department had flourished since 1875 under Alexander Kennedy. Electrical engineering had been established in 1885 under Ambrose Fleming. It also had grown steadily, and attracted 41 students in 1893-4.[104] By contrast the College appeared to have had quite enough of chemical technology. Since his appointment Smith had been on an annual contract. When he was re-appointed in 1893 Senate referred the question of the continuation of the lectureship to the Faculty of Science.[105] In November 1894 the appointment was allowed to lapse. During a discussion on chemical engineering in 1917 a student in the final class told the Faraday Society that the failure to attract students was the basic reason for the closure of the course.[106] Its closure provoked Crookes to comment in Chemical News that "Chemico-Technical" study in the UK was "receding".[107]

The collapse of the chemical technology department was followed by a gap in provision of this kind at University College. The Department of Applied Science and Technology which existed around the turn of the century included no chemical component, while the Department of Science presented the subject without reference to directly industrial aspects.[108] By 1910 a Faculty of Engineering had been established, and this included only an introductory chemistry course.[109] Ramsay felt that his department (no doubt boosted by his own success in the field of the noble gases) did not require to draw on this area to recruit students. In 1911 he responded to a letter from Alfred Keogh at Imperial College, discussing the new College's proposal to establish a Department of Chemical Technology, with the comment that at University College "we have enough to do with our pure science."[110] The College was however not finished with the field. The initiatives which occurred later in that decade will be referred to in chapter 7.

E. Owens College and the Victoria University, 1870 to 1910

Owens College passed through a significant shift in status during the 1870s and 1880s. This shift was led by the science departments and aided by the possibility of preparing students for London University degrees. From the struggling institution of the mid-1850s the College had grown to a position where in 1873 it was able to move into a large purpose-built building in Oxford St. and aspired to the status of a university serving the north of England: Roscoe's "University of the Busy". With the establishment of the Victoria University in 1880 and the Victoria University of Manchester in 1904 the institutional forms of this aspiration were in place.[111] The main interest in Roscoe's phrase is precisely its encapsulation, when contrasted with the views of Newman, of the shifting notion of a university. The period when the College underwent its main transition corresponds with that when the ancient universities were colonized by the upper reaches of the commercial and administrative middle class, and, more particularly at Cambridge, appropriated the natural sciences as academic vehicles.[112]

The functions envisaged for the new university, and the class which it serviced, were thus doubly problematic: both as part of the general notion of a university and in relation to the reconstruction by the ancient universities of their academic and social leadership.[113]

Despite its occasional failure to be formed during the sixties the Technological Chemistry class at Owens was never officially discontinued. Its overall numerical significance in relation to the main chemistry course fell steadily, reaching a minimum in 1880.[114] However, during the period of the early 1870s absolute numbers had increased to a maximum of 33 in 1874-5. More than one course began to be offered. In 1874-5 there were three, dealing respectively with "Water, Air and the Chemistry of the Alkali Manufacture" (20 lectures given by Roscoe), "The Chemistry of Colouring Matter, Dyeing and Calico Printing" (20 lectures given by Carl Schorlemmer) and "Modes of Producing and Utilising Heat and Light" (20 lectures given by William Dittmar). In contrast with the stability exhibited by mainstream chemistry courses the number, subject matter and personnel of these courses varied rapidly. By 1879 again only one course was offered, on "Water, Air, and the Chemistry of Fuel and Gas Manufacture", given now by Thomas Carnelly. None of the men involved had significant industrial experience.[115] The courses which they gave continued to be extensions of the main courses in particular directions, though still focused frequently on analytical work. This was combined with broad descriptive accounts of particular industrial processes and plant.[116]

In December 1879 Carnelly was replaced as Demonstrator by Watson Smith.[117] Two candidates for the post had been considered: Smith and John Kent Crow. Smith had received his early education at Owens College. After leaving Owens he spent some years in industrial employment and consultancy. In 1870 he was working on naphthalene at John Barrow's Dalton Chemical Works, but he had worked in the alkali industry. During the late 70s he studied at Heidelberg University and Zurich Polytechnic, and he published a series of papers on industrially-related areas in 1876/7.[118] Crow was also an ex-student at Owens who had taken the London B.Sc. and D.Sc. degrees. Despite his superior "academical honours" he was rejected because he had achieved "very much less original work than Mr. Smith".[119] No reference was made to Smith's industrial work. However, immediately on his appointment Smith took responsibility for two reorganized courses: "Alkali and Sulphuric Acid Manufacture; Bleaching Powder and Liquor; Potassium Chlorate; Carbon Bisulphide" and "Destructive Distillation of Coal; Gas Manufacture; Distillation of Coal Tar; Ammonia and Ammonium Salts from Gas Liquor."[120] The shift in emphasis recalls the contingent aspects of the courses at University College and the Andersonian. The work was evidently based on those industrial sectors of which Smith had direct experience.

In March 1881, the academic year following Smith's arrival, Henry Roscoe submitted to the Owens Senate a scheme for instruction in "technical chemistry".[121] The origins of this proposal will be discussed shortly. The Senate approved the proposal in principle, and set up a sub-committee to consider it in detail. In May a syllabus was submitted and approved, together with a proposal for a Certificate in Technological Chemistry.[122] The Certificate was to require 4 years attendance. When the proposals were submitted to the College Council the wisdom of this last element was questioned, and Senate responded by increasing the possibilities of exemption to exclude both the first and second years.[123]

Roscoe's proposal proved to be merely the first stage of an attempt to inaugurate a more wide-ranging technical curriculum. In January 1882 he proposed to Senate that, in view of the new chemistry certificate and the impetus likely to be given to technical education by the Samuelson Commission, a Sub-Committee be set up to consider "the principles on which the College should proceed in the introduction of Technical Departments".[124] The resulting scheme of Technical Instruction envisaged a number of courses paralleling that in Technological Chemistry. It was considered at a special meeting and recommended to Council in May for urgent implementation at the start of the new academic year.[125] The enthusiasm of Senate was not fully matched by Council, which discussed the scheme at a long sequence of meetings, submitted it to a financial committee, and finally decided to implement it only in part.[126] Roscoe was very restive, and warned particularly that the proposal to convert the Mechanics' Institute into a Technical School made "the necessity of an extension of the teaching of the College ...even greater".[127] There is no evidence here of academics reluctant to implement a nominally technical curriculum.

The published syllabus for the Certificate in Technological Chemistry was a combination of those courses already available within the Chemistry Department, together with small amounts of Mechanical Drawing. It included material relating to diverse industrial sectors: alkali and acid manufacture, coal tar and wood distillation products, the manufacture of organic chemicals and bleaching dyeing and printing. The laboratory component was mainly analytical.[128] The aim of the full course was stated as being

> to offer to students intending to devote themselves more especially to Applied Chemistry as complete a training as the College can provide in those branches of instruction, which form the Scientific foundation of the subject.

The terms of this description show an ambivalence surrounding the proposal. Apart from the shift from "Technological" to "Applied" Chemistry the certificate course promised tuition in fields forming "the Scientific foundation" of the subject, with "Applied Chemistry" proper apparently identified as the subsequent practice. The student might well have asked whether the course was in "applied chemistry" proper or in chemistry and such related fields as a future "applied chemist" might be thought likely to benefit from. The formulation of the relations between industrial practice and academic chemistry thus continued to exhibit those tensions identified earlier.

General and specific factors were in play in determining the course's history. There was firstly the presence of Smith himself. As technological departments developed it was a common complaint that the teachers they required were difficult to find. The combination of academic training (increasingly a prerequisite of any kind of recognition, even from the Institute of Chemistry), industrial experience, willingness to undertake "academic" research rather than financially profitable consultancy and willingness to leave industrial positions was only rarely found.[129] Men appear rarely to have left such positions other than paid employment as a routine analysts.

The institution of the new Victoria University B.Sc. degree may also have had a part to play. The Honours degree in chemistry included an optional Technological Chemistry component in the third year. This was intended to be equivalent to a course of 2 to 3 hours per week.[130] A student following the syllabus for the College Certificate could be a candidate for the Victoria degree with some limited adaptation of timetable. Allowing credits to be gained for both forms of certification had advantages in attracting students. A number did gain both in the early years. However, the largest single influence on the College was probably the prospect of a reorganization of the Manchester Mechanics' Institute to a Technical School. It is appropriate to give some attention to this development. In discussing the relationship between these two institutions it is necessary to move quite freely between them. The following pages focus on the reorganization of the Mechanics' Institute and its curriculum.

Like a number of northern mechanics' institutes that at Manchester had successfully adapted itself to the DSA examination system during the 1860s and 1870s.[131] The validation of courses and certificates which the Department provided, not to mention the payments to teachers and other grants increasingly made available, provided a powerful impetus to growth. The Department's examination system constituted a kind of secondary education, much of it undertaken in conjunction with Board Schools, but with institutions such as that at Manchester taking a considerable part. The institutes tapped a large supply of men and later women whose education had been limited to what would now be called the primary stage. This group appears to have been drawn only to a limited extent from the industrial shopfloor, except in a few examinations such as Metallurgy. Elsewhere it consisted mainly of aspirant clerks, warehousemen, teachers and similar occupational groupings. The certification provided by the Department appears to have acted as a useful selection process for employers looking for reliable employees with basic literary and numeracy skills to fill minor administrative positions.[132]

Despite the original intentions which had been expressed, the examinations did not fulfil any clear role for industrial occupations proper. The Technological Examinations of the Society of Arts and City and Guilds developed to occupy this position. The Manchester Institute began offering courses leading to these examinations in 1879 and the proposal to reorganize the Institute as a Technical School first appeared in April 1880.[133] Under the impetus of the Institute's secretary, J.H. Reynolds, the scheme was matured slowly, with the support of local organizations being carefully cultivated. Eventually an Executive Committee undertook negotiations over two years to raise funds, and the scheme appeared in more developed form in July 1882.[134] This was precisely the period when Roscoe was attempting to push Owens into a comprehensive "technical" scheme. In December 1882 a Special General Meeting of the Institute approved the new scheme, with one dissenter.[135] The Technical School and Mechanics' Institute, as it was to be known, was to include a School of Applied Science, a School of Art and Design and a School of Commerce, and to be controlled by a Council representative of the major commercial and educational organizations of Manchester and Salford. During its first year the new School attracted 1045 students, attending 75 classes, with a total class membership of 2280. These classes were mainly orientated towards the DSA and City and Guilds examinations.[136]

Though the Council of the Technical School included Henry Roscoe, the structure of authority within the School had no powerful academic influence equivalent to the Senate at Owens. Men from industrial backgrounds were numerically dominant, and though the Technical School called its activity applied science, its curriculum showed a radical shift which was typical of the provincial technical colleges being founded at this time. The intended direction of the activity, and particularly the intention to make it more directly industrial in its orientation, is shown in the evidence given by the Secretary, J.H. Reynolds, to the Samuelson Commission in 1882. Reynolds referred several times to the need for "typical" examples of industrial plant, such as machine tools, to be used in the teaching.[137] This was elaborated in the following exchange:

> What is the general feeling among practical men as to the introduction of machinery into technical schools of a secondary grade?--I think the feeling is that where the machinery is of a standard character it should be introduced. (Professor Roscoe.) Where the machinery illustrates principles, it should be introduced?--Yes, but that you should not seek to introduce into the school machinery that is rapidly changing, because the school cannot keep up with the workshop.[138]

There are three significant components in this short exchange. Firstly there is the mere fact of the serious examination of the role of industrial plant. A few years previously, and still in many formulations of technical education, this would have been represented as an absurdity. Secondly Roscoe's quick intervention to assimilate the idea within the notion of industrial "principles" can be observed. The origins of this strategy are clear enough, though the flexibility of the term meant that it could no longer readily be confined to "scientific" principles. Nevertheless, alternating between the narrower and more extended interpretations could provide a useful tactic in attempting to control novel curricula. Finally the pragmatism of Reynolds' responses can be noted. Elsewhere in his evidence he suggested that the City and Guilds examinations (themselves a radical development) needed "in many departments to be made much more practical".[139] So far as textiles was concerned he argued vigorously and without challenge that "(t)here is now an immediate prospect of teaching, not merely the principles and elements of cotton spinning, but of practical weaving."[140] It is indicative of the changes occurring that Reynolds was even allowed to go beyond the principles/practice formula without challenge.

The willingness of the authorities in the Technical School to demolish the boundaries which had been constructed, at the level of representation, around the technical curriculum could be neither prevented nor ignored. It had implications for the attraction of students and for the class and subsequent employment of those students. It was a major mechanism by which the meaning of the term technical education was reconstructed. The situation in Manchester was, in this respect, representative of other institutional relationships in the UK during this period.[141]

The potential competition between the Technical School and Owens College is made clearer when it is recalled that most of the students attending the latter at this time obtained no formal qualification. They appear often to have taken some limited combination of courses for specific purposes, a situation which paralleled that at University College London. The College was by no means an exclusively undergraduate and postgraduate institution. Moreover, though it received little attention in the Annual Reports, the Chemistry Department quickly began to enter students for the City and Guilds examinations.[142] Men like Arthur Harden, W.B. Hart and H.L. Snape passed the examination in Alkali Manufacture, illustrating the uncertainty of their intended employment at that time, together with the uncrystallized nature both of Owens and the examinations.[143] It is not even clear when Owens ceased to enter students for the DSA examinations (they would not, of course, have been eligible for payments on results). One of Roscoe's correspondents gave this as a reason for refusing to support the College's efforts to obtain a university charter.[144]

The chemical component of the Technical School curriculum will be discussed later. It constituted the most well-defined area of overlap between the School and Owens. An attempt was made to establish a School of Dyeing within the Technical School, and this was intended to undertake both teaching and research in the dyeing process itself and the manufacture of dyestuffs.[145] When Joseph Lee gave evidence to the Royal Commission on the Depression of Trade and Industry in 1886, he noted of the Technical School that it was mainly "attended by the middle class", and that its major industrial value was through the chemistry department. This was supplying "managers of chemical, dyeing and printing works".[146] It is difficult to know how much reliance can be placed on this view of the School's activities, though it corresponds with the programme envisaged for the School of Dyeing. In any event it indicates the tensions in the relationship between Owens College and the Technical School, and the central subject matter of the negotiations which would occur between them in later years. These were based less on curricular issues than on the class of students involved, and their likely position within the workplace. Owens and the Technical School were potentially in conflict at many levels.

The Certificate in Chemical Technology at Owens could have constituted an element in this conflict. It provided a more prestigious and organized certification than anything available to the School, in the way that Victoria degrees did in "pure" chemistry. The Certificate was, however, not a success. In the period from its establishment to 1900 it was awarded only 14 times.[147] The individual classes were more popular. In 1882 total attendance at the technological classes was 47, rising to 62 in 1886.[148] It is evident, however, from the number of certificates awarded, and again paralleling the situation at University College London, that an insignificant number of students treated the courses as an integrated unit. Individual courses were apparently followed in the main for their own sake, or in conjunction with some other *ad hoc* combination of courses or as part of the Victoria University B.Sc. requirements. They could also lead to the City and Guilds examinations.

It is appropriate at this point to address the question of the competencies implied by the certificate. The structure of the Certificate course has been referred to previously. The technical element within it covered a diverse set of industrial sectors. The examination papers produced by Smith attempted to test a body of knowledge which had shifted considerably from the constraints of mainstream academic chemistry. They included much analytical material, but focused also on highly practical knowledge concerned with day to day plant operation, such as would be required by a plant manager or a senior process foreman of that period.[149] Plant-based knowledge was central to many of the problems addressed. In such cases mainstream academic chemistry constituted a body of important concepts fulfilling a mainly service role.

Three further points can be made about this curricular material. Firstly, as the structure of the syllabus implied, the competencies developed were unlikely to be transferable: each course transmitted sector-specific knowledge, and the whole could not be thought of as being of immediate significance in any actual works. Secondly, it is difficult to imagine it being taught by anyone not directly familiar with the particular industrial sector involved. Lastly, and in apparent contradiction, it was in pedagogic terms "theoretical" knowledge. The activity received little in the way of special apparatus. In January 1882 Roscoe can be found asking the full Council for "a new diagram case for the Technology Department", indicating both the stringency and the extent of control of new expenditure.[150] In any case, the nature of any new apparatus would have been problematic. The provision of anything resembling industrial plant, as well as being very demanding of various kinds of resources, would have represented a new stage in curricular innovation. While the teaching and examination of the operation of such plant in a non-practical way could be undertaken with minimal comment, practical activity was a different matter. It bore some resemblance to teaching "handicraft skills", long acknowledged to be the touchstone for the boundary of the curriculum. The workplace role of men whose training required the presence (and thus manipulation) of industrial plant introduced in particularly explicit form the question of whether such men were to be in a managerial or operative role. The new acceptability of industrial plant proper in the curriculum, noted in the evidence to the Samuelson Commission above, was identified there with institutions of "secondary grade".

The institutional position of chemical technology at Owens was an unstable one. Smith was approaching forty, and must have wondered what future lay in the specialism he was developing. In April 1884 the Senate, at Roscoe's instigation, recommended Smith for promotion to Lecturer.[151] From this time Smith's status was doubtful. He appeared in the Calendar as Lecturer in Technological Chemistry in the Victoria University, but was evidently still expected to function as Demonstrator in Owens College. The matter was the subject of correspondence and other comment, which reached a peak in early 1887. On Roscoe's departure Smith wrote to the Council asking to be treated in some way as distinct from the Chemistry Department proper, but this was stated not to be possible.[152] He applied for and was granted an honorarium of £50 for his work, but this had to be renewed annually.[153] Finally Smith's patience appears to have become exhausted. He was not dependent entirely upon his Owens College position. From 1882 he had been Editor of the <u>Journal of the Society of Chemical Industry</u>, the success of which was said to be a major reason for that Society's rapid growth.[154] He felt sufficiently confident of his position to make his complaints public in a letter to the <u>Manchester Guardian</u> at the time of the Manchester BAAS meeting in 1887. The letter indicates both the tensions in the institution and the problems of curricular definition. Technological chemistry at Owens lacked

> special laboratories, lecture rooms, museums and appliances, and (a) head and representative of the subject of applied chemistry...placed in such a position that he can devote the whole of his time and energy to the subject.[155]

He presented a view of the subject as "the application of chemistry and the principles of chemical physics and engineering to chemical industrial operations on the large scale" (a considerable qualification of "applied chemistry"), and argued that

> it is...sheer...absurdity to expect the votary of pure chemistry, who has never made the operations of chemical manufacture a matter of living and actual experience to teach such applied chemistry.

Smith's comments in 1887, when compared with his views at the commencement of the Technological Chemistry course in 1882, showed an increased emphasis on the distinct character of the field in terms of staffing and apparatus. Earlier he had stressed the connection with pure chemistry, the futility of using special industrially-orientated apparatus and the need for the student to maintain his studies in "scientific chemistry" throughout his course.[156] By 1889 his views had apparently developed further and he commented to the Society of Chemical Industry that the chemical activity at South Kensington (it is probable but not certain that he meant the Royal College of Science rather than the national examinations) prepared students "to become scientists rather than technologists, more probably to become teachers".[157] It seems that the need to delineate a new academic role differentiated from mainstream academic chemistry was shifting Smith's view on matters of curricular content, as was seen with Charles Graham. It was in 1886 that he began taking students to visit industrial plants.[158]

His efforts to obtain increased independence were unsuccessful. The eventual result of his campaign was the establishment of a committee on the status of demonstrators. It recommended two classes of demonstrator, and gave particular attention to Smith. He was "relieved" of his duties as Demonstrator and recognized unambiguously as being Lecturer in Technological Chemistry.[159] The Report, however, made it quite clear, as Council had previously, that the change was of only personal significance.

> Whilst proposing this change in the status of Mr. Smith the Committee is of opinion that the Lectureship in Technological Chemistry forms part of the Chemical Department and that the Lecturer is under the General Direction of the Professor of Chemistry.

Smith was operating in circumstances of limited potential. The material, ideological and personal forces in play were numerous and generally hostile to his efforts.[160] At about this time numbers following the technological courses showed signs of decline (falling to 21 students on three courses in 1889-90). Now aged 44, he decided that he was unlikely to progress further, and moved to London in May 1889.[161]

The Senate saw his departure as an opportunity to reorganize the course which had caused such embarrassment, and rather than advertising for a replacement, set up a Committee to consider its position.[162] This Committee recommended that no individual should replace Smith and that, with the significant exception of dyeing and printing, the subjects offered were within the competence of existing lecturers in the Chemistry Department.[163] The men selected (G.H. Bailey, J.B. Cohen and Dixon himself) had little or no industrial experience.[164] The course itself was restructured and the title changed from "Technological Chemistry" to "Applied Chemistry". The restructuring involved a shortening, the allowance of a division between Organic and Inorganic Chemistry, and the provision for some specialization on the part of the students. Explicit reference to the "technology" of industrial fields was removed from the syllabus.[165] These changes involved a considerable retrenchment towards mainstream chemistry. They were, however, more complex than this in two respects.

The course in "printing and dyeing of fabrics" was treated differently from the others. It was argued by the Committee that a lecturer "intimately associated with these industries" was required. The College recruited a teacher from the Technical School, Ernest Bentz, for this course. Bentz had such industrial experience.[166] The subsequent Annual Report of the Chemistry Department indicated that a set of rooms had been set aside and equipped with dyeing and printing apparatus for teaching the subject.[167] This development shows that the attitude adopted in relation to technical sectors was essentially pragmatic. The curricular content in this area could, in the absence of embarrassing claims to independence, even move towards a more explicitly industrial orientation than that during Smith's time. Moreover the Certificate in Applied Chemistry now represented the most specialized qualification available from the Owens Chemistry Department. Though it was nominally mapped against the two emergent academic sub-disciplines of Inorganic and Organic Chemistry, the specialist underpinning was industrial. The "Organic" element in particular was largely orientated towards textile dyeing and related industries.[168]

In fact, it is possible to connect the structure of the reorganization directly with the developing activities at the Technical School. Before returning to these, however, it is appropriate at this point to note two further changes in the Owens Department which occurred at about this time. It ceased, as a matter of policy, to accept commercial work. The undertaking of such work using institutional facilities had for many years been considered appropriate for academics. Henry Roscoe's letter books indicate something of its extent.[169] Apart from anything else, it represented a useful supplement to small academic salaries. Dixon was guaranteed a minimum of £1,000 per year, as well as a portion of students fees, and may not have felt the need for such a supplement. He reported in 1889 that all such work would now pass through him, and in 1890 that any work submitted had been returned except that already accepted, significantly perhaps, by Watson Smith. From 1891 all such work was returned.[170] Though some part of this change may have stemmed from pressure from the Institute of Chemistry, it also appears to have represented a facet of the self-definition of both Owens College and its personnel. A second change which may also have reflected this was the reorganization of the main chemistry courses available into three basic elements entitled "General", "First Year Honours" and "Second Year Honours". This demonstrated both the emphasis and the stability which the main chemical teaching at Owens was achieving by this time.[171]

During the 1880s the curriculum of the Technical School had been based mainly around the City and Guilds examinations. From the beginning its chemical aspect had been dominated by activity related to textiles. The School of Dyeing referred to above established a laboratory fitted out for "sound practical instruction in bleaching, dyeing and calico-printing". During 1881-2 this class had been the most popular in the Mechanics' Institute, attracting 53 students. It was taught by Charles O'Neill, editor of the Textile Colourist, and later by Antonio Sansone. Both men had wide industrial experience.[172] At the more general chemical level the School employed a sequence of well-qualified teachers. These included A.H. Sexton, E.L. Rhead, A.B. Griffiths and later H.L. Snape.[173] Griffiths and Snape each had German Ph.Ds. Rhead had trained at the Royal School of Mines and the City and Guilds Central Institution. Sexton had also trained at the Royal School of Mines and would later become Professor of Metallurgy at the Royal Technical College in Glasgow. Clearly these men did not have the status of Roscoe or Schorlemmer at Owens College, but they were not academically weak. During this period the Technical School developed a main chemistry course for day students extending over two and later three years, and a variety of "special lecture courses" on particular chemistry-related fields.[174] However the main day course in chemistry became increasingly orientated to textiles. In 1890 Edmund Knecht of the Bradford Technical College was appointed Chief Lecturer.[175] Knecht was a dyeing specialist. Adolph Liebmann, also a German Ph.D. with experience in organic dyestuffs, was recruited in the same year.[176]

By 1891 the two-year Day Course consisted of: Inorganic and Organic Chemistry; Technology of the Textile Fibres, Natural Colouring Matters and Mordants; Technology and Chemistry of the Coal Tar Colours; and practical work in the chemistry and dyeing laboratories. Within this area it was less inhibited than Owens, promising students experience in "carrying out bleaching, dyeing, and printing on half-scale machinery". Even a course at this time in "Chemical Engineering" (not to be confused with the well-known but short-lived course given by George Davis in 1888, which will be discussed later) turns out to be in "Bleaching, Dyeing and Finishing Machinery".[177] The basic day course covered only two years, but there was provision for a third year of full specialization. The evening work too focused on this area, and by 1891-2 the 25 entries to the City and Guilds examinations in dyeing outnumbered those of any other chemical sector.[178]

Dyeing and printing occupied a special position in the chemistry-related field partly because of its numerical significance, which reflected that of the textile industry generally. But it had given evidence from an early stage of posing fewer curricular problems and lending itself more readily to an independent pedagogic practice.[179] It was possible to break down the processes into their various stages, and study, for example, the dyeing process under the rubric of "dye trials" in a way which gave analytical chemistry an important but essentially ancillary role. This conceptualization of an independent "applied science" posed relatively few practical problems, as well as proving attractive to reasonable numbers of students. In 1882 Watson Smith, when asked by the Samuelson Commissioners how "a young man who desires to enter a calico print works" would occupy himself practically on the course at Owens, observed that he would be studying "the dyeing power of commercial alizarine and the like".[180] By the end of the decade the class in dyeing and printing was proving the most popular of the chemical technology courses at Owens.

In the reorganization of the technological chemistry courses at Owens the area where the authorities found themselves justified in accepting a more directly industrial content, textile-dyeing and printing, was precisely that where an independent, industrially-orientated curricular domain existed. The field was marketable and attracted students. It was also the area in which the most explicit competition for students with the Technical School existed. Under these circumstances the authorities at Owens were willing even to poach the teacher from the Technical School. By contrast, other less tractable or numerically successful curricular areas were redefined as within the competence of mainstream academic chemists. This early conflict between the two institutions developed in a tacit way. It can be reconstructed only from indirect curricular evidence. However, during the 1890s the conflict became more public.

This shift was triggered by the changing control and financial position of the Technical School. National legislative changes in 1889 permitted the City Council to raise a rate for the purposes of technical education. It received, in addition, substantial sums of "whiskey money" from the Exchequer, which could also be used for this purpose.[181] These changes had direct and indirect effects on university colleges, as was seen at University College London. In Manchester the City Council had established its Technical Instruction Committee in 1890. It agreed to take over responsibility for the Technical School, after a brief inter-regnum when the School was the responsibility of the Whitworth Institute. The Sub-Committee responsible for its management was established in April 1892.[182]

The School had received considerable material support from the Whitworth Institute, notably a new site at Sackville St. During the 1890s the City Council embarked on a large scale programme of investment in this site. This new financial stability allowed the recruitment of men like Knecht and the expansion of plant. Under these circumstances the question of the student body for which the Technical School was intended became more clearly a focus of dispute.

Some indication of the direction in which the Technical School was being moved can be obtained from the statements of Ivan Levinstein.

Levinstein was the owner of the largest dyestuffs firm in Manchester, and probably in the UK.[183] He was also actively involved with both the Technical School and Owens College. At the former he would become the Chairman of the Sectional Committee on Chemistry: in effect the most important lay influence on the School's chemical activities. Moreover, the structure which controlled the School was much more clearly lay-dominated than that at Owens, where the Senate had a central curricular influence. In 1890, addressing the assembled students of the Chemistry department Levinstein commented that technical instruction, under the recently passed legislation

> is intended to go very much further than only teaching science; indeed the teaching of scientific principles,...important as it is, is after all only a preparatory course for the study of 'Technology'...by means of which the application of scientific principles to our trades and manufactures ought to be demonstrated and illustrated by appliances as near as possible similar to those in use in our works.[184]

By such means the student would become familiar with all of the "manipulations, appliances, apparatus and plant he may meet". This approach drew the heavy sarcasm of Arthur Smithells in Yorkshire, but it was reprinted in the Manchester Guardian, and drew a letter of support from Henry Roscoe.[185] The other major theme in his comments, was the need to generate a body of workers of the appropriate type, this type being highly trained technical and scientific "experts". Levinstein was articulating here a general shift in emphasis among men representative of chemical manufacturers. It contrasted with the focus in earlier years on the need to educate the sons and future owners of chemical and related works. Levinstein had also made this his major emphasis in his contribution to a collection of views published in 1889 by the NAPTSE, and in which he had been acting as just such a representative.[186] This particular theme within the 1890 speech was taken further, in that he explicitly emphasized the need to produce men able to take a controlling function within industrial operations, and complained that efforts in Manchester were so diversified as to produce too many students of too low a standard.

Confronted by the prospect of a more prosperous Technical School with an expanding curriculum and facilities, and aspirations of this kind, Owens initiated a sequence of negotiations with the authorities of the School. In 1892 a paper on the relationship by the historian A.W. Ward summarized the negotiations and formulated the College's attitude to technical aspects of its curriculum as follows:

> the authorities of the College were unwilling to relinquish any course of higher instruction which might present itself as a useful adjunct to the training received by students of General Chemistry...The College will, therefore, continue to furnish technical instruction in Chemistry of an advanced character to Day Students.[187]

He went on to refer specifically to the Dyeing and Printing class. The curricular pragmatism contained in the words "any course" was quite categorical. However the sharpest edge of the College's attitude to the School was not expressed in terms of curriculum. The nature of the relationship envisaged between the two institutions was related by Ward to that between the the German Gewerbschule and Polytechnicum as much as to any cognitive distinction:

> the one is intended to train the skilled artisan and craftsman, while the other is intended to instil the principles of the sciences, and to take into its instruction those who will be masters of industrial operations.

No simple argument emerges if these two statements are combined. A relationship was however being presented between curriculum, institution and class of worker, and if any of these categories was dominant it was the last. The central importance of abstract science was retained, but a curricular pragmatism was added to it. Within this pragmatism curricula and institutions were both to be mapped against a hierarchically understood industrial function. The hierarchical message was central to the arguments of both Levinstein the manufacturer and Ward the historian and underpinned apparent curricular differences about the role of "technology". This can be compared with a contemporaneous statement from the Technical School Calendar, which gave the general aims of the Chemistry Department as being

> to supply the sons of Masters, Managers, or Foremen, or young men wishing to enter Chemical, Dye, Print, Bleach, or Metallurgical Works, with a sound knowledge of the Sciences which underlie these industries, and to train them how (sic) to apply their knowledge.[188]

It is the first part of this statement which most clearly defined the area of competition of the institutions. They were, from this point of view, engaged on the same project, though the curricular responses envisaged were somewhat different. This is not to say that the nature of this project was itself well understood or static, particularly in respect of the type of works function which it encompassed. The two institutions were, so to speak, constructing educational solutions to a "problem" of personnel supply which was itself in the process of formulation. The negotiations around 1892 had no explicit outcome. Curricular shifts continued at both institutions, and the tensions between them continued to grow.

Bleaching and dyeing was not the only chemical field which was open to novel curricular treatment, though it was, to date, the most successful. The older branches of manufacturing chemistry presented large problems for a direct and practical treatment in educational institutions, and this was particularly true of the manufacture of alkali by the Leblanc process. Some of the newer branches, such as the organic field, were, however, characterized by smaller scale and diversified batch production which required careful monitoring and multi-stage processing. As if to emphasize the parallelism in the two institutions' programmes Ivan Levinstein turned his attention to the curriculum at Owens College. In 1894-5 he instigated a fund for apparatus "suitable for higher technical investigations" in organic chemistry. This was to include "a scheme for higher technical training in Organic Chemistry".[189] When the scheme appeared in the College Calendar it was stated that the intention was "to train students in the practical methods of preparing organic substances such as are made in the larger scale dyeworks".[190] The course was to be mainly given by J.F. Thorpe, but, perhaps to prevent any repetition of the debacle with Watson Smith, it was stated explicitly to be under the direction of the Professor of Organic Chemistry.[191] The occupant of this Chair was W.H. Perkin jun. and he described to the Society of Dyers and Colourists how the course would involve small-scale industrial apparatus, and allow dyes to be made "under precisely the same conditions as are used in works."[192]

It can be seen again from these comments that the objections which may have existed within the College to teaching industrial "practice" were negotiable. "Applied" chemistry had been in some respects shifted further along the line developed by Watson Smith, with the introduction of practical activity allowing, at least potentially, a research programme. Within this approach there was a presumptive need to introduce plant and techniques drawn from industrial practice, as well as a recognition that the change of scale required particular attention. The implication was that the conversion of understandings derived from mainstream chemistry to works scale activity was not merely the imposition of new values on well-understood laboratory variables The industrial plant implied a qualitatively new conceptualization. Yet, from other perspectives, the new approach was less industrial than that of Smith. It presented a more abstracted form of works practice, which was combined with the notion of scaling up and scaling down for works and investigatory activity.

The introduction of industrially-related plant into Owens College was not justified in these terms. In practice it was scarcely "justified" at all. There is no record of a significant body of opposition to the activity on the grounds that it was inappropriate within a university. Anecdotal evidence of such opposition exists, but it is noticeable that it occurs in the context of closer relations with the Technical School.[193] Curricular innovation was fairly painless, particularly when constrained by available resources and other material factors. As the authorities at Owens College perceived either threat or opportunity, this appears to have been weighed quickly in the balance of existing and potential student enrolment, and the type of student, and resources, available. If men like Levinstein and firms such as Claus & Ree and the Clayton Aniline Co. were willing to employ graduates, and considered the courses appropriate, there was little to add. Attention was given to the integration of such activity within existing course options and the fields covered were carefully selected. It was impressed on teachers that their work fell within the responsibility of the chemistry professor. This can be seen as a mechanism for operating disciplinary and cognitive authority through the existing chemistry department.

In 1896 the intermittent negotiations between Owens and the Technical School resulted at last in a formal "Memorandum of Arrangement", signed respectively by the chairmen of the Council and of the Technical Instruction Committee.[194] The terms of this agreement were represented as setting up a less ambiguous division of labour across the two institutions between science and technology. In fact the agreement showed a systematic confounding between these categories and the level of the student. The agreement stipulated that the Technical School would cease to teach, not science, but science to the level of "Honours Courses in English Universities". Again the textile-related courses came in for special attention. The College would "cease to give special instruction under a technical lecturer in bleaching, dyeing and printing" (the only course specifically referred to). Yet, as the Senate Minutes at Owens made clear

> (i)n so far as a knowledge of the application of Chemistry to these subjects is necessary for advanced students, the instruction in them will form part of the Organic Chemistry Courses.[195]

In fact the new course at Owens in "Higher Technical Organic Chemistry" included, as well as works-based apparatus for organic preparations, "a small laboratory fitted with apparatus for Dyeing and Printing". Thus the explicit curricular overlap was not really removed at this level. The Owens Calendar attempted to clarify the position by stating that the course was meant for those "who intend to take leading positions as chemists in Coal Tar Colour Works, Calico Printing Works, Dye Works etc."[196] The Calendar went on, as agreed with the Technical School, that the course was not intended for "instruction of dyers and printers, such as is given in the Technical School". That a distinction in works function and authority was intended between those occupying "leading positions as chemists" and "dyers and printers" is clear. In reality the term "leading" was tendentious rather than clarificatory. Conflicting notions of the function of men trained as "chemists" were common, their status was frequently low, and their performance often held to be disappointing. Owens was confident enough to stand on the rhetoric of the instrumental value of chemical expertise to controlling processes, while implementing a more pragmatic approach in its curriculum. In regard to the Evening Classes the confounding of curriculum and status is still more clear: following the 1896 Memorandum the College dropped its evening class in Applied Chemistry. Again this may have appeared as a shift in curricular terms. However the Certificate in Applied Chemistry for Day Students was retained.

The mapping of institution against industrial position and student status, which Ward had sketched, thus showed signs of being put into operation by mutual agreement. P.J. Hartog took the opportunity to reinforce it in general terms, as well as to indicate the claims still being made by Owens, even as a university college, under the rubric of technical education. In 1895, writing of the College in the NAPTSE Record, he emphasized the distinction between "managers and manufacturers" and "foremen and workmen", and noted that the German technische hochshule was frequently identified with British technical schools. However in Germany the technische hochschulen were in fact orientated towards the former group, and therefore British technical schools should not be thought of as comparable with them. Hartog made it clear that it was university colleges which were the appropriate British equivalent. The message for the Technical School (and its students) was clear.[197]

Though Owens was at pains to retain this claim on the terrain of technical education, the numerical significance of its technical courses in chemical fields became comparatively small. The character of the student body continued to change quite rapidly during the 1890s. The main chemistry course was increasingly organized around preparation for Victoria University degrees, and the number of "occasional" students was falling. This situation had parallels at institutions such as University College, London and the Royal College of Science. Statistics on student destinations and certification will be presented in chapter 5.

In the negotiations with the Technical School Owens College easily retained for itself the teaching of academic courses leading to science degrees. Though the Technical School had no direct connection with a university there was formally nothing to prevent it from preparing students for London University degrees. The explicit references to the fact that it did not intend to reach Honours degree standard in its courses may have reflected this possibility. Though the Technical School did not appear to have any aspirations to prepare students for other than industrial occupations it was less happy about being constrained only to train "workmen and foremen". Indeed, unless this type of constraint was the major irritant it is difficult to see what source of conflict could have been in operation. The authorities at the School were never recorded as taking any exception to the teaching of "technology" at Owens. In July 1900, with the Technical School's resources still expanding and a large new building nearing completion in Sackville St., the Technical Instruction Committee unilaterally rejected the agreement of 1896. This was the precursor of yet another round of negotiations.[198]

The action of the Committee may not have seemed quite so unilateral at the time. The Victoria University General Board of Studies had only only months before (February 1900) begun to consider instituting technical degrees, and this question was to remain on the agenda of the university for some time.[199] For all the resources and stability of the Technical School this was a mode of certification in the technological field which posed a real threat to its higher level activity. During 1900-01 the Technical Instruction Committee was actively considering a new scheme of organization for the School, to be implemented in conjunction with the move into the new building. The key elements in the scheme involved raising the status of the School by recruiting staff "on an equality with men occupying like positions in University Colleges" but who would nevertheless "command the respect and sympathy of...employers and managers".[200] In addition the School was to offer a Diploma and Associateship to both Day and Evening students who had followed an organized course of study, and an academic Board of Studies was to be established. It appears that the Committee intended to supply the Technical School (the name of which was also to be changed to "School of Technology") with the trappings and status of a university college. The scheme was adopted by the City Council in June 1901.[201]

In its implementation of the staffing recommendations the Committee seems to have recognized that the only available route to higher status, in the chemical field, was via the recruitment of academic chemists. An outsider, William Pope, was appointed Head of Department, in preference to the technically-orientated Knecht. Pope had been trained at the City and Guilds Central Institution, and was currently Head of Department at Goldsmiths' College. He appears to have had no industrial experience, but an excellent research record on optical activity.[202] His orientation to mainstream chemistry was confirmed in 1908 when he left Manchester for a Chair of Chemistry at Cambridge University. It was probably Pope which the editor of the Manchester-based Chemical Trade Journal had in mind when he made the critical comments referred to below (p.164).

The report on the new scheme of organization at the Technical School made little reference to the target student population. However, within days of its adoption the Council of Owens College had received a report on its implications which compensated for this omission.[203] This document is full of ambivalences, and while casting a hopeful glance towards the 1896 agreement seemed resigned to its supercession. This may have been connected with the fact that the Technical Instruction Committee had taken the preemptive action of indicating that it was about to withdraw its grant to Owens. The Owens report began by reasserting the college's role as

> the proper place for the scientific training of men who are to enter Engineering or Chemical works, prepared to occupy leading positions...[204]

It rewrote history, claiming that Smith's lectureship had been suppressed only at the request of the Technical Instruction Committee in order to prevent curricular overlap. Yet it went on to claim that the current absence of conflict was due to the fact that the Technical School was limited to giving courses of lower academic status to younger students. Thus the potential conflict was most clearly defined in terms of the choice facing the "perplexed" parent who "is willing to keep (his son) at his studies until he is 19 or 20".[205] The report stated the claims of Owens to supply Higher Technical Instruction in organic chemistry. Yet this was contradicted later by the suggestion that the most appropriate training for employment in chemical industry would involve a scientific course at Owens and a technical course at the Technical School.

The report is casual and confusing in all respects except one: that Owens College must have a role in the education of full-time students willing to undertake higher education and intending to enter industry. Technical activity could occur at Owens, or it could occur at the Technical School in a division of labour, so long as Owens retained this role. In curricular terms engineering, especially electrical engineering, was considered a more immediate problem than chemistry. It appears that the internal negotiations within the College and the Victoria University over the possibility of offering certification constituted part of the response: it was after all the College's main tactical advantage. It is significant that it was in electrical engineering where Owens made progress towards a certificate.[206]

A Conference on the matter was convened, attended by men representative of the Technical School and Owens, but clearly homogeneous in attitude.[207] A mutually complimentary resolution was passed, and a joint committee established. The subsequent negotiations are not recorded but, under the financial pressure which the City Council was able to bring to bear the College agreed to look for some kind of agreement under the aegis of the Victoria University.[208] Within the University the question of technical degrees was again under discussion, though both it and the negotiations with the Technical School were overtaken by the break-up of Victoria as a federal university.[209]

With the establishment of the Victoria University of Manchester the negotiations were reopened, leading in 1904 to an agreement whereby a narrowly-defined part of the work of the Technical School was to be recognized as of university standard. This activity was to be institutionalized as the Faculty of Technology of the University.[210] The College and the Technical School were apparently too uniform in their support and their underlying programme for the shadow boxing to turn into a real conflict. For example, in January 1905 central figures from both institutions, including Alfred Hopkinson and Ivan Levinstein, under the chairmanship of the President of the Chamber of Commerce, Frank Forbes Adams, attended a conference on the relations between universities (and "institutions of similar character") and commerce. The requirement to channel men from such institutions into potential senior positions in manufacturing industry was the major theme of the conference, and a proposal to establish a "bureau of graduates" in the Chamber of Commerce was accepted.[211]

In the new relationship, the major issues which required resolution were the membership of the Board of the Faculty of Technology, the title and content of the degrees to be awarded, and the distribution of curricular activity. Of these the last appears to have caused very few problems, mainly because the issue of most significance to Owens, the exclusion of the Technical School from supplying degrees in pure science, at once became unproblematic. This point accepted, the allocation of curricular areas was largely pragmatic and, despite the earlier hand-wringing about overlap, was governed by the distribution already existing. The fact that it was full of anomalies did not cause significant discussion. Thus, while Applied Chemistry was allocated to the Technical School, the Chemistry Department at Owens retained its Certificate in Applied Chemistry and the Technological options in the Honours School of Chemistry. Engineering was retained in both the Faculty of Science and the Faculty of Technology.[212]

The new Faculty commenced operations in the autumn of 1905 amid general approval. The Manchester Guardian expressed relief at the avoidance of conflict between Owens "having the prestige of a wide reputation and the advantage of a charter empowering it to confer degrees" and the Technical School "lavishly equipped and more liberally provided with funds".[213] It was left to a letter from "Evening Student" a few days later to lament the fact that students of his class, without the resources to remain in full time education, were no longer provided with any route to the Technical School's highest qualifications.[214]

The first meeting of the Board of Studies of the Faculty of Technology, took place in November 1905. It was moved by Julius Huebner and seconded by Pope that the latter should be referred to as Professor of Chemistry rather than Applied Chemistry. This was not accepted, and in a compromise the Chair was referred to as in Pure and Applied Chemistry. The first degree course in Applied Chemistry was in two parts: the first part required candidates to reach the chemistry standard of the Final B.Sc. of the Faculty of Science.[215] The second part allowed specialization in any of seven areas. The first of these was called "general technological chemistry" and covered the design and construction of plant, analytical methods and "chemical, physical and mechanical principles as applied to chemical technology". In later months provision was also made for a University Certificate of Technology.[216] The Technical School also retained its own Diploma and Associateship. The differences between these various courses was mainly based on the standard of "pure" chemistry reached by the graduates. No linkage to the B.Sc. course was specified for Certificate students.

The establishment of a connection between the University and the

Technical School was a partial resolution of the tensions which had dominated their relationship. The Technical School had provided an institutional location for the construction of a curriculum in direct connection with industrial technique, which appears always to have been in the programme of certain manufacturers. It is unlikely that Owens would have resisted such innovations had resources and day students been available, but the capital involved was large. It is doubtful whether the College could have raised such sums. Public funds appear to have been essential to cover the capital and running costs of the industrial plant which the Technical School contained, and which figured so largely in the accounts of the Faculty in the Victoria University Calendar[217] The only available source of public finance, the Technical Instruction Committee, rendered inevitable the connection with the other levels of activity convened within the term "technical education" and represented at the Technical School. The symbiosis between the 5-6,000 evening students and the 350 full-time university students in the Technical School (the fundamental administrative breakdown) was thus materially and politically necessary. However, the position of the Faculty was anomalous.

The compromise of carrying on higher level activity in the Technical School was not altogether welcome, even while it was not clear precisely how the new educational activity would engage with industrial organization. Speaking to the Society of Chemical Industry in 1902, while negotiations were in progress, Levinstein stated that he had "grave doubts about the wisdom of combining the day classes in technology with "an evening continuation school (and) a trade school".[218]. Nevertheless, manufacturers were willing to employ "the right article", as they had done in relation to Owens. What "the right article" constituted was still in the process of definition, not least in Levinstein's own works. Other anomalies were more narrowly defined. There was, for example, no Honours School of Technology. The first division of the B.Sc.Tech. was simply called the Honours Division. Only three of the Technical School staff were allocated full university chairs and seats on the Senate, whereas Owens was heavily represented on the Board of the Faculty of Technology.[219]

When attempting to disentangle the relationship which was negotiated between the Technical School and Owens College a complex of mutually reinforcing hierarchies is evident. In part it could already be perceived in the view taken by Ward in 1892. From the departure of Watson Smith any activity in chemical technology was maintained under the control of the chemistry department. The dominance of the mainstream discipline developed to such an extent that the Technical School found that high status academic personnel and, later, increased chemical content were a prerequisite of the shift towards university recognition. Underpinning these issues, for both institutions, were those of the nature of the student body and representations of their future employment. Each institution staked a claim to a body of day students aspiring to 'managerial' positions, often with a terminological shift to 'technological' rather than 'technical' education. The key point for both institutions was to secure a location in the highest level of the stratified system envisaged in the production of an industrial workforce through formal education. The resolution which emerged in 1905 involved an articulation of these three hierarchies (workplace, institution and academic discipline). Compromises were, however, forced at the level of curriculum, and it was academic chemistry which most effectively maintained its position.

The major curricular problems remained in the Technical School. The tension between "general chemical technology" and specific technical areas has already been alluded to. The influence of Owens, and possibly of Pope, meant that the element of mainstream academic chemistry required for the B.Sc.Tech. was very high. An editorial, possibly by Norman Swindin, in the Chemical Trade Journal, was heavily critical of the School and the insufficiently technical orientation of the chemical chair. It suggested that the Technical School had "bartered away its birthright for a mess of pottage", and that the student was compelled to study too much chemistry which would constitute "useless ballast" in the future.[220] The chemical department attracted students in reasonable numbers, but was much smaller than that at Owens. By 1913-14, while the Owens Department was preparing 270 students, mainly for degrees and mainly, in Dixon's view, for industry, that at the Technical School had 56 degree and certificate students out of the Faculty's total of 336 students.[221] In the Faculty as a whole Certificate students outnumbered degree students considerably. Moreover, in the conflict over general as opposed to specific technical chemistry students appeared to prefer to keep options open. Twenty three of the "university" students were following the course in "general chemical technology", leaving the remainder thinly distributed between six specialist fields.

This information is obtained from a confidential report on the department compiled by George Beilby for the Board of Education in March 1914.[222] It is not apparent from the Annual Reports on the School. In addition the Department catered for 850 evening students, following a confusing variety of specific courses.[223] In his report Beilby commented that he had experienced "a slight sense of bewilderment" at the diversity of courses, going on to argue that "the multiplication of highly-specialized degrees in any one Institution is to be deprecated".[224] It was scarcely a glowing tribute. Beilby, had been an advocate of general chemical engineering when he was President of the Society of Chemical Industry in 1899. The development of this approach will be the subject of chapter 7. "Pure" chemistry continued to develop quickly at Owens. By contrast chemical technology maintained a precarious existence numerically, in terms of its curricular independence from pure chemistry and in terms of its claims to represent a coherent curricular domain.

F. Technological Examinations in the City and Guilds and the Institute of Chemistry 1870-1910

The final areas to be surveyed in this chapter are forms of certification rather than strictly educational activity. That of the City and Guilds Institute was older and much the more large scale. In 1872 the Society of Arts, then in the process of reducing the scale of its more general examination system, was persuaded by John Donnelly to set up a committee on the subject of technical examinations.[225] The committee recommended that examinations should be established in "the science and technology of the various arts and manufactures of the country".[226] The committee went on to argue that the curriculum and certification should be based on class of industrial worker, as referred to in the previous chapter. It distinguished the "workman's", "foreman's" and "manager's" certificate.

A conference of "manufacturers and others likely co-operate in the matter" was called for Easter 1872, though its attendance was notable mainly for the absence of manufacturers, and particularly of chemical manufacturers. It was dominated by the body of "professional" academics, educators and administrators which was an important element in the previous chapter.[227] The structure which was eventually established pinned together certification through science education (via the DSA examinations), the "technological examination" and the requirement for an employer's statement of practical competence. In particular, men who had not passed the DSA examination in two relevant subjects were ineligible for the Society of Arts certificate. Two elements in this can be highlighted. Firstly, it recognized that the connection between industrial technologies and academic science was not so intimate as to be automatic, and this connection would cause conflict for some years. Secondly, the codification of such technological knowledge was seen to be connected with workplace function, interpreted in terms of the existing workplace hierarchy. It can be observed, however, that the examination system placed them within a single institutional form, and that the content of the examinations was also relatively homogeneous.

The first examinations were in cotton and paper manufacture, and attracted few candidates. The first in directly chemical industries were those in alkali manufacture. They were offered from 1875, but did not attract candidates until 1877, when 6 students from the Widnes Science School presented themselves.[228] In 1879 the examinations were transferred to the newly-established City and Guilds of London Institute.[229] Under the influence of this body the examinations became part of a more differentiated body of activity, and cannot be considered apart from this.

The events leading to the formation of the City and Guilds Institute had a complex history, but the key formal step occurred at a meeting in Mercers' Hall in June 1877. This set up a general and an executive committee to prepare "a scheme for a National System of Technical Education".[230] The Executive Committee commissioned a number of "experts" to make recommendations about the organization and curricula of the scheme.[231] These reports were grounded firmly in the standard language about the balance between "principles" and "practice". The former tended to be identified with "Science", while "practice" was specified as inappropriate for location in educational institutions and frequently identified with handicraft skill. The Executive Committee, in approving of this approach, used an example from the iron and steel industry as an illustration. A puddler would not be instructed in "how to handle his tools in a superior manner". Such men would instead be given[232]

> the scientific instruction which will enable them to know why it is that occasionally, in spite of manual dexterity, and in spite of attention, the puddle-bar is bad...The application of the science of Chemistry to the manufacture affords this knowledge. Instructed in such application, the ironmaster, his manager, his foremen and even his workmen will know how, when varying fuel or varying minerals or fluxes are brought under treatment, to alter that treatment...

These comments indicate, as well as the tenacity of the language of a directly instrumental scientific knowledge, that the Committee had not yet developed that independence of view which was seen to characterize their evidence to the Samuelson Commission in the previous chapter. At this stage the scheme already envisaged the three main elements which eventually came into being: a central institution, model technical schools and the national examination system. The comments of the Committee at this period also indicate that the scheme was represented as being relatively undifferentiated in relation to the different classes of industrial worker. Thus the Central Institution was seen as producing, apart from technical teachers, "a supply of superior Workmen, Foremen, Managers or Principals".[233]

Though the intention had been that the Central Institution should have first priority, circumstances favoured an early emphasis on the model technical school at Finsbury, which could be developed on the basis of existing classes. When the Central Institution came to be planned, during 1884, its organization and functions were defined by a Committee chaired by T.H. Huxley. The "Scheme of Organization" which this Committee produced showed that the function of the Institution had undergone a considerable shift. It was now seen as supplying, again apart from teachers, "Principals, superintendents and managers of chemical and other manufacturing works".[234] However, while the Technological Examinations, and to a lesser extent the Finsbury institution, were developed to encompass many directly industrial fields, the Central Institution was constrained within disciplines already established in high level academic institutions: engineering, physics, chemistry and mathematics. This parallels the tendency observed above in Manchester.

The other elements within the scheme developed towards servicing different components of the industrial hierarchy. Thus by 1892 the model technical school at Finsbury was described as drawing students mostly from "middle class schools", with only a very small number attending from Board Schools.[235] The majority of its students were able to enter immediately into works where they were "fitted, after a few years practical experience, to fill intermediate posts". From this perspective the Technological Examinations showed a consistent and long-term decline in status. In 1881 a sub-committee recommended that the number of stages in the Examinations be reduced from two to three because this "better matches the class of candidates who compete".[236] The subjects available in the examinations were expanded in the direction of handicrafts. Eventually, as Owen Roberts had indicated to the Samuelson Commissioners, practical tests were introduced into areas such as plumbing and breadmaking. By the turn of the century the official history of the Institute described the examinations as covering "Technology and Manual Training" and as being "suitable for artizans, apprentices, and others attending evening classes".[237]

The Institute also attempted to weaken the connection between the examinations and those of the DSA. While still under the control of the Society of Arts the examinations had already received criticism for this connection. George Howell of the TUC commented in 1875 that the programme required "a far wider acquaintance with abstract science" than workman were able to acquire.[238] Others, representing the DSA as bureaucratic, centralized and encouraging cramming, urged the City and Guilds to "steer clear of South Kensington and all its ways".[239] When the new regulations for the examinations were published they duly contained a reduced reliance on DSA certification. The comment of the Council was simply that the conditions had been relaxed because they "prevented many eligible candidates from coming up for examination."[240] Donnelly wrote angrily to The Times that the careful structure established by the Society of Arts had been "emasculated".[241] Owen

Roberts answered for the Institute with a dismissive reference to the cramming tendencies of the DSA system. Donnelly replied with a claim that the Institute was apparently not interested in using the examinations to train both the sons of manufacturers and the workman potentially to be able to supervise works. It was more interested in attracting and certifying large numbers of students, and of focusing on handicraft skill.[242] To this Roberts made no reply.

The stratification which the City and Guilds system underwent goes some way to explaining the development of the chemical components within the Technological Examinations. Chemistry had often been presented as the main focus of the City and Guilds' activities. Reporting in 1880 on the classes at Cowper St., which were the precursors of the Finsbury Technical College, H. Trueman Wood wrote that "(a)mongst all the applications of the Sciences to the Arts, there is no possible question but that the foremost place is held by chemistry."[243] In 1895, writing retrospectively, Ray Lineham claimed that in the earliest stages of the City and Guilds activities "(c)hemistry...was to be the head and corner-stone of all technical instruction", though he added significantly "not the chemistry of the Science and Art Department, however, but just such chemistry as would apply to the particular craft under consideration..."[244] As might be anticipated from the earlier parts of this chapter, while chemistry struggled to some extent in all components of the Institute's activities, it fared worst in the Technological Examinations.

While the handicraft components of the Technological Examinations grew quite quickly, the chemically-orientated examinations were first erratic and then stagnant. The examination in Alkali Manufacture grew quickly to a peak of 54 students, before falling away equally rapidly.[245] In the late 1880s and the 1890s, as the total examinees approached 10,000, it attracted candidates in single figures, and sometimes none. While some part of this may have been connected with decline of the Leblanc industry during this period, it is noticeable that the other main examination relating directly to chemical manufacture, that in Coal-tar Products, attracted similar numbers. In 1891, while these examinations attracted 11 and 16 candidates respectively (in quite a good year), Cotton Spinning attracted 1,116 candidates Carpentry and Joinery 837 and Telegraphy and Telephony

206.[246] In 1889 the Report on the examinations concluded that[247]

> the best means of providing operatives engaged in Chemical works with the kind of instruction which will prove most serviceable to them has not yet been discovered.

The shift towards examinations orientated largely towards artizans was recognized by Sub-Committee D which had responsibility for the examinations. The response to this was to set up a Special Committee.[248] This group suggested that the most appropriate response to the loss of higher level students was to establish an institutionally distinct examinations system. It suggested a "Scheme of Examinations in Higher Technology", to be directed towards "managers and scientific advisers". This was to reach a high scientific standard, and to be intended for day students. The scheme was to be operated in association with university colleges, but no further development of it was undertaken. The components of the proposal will not be unfamiliar.

A further difficulty which particularly affected the chemically-related examinations was that of secrecy. J.F. Donnelly, Owen Roberts and Sydney Waterlow all commented on the hostility which had been displayed by manufacturers on the grounds of the threat posed to the commercially significant knowledge of individual firms.[249] This type of problem appears to have been particularly prevalent in the fields of dyeing and printing, and of organic dyestuffs. In 1896 J.H. Reynolds wrote to the Board of Examiners about a complaint from "an influential member of my committee" (almost certainly Ivan Levinstein) about a question on β-naphthol and β-naphthalinine (sic) manufacture, which was said to be undertaken at only one place in the UK.

> This is considered to be in the nature of a 'fishing' question...If employers get the idea that there is a danger of their particular processes or methods being revealed...I can hardly imagine anything more disastrous.[250]

He suggested that men would be forbidden to attend, or sacked if they did. Despite the somewhat libellous implication for the examiner (at that time A.G. Green, research chemist and works manager at the Clayton Aniline Co., Levinstein's near neighbour and direct competitor) the Board responded mildly enough by stating that the question was considered to be reasonable. It is not clear whether the two events were connected, but Green resigned from the examinership later in the year.[251] Questions on this and other chemical papers began to be preceded by a statement that:

> Candidates are cautioned to avoid giving in their answers to the following questions any particulars of processes used in the works in which they are employed which are not matters of public knowledge.[252]

A survey of the early examinations and syllabuses in Alkali Manufacture indicates that they required considerable familiarity with the day-to-day operations of an alkali works. Some attention was also given to routine analysis, while questions about reasonable (though not necessarily stoichiometric) yields and the operation of standard processes were common.[253] The more advanced papers were similar in standard to those used for the technological chemistry course at Owens College. This is not altogether surprising, since the examiner at this time was Watson Smith, but the point is of wider significance.

The average age of the candidates in 1879 was 22.[254] Many of those who can be identified at this time went on to become senior foremen or managers. Overall the mixture of candidates in the early stages was diverse, including men from Widnes works, students at Owens College, and at least one son of an alkali works owner. The early entries from Owens quickly disappeared. The question of students' employment when the examinations had settled down was provisionally answered by the Examiner in 1898, A.E. Fletcher, who noted that they were mainly "foremen and under-managers in works."[255]

To some extent the problems of the Alkali examinations could be presented by examiners as due to the difficulty of enabling such men to gain a sufficient knowledge of academic chemistry. The same is true, though at a level more obviously connected with academic chemistry, of the examination in Coal Tar Products. Both examinations attracted a trickle of candidates but were a highly specialized form of certification for men often already occupying intermediate positions in works. In content they grafted operational knowledge onto a body of academically-defined chemistry, the difficulties of which have already been noted. In 1888 Thomas Twining commented in relation to the syllabuses combining academic science and technical detail that "(w)ith regard to Chemistry, the most important of the Sciences, the awkwardness has been particularly felt", and argued that such "special fragments" of science as were needed should be tested in the

Technological Examinations themselves.[256] This was never likely to be acceptable given the largely academic background of the Board of Examiners. The need for a high standard of chemical knowledge was repeatedly brought home to candidates by high failure rates and heavy criticism. T.L. Bailey commented in his examiner's report for 1900 that[257]

> the standard of attainment was extremely disappointing, more especially in the Honours Grade. There are, throughout, indications that broader reading is required on the part of students, and the theory of processes needs greater attention.

However, the problems of the examination had other roots beside curricular definition or the access of candidates to chemical knowledge. When the Institute's Council made the comment referred to above in their report for 1889 they targetted "operatives". In fact this group (or even "artisans") was not a population of any significance in the chemical industry (qua chemical: plumbers, joiners etc. were important.) The chemical industry was very different from engineering or handicraft industries in this respect. The control of large-scale plants, continuous processes or obscure and in many cases novel batch processes was increasingly the concern of the industry. More perhaps than any other sector at the time it lent itself to the language of expertise and direct managerial control. Speaking to the LCC Sub-Committee on the teaching of chemistry in 1896 Ferdinand Hurter commented dismissively that "lectures... given on alkali manufacture in Widnes" were "not really necessary". While "technical direction" might be useful for the education of "painters and plumbers, where the men undertake work away from the foreman", in the chemical industry "(t)he man who will work steadily and do what he is told" was preferred. Only foremen, he suggested, had any chance of promotion, and it seems to have been this group that the examinations attracted.[258] Raphael Meldola commented in 1909:[259]

> I have pointed out again and again that the workman in a chemical factory is not the analogue of the skilled artisan of the engineering workshops, and that the handicraft view of technical education is worthless from the point of view of the chemical manufacturer.

He went on to note that chemical processes needed to be under the direct control of "higher powers".

Both Hurter and Meldola may have had the City and Guilds examinations in mind. In any event it seems likely that they were identifying a central reason for the relative failure of the chemistry-related examinations. Not that the City and Guilds examinations in chemical sectors were based on handicrafts in the sense that Meldola was using the word. The examinations in Alkali Manufacture did attempt to conceptualize a body of knowledge appropriate to the "higher powers". However they were within an institutional framework in which the examinations had crystallized as appropriate for artizans. They were increasingly placed in direct competition with the alternative route into senior positions represented by full-time higher education. This parallels that connection between institutional provision and class of student and worker seen in Manchester. The City and Guilds examinations were precisely the form of certification operated by the evening component of the Technical School. For the technically and organizationally innovative chemical industries the distinction was a particularly sharp one, as was the anomalous position of the chemical examinations. Their relative failure can be seen as a consequence of this. The examination in Alkali Manufacture survived until 1923, with single figure entries.

The Institute of Chemistry did not begin its technological examinations until 1906. The original proposal for an examination in "Chemical Engineering and Technology" had been made in 1902 by E.J. Mills.[260] The impetus for the scheme seems to have been mainly internal. The Institute's Council had recently demonstrated that a large proportion of the membership was employed in industry.[261] The aim of providing a certificate appropriate to such men was a shift from the established orientation of the Institute towards analytical practitioners, yet one which reflected the rising significance of industrial employment among men earning their living using chemical knowledge.[262]

A Special Committee was established to investigate the proposal.[263] The Committee immediately found itself bogged down in questions of curricular definition, and this was to characterize the entire development of the scheme. The most useful mechanism for making progress was thought to be "a private conference with prominent manufacturers". This was said to be required to establish "in what respects they considered the education at present afforded to works chemist failed in giving the knowledge necessary to the manufacturer."[264] The Committee presented a number of drafts of its report, and these indicate that the subject of curricular content still generated problems, focused mainly on the questions of generality and secrecy. At first the Committee showed a preference for a single generalized examination. This was to be encompassed by the title "Chemical Engineering".[265] A draft report on this basis was published. It was received favourably by the full Council, which chose however to emphasize the issue of secrecy in the examination and stressed that "no questions should be asked involving the disclosure by Candidates of processes and plant peculiar to particular works."[266]

The Report was passed back to the Committee. In the light of the comments which it had received the Committee produced a new report which increased the emphasis on specific sectors, intended to be representative of the chemical field.[267] Something of the motivation for this more focused approach is indicated by the comment that they must be "stripped as far as possible of all elements of a doubtful or controversial character". Sulphuric acid manufacture and gas manufacture were selected as appropriate areas on which to base the examination. The report again passed through numerous drafts, with an expansion of the range of sectors covered. The criterion for inclusion was that "(s)uch industries are established in or near every large town and are, as a rule, carried on without secrecy".[268] After a long delay the final report was considered by Council in June 1905. Here it was amended radically so that each candidate could select a field in which to be tested.[269] An Advisory Committee was set up to implement these proposals, nearly three years after the original suggestion. The examination as eventually constituted involved two compulsory examination papers entitled "General Chemical Technology". In addition candidates were required to select one specialist area, also for examination in two papers.

No objection was exhibited to examining knowledge of industrial "practice". Candidates were required to "show a practical knowledge of operations, chemical and mechanical, and of the apparatus and machinery commonly used in chemical manufactures." However only those who were already Fellows or Associates of the Institute were eligible for entry. Thus the qualification was subordinated to chemical competence as defined through the existing examinations and in existing chemical curricula. It was not until 1917 that technical chemistry became an option within the Associateship examination itself. The examination was firmly identified with Meldola's "higher orders": the candidate was to be able "intelligently and economically (to) supervise manufacturing operations...and know how profits are made". The issues of commercial secrecy were addressed explicitly. Candidates (or perhaps their employers) were assured that

> (q)uestions which might involve the disclosure of unpublished processes and details of plant in particular works will not be asked.

From the first the scheme was criticised from various directions, particularly for its implicit requirement of training through mainstream academic courses, its refusal to recognize lower level qualifications such as those of the Board of Education, and for its intention to examine men who were already experienced in works. The Chemical Trade Journal took the opportunity simultaneously to attack the tendency of academic institutions to appoint men "whose whole time is taken up in the study of pure theoretical chemistry, to occupy a chair of technical chemistry", and the failure to value works experience.[270] The first examination, in 1906, drew only four candidates, of whom three failed. No further candidates presented themselves until 1912. One candidate in that year, and one in 1913 were followed by a further gap till 1919.[271] The failure of the examinations cannot be attributed to any single cause, but evidently had its basis in the fact that they did not either tap or create a student body. They could be undertaken only by men with an existing practical experience and competence, which they attempted both to codify and certificate. It seemed that men with this experience and competence were unwilling to pass through this process, and that employers did not expect it of them.[272]

Meldola, in his Presidential Address to the Institute in 1913, commented that the examination was "flagging" because the Institute was out of contact both with teachers of applied chemistry and with manufacturers. This reflected the general perception of the Institute as a body dominated by academics in pure chemistry and analysts in private practice.[273] His comments led directly to the 1913 Conference of Professors of Chemistry which has been referred to at intervals. The main topic here was the relationship of the Institute to industrial and technological fields. The history of the Certificate was grounded in the specific circumstances of the Institute of Chemistry. Nevertheless in relation to curricular content and target population its difficulties derived from similar sources to those which have been seen throughout this chapter.

G The position of chemical technology in the curriculum.

The attempts to construct more directly "industrial" curricula which have been described in this chapter came about mainly through the efforts of groups and individuals not professionally involved in educational institutions. Their intervention was both direct, as at the Andersonian, the City and Guilds and at the Manchester Technical School, and indirect, as at University College, London and Owens College. It cannot be seen as merely due to utilitarian, scientifically ignorant men of business. Men like James Young and Ivan Levinstein do not fit this description. Industrial capitalists who were active in the field often did not take up the ideological positions supplied for them by academics, while others exhibited simple hostility or scepticism to aspects of the "technical education movement".[274] The former group, while they envisaged a more targetted educational provision had no models to hand of what such provision would be like, and their expressions of view and initiatives were exploratory. Immediate responsibility for defining the content and methods of the new courses was placed on an embryonic body of 'technological' academics, whose commitment was mixed, and many other forces were in play within this innovatory activity.

The knowledges constituting the new curricula occupied a continuum, beginning with those based on more focused analytical and descriptive accounts of industrial materials and processes, mainly orientated towards monitoring and exchange. The continuum reached through areas where the categories of academic chemistry were presented as tools in the understanding, control and development of manufacturing processes, though still within the convention that laboratory processes were paradigmatic. Finally there were attempts to introduce the details of plant operations into the the curriculum, with mainstream academic chemistry largely ancillary.

The relation of the 'pure' discipline to industrial technique was usually encompassed by the phrase that it constituted the "principles" of such technique. If this term is not understood to refer almost tautologously to 'pure' chemistry it must clearly carry some further meaning. As used the term seems to have encapsulated a number of further characteristics such as generality, suitability for public transmission, the propagation of identifiable competencies of direct value in the workplace, a conceptual explicitness which allowed the creation of a pedagogy, rather than relying on personal contact and, finally, distance from immediate plant practice, understood as a handicraft activity. Attempts to appropriate or broaden the notion of industrial principles were under pressure to establish the claims of novel curricular content in relation to each of these points.

'Pure' chemistry could be represented as treating the phenomena of the chemical industry in a generalized way. The question of how curricula involving the diverse technical activity of industrial chemistry could be so treated was rarely exposed publicly. One solution generally adopted for full-time day students was to cover a range of those sectors thought to be economically significant and relevant to employment. It appears that such 'integrated' activity was often little more than a formality for Prospectus purposes and attracted almost no students. This is not to say that the constituent courses had no students, since institutions were careful to ensure that they could be exploited in a piecemeal way. There are repeated references to parents' requests for tuition in one industrial sector only, and transient and apparently highly selective student bodies are evident at Owens College and University College London. Often there were variations in the areas covered by individual institutions from year to year during the 1870s and 1880s. All of this suggests that the problem was one which exercised the minds of the teachers, administrators and controllers in institutions, but which they could not satisfactorily resolve. An effort to develop the notion of a "general chemical technology", prefiguring chemical engineering, occurred in a number of the institutions.

The sensitivity of commercial significance within attempts at codification has appeared regularly in this chapter. Technical knowledge had a differential commercial significance only if it was possessed by individuals rather than generally: if it was private rather than public knowledge. It was necessary for the curricula of educational institutions to define and remain within this boundary, to be, as it were, commercially insensitive. The model of such knowledges had again been provided by the natural sciences, especially as institutionalized in an academic setting: publication was indeed central to their validation. The difficulty for industrial curricula was the fact that the knowledge they could transmit was prone, or seen as being prone, to slip into the paradoxical region of being a private knowledge of such immediate operational value as to preclude its public transmission. This caused problems, in terms of hostility from potential employers and patrons of institutions.

The construction of technical curricula meant producing an abstracted account of industrial phenomena which yet transmitted identifiable works competencies. It was in part the absence of such competencies (recognized above by James Napier, Ivan Levinstein and the editor of the Chemical Trade Journal) which prevented academic chemistry, despite the best efforts of its protagonists, from unilaterally taking up the role, for which it was qualified on grounds of generality, relative commercial insensitivity, and independence from manual labour in the works.[275] Yet the alternatives generated during this period were scarcely more successful, at least so far as convincing potential employers and students was concerned. In 1892 the Annual Report to the Council of the City and Guilds noted of students holding the Diploma of the Central Institution (not yet discussed) that it "helps a student very little in obtaining practical work".[276] Perceptions of likely employment prospects had a considerable impact on the recruitment of students onto courses. Graham observed in 1879 that parents expected students to be qualified to go straight into relatively responsible positions in works.[277]

There was also hostility to the use of anything resembling industrial plant within potential new fields. This was partly a consequence of the issue of secrecy just discussed but had other aspects. For educational institutions there were questions of resourcing and updating. Equally or more important was the association which would be implied with "handicraft skill", and the actual operation of plant. The comments by Smithells on Levinstein's proposals for Manchester highlighted the key role of the student as potential manager. It became acceptable quite quickly for lower level technical education to involve such "manual" skill, but the situation for higher-level workers and institutions was problematic. Here the argument begins to move into the field of employment hierarchy.

Academic training, whether in 'pure' or 'technical' chemistry, in fact constituted a radical shift in the reproduction of the industrial workforce. A key aspect of that workforce was of course the stratification it contained. It was seen in the previous chapter that this came to be an important component of the public exploration of technical education. Within the chemical field it often appears that curricular differences were less of significance than potential relationship to the hierarchy of works personnel. In Manchester, the relationship between the Technical School and Owens College was dominated by claims to constitute an educational 'track', appropriate to managerial positions. From this perspective 'pure' chemistry, as well as occupying a more flexible cognitive position, offered a more secure location within other developing curricular and institutional hierarchies. This is most graphically indicated by the increasing contrast drawn between day and evening students, a distinction which had a key place in the outcome of the negotiations at Manchester. It is necessary to state here that this putative route into industrial hierachies, while drawn clearly in the domain of educational rhetoric, was more problematic in terms of actual careers, as chapter 6 will indicate.

The question of the differing academic "status", within educational institutions, between the mainstream academic disciplines and the new technological fields has often been discussed. It is hoped that the problematic aspects of innovation in the technological curriculum, so far as chemistry is concerned, have been shown to be more complex than simple hostility manifested by academics in well-established disciplines. Nevertheless this had a role. The assimilation of the natural sciences into the ancient universities and the major public schools had evidently gone some way to establishing these fields as appropriate to form the basis of a general or liberal education.[278] It was here that the new foundations in London and the provinces were often strongest, and this gave physical science an important role within them. Institutions such as Owens College were engaged in an unsuccessful attempt to retain the brief and partial curricular hegemony they had held over the ancient universities. The institutional strength of chemistry within Owens gave its staff power to resist inroads from novel but related fields. The representatives of the discipline easily overcame the efforts of Watson Smith to gain independence. They quickly established its authority, with the connivance of Pope, over the chemical course leading to the B.Sc.Tech. in the Faculty of Technology.

At a more general level the linking of curricular and institutional status can be seen in the reflections of the Committee set up by the Treasury to oversee the distribution of the grant-in-aid to the university colleges in 1904. The Committee was required to consider only "University work" and to distinguish it "as far as possible from technological or trade instruction". By 1907, when Alexander Hill and Sir Thomas Raleigh were requested to report on the work of the colleges, they could comment:[279]

> It was less difficult to distinguish 'University work' from 'technical education', and since the Universities have extended their aegis over various technological subjects it no longer rests with us to give a definition of 'subjects of University rank'.

This oddly tautologous approach was clarified by their further observation that the new courses were thus made "broader and more scientific" than those the students themselves would have followed were they not eager to obtain a degree. The formulation nevertheless indicates at least a partial dependence of curricular on institutional status. When, in 1900, the Board of Education set up a Committee to look at the coordination of technological education, it based its recommendations less on a curricular division than on a stratification between lower level work (which should come under the Board) and the higher level work undertaken by the university colleges.[280]

Academic programmes of chemical technology thus faced many problems beyond the merely cognitive. There were others, such as the difficulty of obtaining teachers, or even of defining the characteristics expected of them. Men experienced in industrial practice were generally able to obtain a better salary even in industrial employment, let alone operating their own works. In 1889 during a discussion on the Technical instruction Bill, John Ashwell observed to the Nottingham Section of the Society of Chemical Industry that "...if (technical teachers) were practical men surely it was strange that they did not double their salaries promptly by going into commerce."[281] To this could be added the manner of their functioning within an academic environment where research was now considered an intrinsic activity and where consultancy (while often recognized as a useful method of retaining industrial contact) was coming under hostile scrutiny. There was an obvious difficulty in undertaking technical research which might be of immediate commercial significance. In chapter 3 it was observed that the capacity to undertake research was given the central place by men like Meldola and Lockyer in defining the status of institutions. In 1908 the Chemical Trade Journal was critical of the Victoria University for its proposed ban on the new Professor of Pure and Applied Chemistry undertaking consultancy work. Yet it was equally critical of the proposal that the University should offer its facilities for private research by firms, on the grounds that "the essential idea of a university is that it should be a means of disseminating knowledge...".[282] The editor was not apparently conscious of any tension between these two positions.

This chapter has explored, on the basis of a number of representative institutions, the characteristics of curricular initiatives in technical chemistry. There are similarities across institutions. An attempt has been made in this conclusion to identify some of the underlying forces. They include: the conceptualization of chemical manufacturing processes in a form suitable to be the basis of an academic discipline of public generalized knowledge, the recruitment of a body of teachers combining academic and industrial expertise; and the tensions generated by redrawing disciplinary boundaries within and between academic institutions. Underpinning these was the attempted construction of a system for the reproduction of the industrial labour force involving hierarchies in the workplace, mapped against institutional and disciplinary hierarchies. All three were at that time in a particularly dynamic state. Within the latter two mainstream academic chemistry was firmly established as of higher status. It was also presented as fulfilling a more generalized educational function.

The outcome of the situation was that initiatives in technical chemistry were to a large extent failures.[283] Under these circumstances it is not surprising that "pure" chemistry maintained a dominant position as a route into industrial employment. Curricula based on more narrowly defined technical sectors, in such chemically-related fields as dyeing and printing and metallurgy, were less problematic and more successful than technological chemistry. Engineering disciplines too exhibited greater success. The main candidate to constitute a general or 'primary' technology of manufacturing chemistry was "chemical engineering". The emergence of this field will be discussed in chapter 7.

The difficulties of academic activity in technical chemistry during the late nineteenth and early twentieth centuries is in obvious contrast to the situation in chemistry itself. The most generally successful educational activity so far as the production of 'scientists' for whatever purpose was concerned, were courses leading to the ordinary science degree and the honours degree in chemistry. While courses and certificates in technical, technological and applied chemistry languished, chemistry remained the largest of the science disciplines. It attracted, for example, the largest number of candidates for the London B.Sc. with Honours, constituted the largest science department at Owens College and so on.[284] Moreover chemistry was generally acknowledged to be the scientific field of greatest relevance to industrial activity. Apologists for the notion of mainstream academic chemistry as sufficient to supply the underlying "principles" of industrial processes could find in this numerical growth a useful propaganda weapon. Chapter 5 shifts focus towards such education in 'pure' chemistry, and surveys the occupational destinations of its growing student output.

Notes to Chapter 4

1 G.K. Roberts, 'The Liberally-educated Chemist: Chemistry in the Cambridge Natural Science Tripos, 1851-1914', Historical Studies in the Physical Sciences, xi (1980), pp.157-83. F. Sherwood Taylor, 'The Teaching of Science at Oxford in the Nineteenth Century', Annals of Science, viii (1952), pp.82-112. Cardwell, op. cit., pp.93-5. H. Butterworth, 'The Science and Art Department Examinations: Origins and Achievements', in Days of Judgement, ed. R. MacLeod (Driffield, 1982), pp.27-44. J.P.C. Roach, Public Examinations in England 1850-1900, (Cambridge, 1971).

2 CN, xxii (1870), pp.121-9. Brock, op. cit. (1976). The 1908 edition of the Institute of Chemistry's Official Chemical Appointments showed 240 men employed in universities and university colleges, excluding pharmacy and similar specialisms, and 307 men in technical colleges.

3 Owens College, Prospectus 1852-3 in Owens College Papers 1851 to 1861, bound volume at Manchester University Library, no continuous pagination.

4 Ibid.

5 Owens College, Annual Report of the Principal (1854).

6 Owens College, Annual Report of the Principal, (1856), p.vi. The following data are taken from the Principal's Annual Reports and the Calendars for the relevant years.

7 The origins of the Royal College of Chemistry have been discussed in G.K. Roberts, op.cit. (1973) and Bud and Roberts, op. cit. (1984). The situation in the Royal School of Mines during the 1850s is discussed in J. Bentley, 'The Chemical Department of the Royal School of Mines. Its Origins and Development under A.W. Hofmann', Ambix cvii (1970), pp.153-81. The attempts which were made to develop the school so as to influence school science education are described in D. Layton, Science for the People. The Origins of the School Science Curriculum in England, (1973), pp.155 et seq. In view of the changing name of the institution it will be referred to throughout this chapter as the Royal School of Mines. By the time of its reorganization alongside the Normal School of Science in 1881 it had ceased to offer a course specifically designated as relating to manufacturing industry.

8 DSA, First Annual Report, PP 1854, xxviii pp.184-5.

9 DSA, Tenth Annual Report, PP 1863, xvi Appendix V.

10 Even by 1868-9 only 12 students in the chemistry laboratory were full-time, compared with 85 "occasional" students. PP 1868-9, xxiii.

11 Frankland to Playfair, 11 January 1853. Playfair correspondence, Imperial College London, MS 278. Frankland envisaged the creation of a School of Mines at Owens, "I hope, in connection with yours (if you will have us)".

12 DSA, First Annual Report, PP 1854, xxviii p.180.

13 Typical questions from Playfair's 1852 examination were:
"1. What is the absolute evaporating power of a Coal of the following composition?--

Carbon	84.72
Hydrogen	6.43
Nitrogen	1.21
Sulphur	0.84
Oxygen	4.80
Ashes	2.00
	100.00

2. If 100 grains of the above Coal be burned in air, what bulk of air is required for the combustion? What products result from it? What is the weight of each product, and what the bulk of Carbonic Acid produced?
3. Explain the Dutch and French methods for making White Lead, the theory of the processes, and the formulae of the products."
Government School of Mines and of Science Applied to the Arts. Museum of Practical Geology. Calendar, 2nd Session 1852-53. pp.11-12.

14 Kargon, op. cit. (1977), p.164.

15 E.K. Muspratt, op. cit., p.92.

16 R. Bunsen and L. Playfair, "Report on the gases evolved from iron furnaces, with reference to the theory of iron smelting", Report of the 15th Meeting of the BAAS (1845), p.142.

17 On the Yorkshire College see Studies in the History of a University 1874-1974. To Commemorate the Centenary of the University of Leeds, ed. P.H.J.H. Gosden and A.J. Taylor (1975). On the Royal School of Naval Architecture see Bud and Roberts, op. cit. (1984), pp.124-5 and 137-8.

18 Other initiatives can however be noted. The reorganization of the School of Science Applied to Mining and the Arts in Dublin (as the Royal College of Science for Ireland) in 1867 converted its two Chairs of General and Practical Chemistry into Chairs of Chemistry and Applied Chemistry occupied by the same individuals (W.K. Sullivan and R. Galloway respectively). However the new chair did not appear to differ substantially from the earlier one, and no formal specialization on the part of students in Division D (Manufactures) towards chemistry seems to have been allowed. The earlier activity had been, if anything, less industrial in orientation than that in the London School. Report of the Commission on the College of Science, Dublin. PP 1867, lv 771. Report of the Council of the Royal College of Science for Ireland, (Appendix G to the DSA Annual Report) PP 1868-9, xxiii. Board of Trade, Department of Science and Art. Government School of Science Applied to the Arts, Museum of Irish Industry, Stephen's green, East. Programme of Educational Arrangments for the Session 1856-1857, (Dublin, 1856), pp.11, 13, 19-23.
In Liverpool there existed the School of Technical Chemistry run by Norman Tate and James Sheridan Muspratt's Liverpool College of Chemistry (both c1869). It seems unlikely that either of these offered much beyond the analytical chemistry which was the major interest of their proprietors. On Tate (1837-92) see JCS lxiii (1893) pp.764-5. On Muspratt (1821-71) see JCS xxiv (1871), p.620, and his Chemistry, Theoretical, Practical and as Applied and Relating to the Arts and Manufactures, (Glasgow, 1856-60). See also G.W. Roderick and

M.D. Stephens, 'Chemical Training in Nineteenth-century Liverpool', in Scientific and Technical Education in Nineteenth Century England, ed. G.W. Roderick and M.D. Stephens (Newton Abbott, 1972), pp.65-73.
19 A.H. Sexton, The First Technical College. A Sketch of 'The Andersonian' and the Institutions Descended from It, (London, 1894).
20 On James Young see J. Butt, 'James Young, Scottish Industrialist and Philanthropist', Ph.D. University of Glasgow, 1963.
21 Ibid, pp.304-5.
22 Anderson's University, Managers' Minute Book, 1 May 1869, 4 June 1869.
23 Ibid.,11 June 1869.
24 Young Chair of Technical Chemistry, Trustees' Minute Book, 9 August 1869.
25 Ibid., 16 August 1869.
26 Anderson's University, Managers' Minute Book, 1 September 1869.
27 On Penny (1816-69) see JCS xxiii (1870), p.301.
28 Dr. Adam's Reasons of Protest against the Appointment of an Additional Professor of Chemistry in Anderson's University, (Glasgow, 1869).
29 Dr. Penny's Remonstrance and Appeal against the Nomination and Appointment of an Additional Professor of Chemistry in Anderson's University, (Glasgow, 1869).
30 Ibid., pp.6-7.
31 Ibid., p.9.
32 Anderson's University, Managers' Minute Book, 22 September 1869.
33 Young Chair of Technical Chemistry, Trustees' Minute Book, 1 September 1869.
34 Anderson's University, Managers' Minute Book, 3 December 1869.
35 Ibid., 19 January 1870. On Napier (1810-84) see JCS xlvii (1884), p.333.
36 Compare the view taken by the Society of Arts Committee, above p.59, or Alexander Williamson, below p.120.
37 See the comments of Henry Roscoe, above n.157 or Fleeming Jenkins' suggestion that there currently existed "scientific" and "technical" approaches to technical education. F. Jenkin, op. cit., p.197-200.
38 L.O. Ward, 'Technical Education and the Politicians, 1870-1918', British Journal of Educational Studies xxi (1973), pp.73-40.
39 Anderson's University, Managers' Minute Book, 19 January 1870.
40 Letter from Perkin, September 1869, in University of Strathclyde Archives, DA5/3/2.
41 Anderson's University, Managers' Minute Book, July 1870.
42 Young Chair of Technical Chemistry, Trustees' Minute Book, 15 March 1871.
43 On Bischof (1835-1903) see PIC (April, 1903). On Thorpe (1845-1925) see DNB. On Dittmar (1833-92) see JSCI xi (1892), 116-7.
44 Anderson's University, Managers' Minute Book, 20 June 1872, 23 June 1873. In 1871-2 the course had covered Sulphur and Sulphuric Acid, Common and Sea Salt, the Manufacture of Soda, Potash and Salts of Potash, Lime Hydraulic and Mortar of Gypsum, Nitric Acid, Boracic Acid and Borax, Ultra Marine, Alum and Compounds of Aluminium. In 1872-3 this became Flax, Hemp, Wool, Silk and Cotton Spinning (sic), Dyeing and Printing, Paper making, Manufacture of Starch and Sugar, Wine Making, Beer Brewing and Distilled Liquids, Bread Making-Milk and Meat, Manufacture of Vinegar, Preservation of Wood, Tanning and Glue Boiling, Manufacture of Phosphorus and Requisites for Producing

Fire, Means and Apparatus for Producing Artificial Light, Animal Charcoal.

45 Young Chair of Technical Chemistry, Trustees' Annual Report, Anderson's University, Managers' Minute Book, 23 June 1873.

46 W. Tilden, Sir William Ramsay K.C.B. F.R.S. Memorials of His Life and Work, (1918), pp.42-3.

47 The Analyst, xli (1916), pp.329-33. On Hehner see PIC (October, 1924), p.270.

48 Young Chair of Technical Chemistry, Trustees' Minute Book, 17 October 1873.

49 Young Chair of Technical Chemistry, Trustees' Annual Report, Anderson's University, Managers' Minute Book, 22 June 1874, 21 June 1875.

50 Comments in D. Sandeman, 'Technical Education', Proceedings of the Philosophical Society of Glasgow, viii (1871-3), pp.421-42 (437-8).

51 Anderson's University, Managers' Minute Book, 22 June 1874.

52 Ibid., 21 June 1875.

53 Young Chair of Technical Chemistry, Trustees' Minute Book, 8 September 1875.

54 Anderson's University, Managers' Minute Book, 11 October 1875. On Mills (1841-1921) see PIC (June, 1921), p.224.

55 Anderson's University, Managers' Minute Book, 21 June 1876.

56 Ibid., 22 June 1877.

57 Calendar of Anderson's College, Glasgow for the Session 1879-80, (Glasgow, 1879), p.37.

58 CN xlii (1880), p.144.

59 Typical examination questions from the 1879 Calendar are:

"Give the average composition of Charbon-roux, Charcoal, and Peat. State, on the basis of Violette's Experiments, the temperatures at which Cellulose Cumelates are respectively formed."

"Describe, with numerical details, any method of making Coke."

"Draw a Wood-distilling Apparatus as used on the large scale, giving dimensions, and the proportions of products formed."

60 Anderson's University, Managers' Minute Book, 22 June 1881.

61 Ibid., 22 June 1883. The lectures given focused particularly on Bleaching and Dyeing and Iron and Steel rather than manufacturing chemistry.

62 L.L. Forrester, 'The Glasgow and West of Scotland Technical College. 1886-1912'. M.Ed. dissertation University of Stirling, 1979, pp.107-10.

63 Glasgow and West of Scotland Technical College, Calendar. 1904-1905.

64 The following account of the earlier period is based on: H.H. Bellot, University College London 1826-1926 (1929), J.S. Rowe, 'Chemical Studies at University College, London' Ph.D. thesis, University of London, 1955, J.N. Collie, A Century of Chemistry at University College, (1927).

65 Bellot, op. cit., p.125.

66 CN xv (1867), p.71.

67 J.H. Harris and W.H. Brock, 'From Giessen to Gower Street: towards a Biography of A.W. Williamson', Annals of Science xxxi (1974), pp.95-130. See above, p.61.

68 A.W. Williamson, A Plea for Pure Science: Being the Inaugural Lecture at the Opening of the Faculty of Science in University College, London, October 4th 1870, (1870).

69 University College London, Senate Minutes, 25 April 1872.

70 On Charles Graham (1836-1909) see PIC (April, 1910), pp.27-8.
71 See the evidence of Edward Frankland and Alexander Williamson (representing a state-funded and a privately funded institution respectively) to the Commission, RCTI qq.5720-91; 1190. See also Bud and Roberts, op. cit. (1984), pp.141-7.
72 Document entitled 'Memorandum 6th December 1876' in the Guildhall Library, MS 21,834. See Foden, op. cit. (1961).
73 Minute Book with the title 'University of London Council Minutes' (evidently that of the Council of University College, London) held in the Records Office at University College, London. Entry for 18 January 1878.
74 Ibid., 10 March 1878.
75 (City and Guilds of London Institute), 'Report of the Executive Committee to the General Committee,...(and) Proposals of the Executive Committee, January 1879'. Guildhall Library MS 21,834. University College London, Council Minutes 10 March 1878.
76 C. Graham, Technical Education. The Introductory Lecture Delivered before the Faculties of Arts and Laws and of Science, October 1st 1879, (1879).
77 See above p.68.
78 University College, London, Calendar 1878-9, (1878), pp.63-65.
79 'For the convenience of those already engaged in business, and of those from other causes prevented from entering for a longer period of study, it is arranged that they can attend a Course of Lectures upon any one subject of Applied Chemistry, without being required to attend any other Lectures either in Applied Chemistry or in other subjects.' Ibid., p.64.
80 Ibid., p.65.
81 The two were C.J. Wilson and W.J. Scrutton. Neither received obituaries from the Institute of Chemistry. The Institute's Registers show that Wilson apparently remained in London as an analyst, while Scrutton moved to Venezuela to become a mine analyst.
82 University College, London, An Account of the New North Wing and Recent Additions (1881), pp.11-12.
83 University College, London, Professors' Fee Books, 1879-9 to 1884-5.
84 RCTI, q.4433.
85 LCC, op. cit. (1902), p.22.
86 University College, London, Calendar 1887-8, (1887), pp.92-5.
87 University College, London, Professors' Fee Book, 1888-9.
88 London County Council, Technical Education Committee, Report to the Special Committee on Technical Education, (1892). The report was compiled by H.L. Smith. See also E.J.T. Brennan, 'Sydney Webb and the London Technical Education Board', Vocational Aspect xi (1959), pp.85-96 and xii (1960), pp.27-43.
89 See chapter 7.
90 University College, London, Senate Minutes, 12 April 1889.
91 Ibid., 28 June 1889.
92 Ibid., 30 May 1889.
93 Society of Chemical Industry, Council Minutes, 21 June 1889.
94 Ibid., 10 July 1889.
95 See below section E.
96 University College, London, Senate Minutes, 28 June 1889.
97 University College, London, Calendar, 1889-90, (1889), p.96.
98 University College, London, Professors' Fee Books, 1889-90.
99 University College, London, Senate Minutes, 18 November 1889.

100 University College, London, Calendar 1890-91, (1890), p.110.
101 University College, London, Senate Minutes, 30 May 1892. See above note 88.
102 London County Council, op. cit. (1892), p.76.
103 University College, London, Report of Council (1894).
104 On Fleming (1849-1945) and Kennedy (1847-1928) see DNB.
105 University College, London, Senate Minutes 12 June 1893.
106 (Faraday Society), 'The Training and Work of the Chemical Engineer', Transactions of the Faraday Society xiii (1917-18), pp.61-118 (100).
107 CN lxx (1894), p.161.
108 University College, London, Calendar 1899-1900.
109 University College, London, Calendar 1910-1911.
110 Ramsay to Keogh 7 October 1911. Imperial College Archives, KCT 10/1. Ramsay had no inherent objection to industrial studies, as his introduction to Jacob Grossman's book indicates. J. Grossman, The Elements of Chemical Engineering (1906)
111 J. Thompson, The Owens College: Its Foundation and Growth; and Its Connection with the Victoria University Manchester, (Manchester, 1886). E. Fiddes, Chapters in the History of Owens College and of Manchester University 1851-1914, (Manchester, 1937). H.B. Charlton, Portrait of a University: 1851-1951, (Manchester, 1951). Roscoe, op. cit. (1907), p.177.
112 See Rothblatt, op. cit., Roberts op. cit. (1980), H. Jenkins and D.C. Jones, 'The Social Class of Cambridge University Alumni of the Eighteenth and Nineteenth Century', British Journal of Sociology i (1950), pp.93-116.
113 On the wider issues connected with growth of higher education see the essays in The Transformation of Higher Learning 1860-1930. Expansion, Diversification, Social Opening, and Professionalization in England, Germany, Russia and the United States, ed.K.H. Jarausch (Chicago, 1983).
114 In that year the total attendance at the Technological Chemistry classes was 10. Attendances at the main Junior and Senior Classes in the Department for that year were 163 and 95 respectively. Owens College, Report of the Council to the Court of Govenors (1880), 'Report on the Chemistry Department'.
115 Carl Schorlemmer (c1834-1892) was educated at German universities and acted as an assistant first to Angus Smith and then to Roscoe. He is however recorded as undertaking some work on organic dyestuffs with members of the Dale family (see chapter 6). JSCI vii (1889), pp.529-30; I. Levinstein, 'The Development and Present State of the Alizarin Industry', ibid., ii (1883), pp.213-27 (214); JCS lxiii (1893), pp.756-63. William Dittmar (1833-92) followed an approximately similar route. JSCI xi (1892), p.116. Thomas Carnelly (1852-1890) was educated at Owens College and eventually obtained the Chair of Chemistry at Aberdeen University. JSCI ix (1890), p.848.
116 Typical questions were:

> "Explain the action of waters on lead. What waters are most likely to act on lead, and how do you determine the presence of this metal when dissolved."
>
> "Enumerate the chief processes in soap-making. Give the chemical composition of fat, glycerine and stearic acid."

Owens College, Calendar 1863-1864 (Manchester, 1863), p.cxli.
117 Owens College, Senate Minutes, 13 December 1879.
118 On Smith (1845-1920) see JCS cxvii (1920), pp.1637-8. For other

indications of his career see CN xxiv (1871), p.183; CN xxxiii (1876), p.199; ibid. xxxvi (1877), p.113, 173.

119 Owens College, Senate Minutes, Appendix III, Report of the Chemistry Demonstratorship Committee, p.322. Crow later became a manager for the firm of Wilkinson, Heywood & Clark. Though a Fellow of the Chemical Society and of the Institute of Chemistry he recieved no obituary from them.

120 Owens College, Calendar, 1880-81, (Manchester, 1880).

121 Owens College, Senate Minutes, 12 March 1881.

122 Ibid., 17 May 1881.

123 Ibid., 15 June 1881; Council Minutes, 3 June 1881.

124 Owens College, Senate Minutes, 22 January 1882.

125 Ibid., 30 May 1882.

126 Owens College, Council Minutes, 31 March 1882, 10 May 1882, 16 June 1882, 6 October 1882, 12 January 1883, 2 February 1883, 2 March 1883.

127 Owens College, Senate Minutes, 19 October 1882.

128 Owens College, Manchester, Syllabus of the Course of Technological Chemistry (1881-2), (Manchester, 1881). The practical component of the third year was as follows: 'Volumetric analysis. Application to determination of certain Commercial Products. Organic Analysis. Vapour Densities. Gas Analysis. Coal Gas. Photometry. Water Analysis. Making Preparations suited to the special requirements of each student.' The shift from the generality of analytical methods to more student-specific activity is sharp, and reflects that in other courses described in this chapter.

129 Arthur Smithells, in an address to the Congress of the Universities of the Empire in 1912, described the qualifications of such teachers as "more complex than those of any other class". Smithells, op. cit. (1912), p.84.

130 Victoria University, Calendar for the Session 1882-3, p.64. The precise nature of the options available at this time was not very clear, and in 1889 J.J. Hummel of the Yorkshire College moved that an "explanatory note" be added to the Calendar. This showed them to be essentially those offered as components of the Owens College Certificate course, with the addition of Fuel. Victoria University, General Board of Studies Minutes, 28 November 1889. Watson Smith confused matters still further by suggesting in 1885 that the Owens course led to a degree with Honours in Chemical Technology. 'On a Course of Instruction in Technological Chemistry, and the Difficulties at Present Encountered and to be Overcome in this Country', JSCI iv (1885), pp.84-93 (88).

131 On the mechanics' institutes during the later nineteenth century see J.P. Hemmings, 'The Mechanics' Institute Movement in the Textile Districts of Lancashire and Yorkshire in the Second Half of the Nineteenth Century', Ph.D. thesis University of Leeds, 1973. E. Royle, 'Mechanics' Institutes and the Working Classes, 1840-60', Historical Journal xiv (1971), pp.305-21. For other accounts of the events described here see M.J. Cruikshank, 'From Mechanics' Institute to Technical School', in Artisan to Graduate, ed. D.S.L. Cardwell (Manchester, 1974), pp.134-56, P.J Short, 'The Municipal School of Technology and the University, 1890-1914', ibid., pp.157-64, and A. Dransfield, 'Applied Science in a University Context: Metallurgy at Manchester, 1875-1906', Ph.D. thesis, University of Leeds, 1985. The institution changed its name a number of times. During the period of this thesis it was called Manchester Technical School (1883),

Manchester Municipal Technical School (1892), Manchester Municipal School of Technology (1902) and Manchester Municipal College of Technology (1918). For convenience it will generally be referred to here as the Manchester Technical School.

132 C. Heward, 'Education, Examinations and the Artisans: the Department of Science and Art in Birmingham, 1853-1902', in Macleod op. cit. (1982), pp.45-64. It may be that, as in Bradford, the shifting role of the Institution was partly precipitated by the decreasing demand for more general courses which accompanied the extension of public education. Donnelly op. cit. (1982). See chapter 5.

133 Manchester Mechanics' Institute, Minute Book, 6 April 1880.

134 Manchester Mechanics' Institute, Proposal to Organise it as a Technical School for Manchester. Report of the Executive to the General Committee. Friday July 28 1882.

135 (Manchester Mechanics' Institute), Special General Meeting of Members for the Purpose of Considering and Adopting Alterations to the Rules, with a View to the Adaptation of the Institution to the Purposes of a Technical School. Wednesday 27 December 1882.

136 Manchester Technical School and Mechanics' Institute, 'First Annual Report' (Typescript document held in the archives of UMIST).

137 RCTI, qq.545-762.

138 Ibid., qq.658-9.

139 Ibid., q.749.

140 Ibid., q.737.

141 The situation in London has already been referred to. That at Leeds and Bradford exhibited a parallel tension between Bradford Technical School and the Yorkshire College. On developments at technical schools see for example H. Lewis, 'The Provision of Technical Education for the Textile Industry in the Huddersfield Area, 1841-91', M.Ed. dissertation, University of Manchester, 1971. On Bradford see J.F. Donnelly 'The Development of Technical Education in Bradford, 1825-1900', M.Ed. dissertation, University of Leeds, 1982.

142 H.E. Roscoe, Record of Work Done in the Chemical Department of the Owens College, 1857-1887 (Manchester, 1887), pp.20-1.

143 City and Guilds of London Institute, Report for the Year Ending March 10th, 1880, Presented by the Council of the City and Guilds of London Institute to the Governors of the Institute, Appendix VI, and subsequent years. Harden (1865-1940) studied in Germany before lecturing at Owens and being appointed to the Lister Institute. DNB. Hart (1864-1926) was employed by the Clayton Aniline Co., before establishing an analytical practice. JPIC (June, 1927), p.180. Snape (1861-1933) was the son of the alkali manufacturer Thomas Snape who owned the Phoenix Works in Widnes (CTJ li (1912), p.173). Snape junior studied in Berlin and then obtained various posts in education and industry before eventually becoming Director of Education for Lancashire. JPIC (1933), p.145.

144 Roscoe to (R.D.?) Darbishire, June 9 1879. Roscoe letter books, John Rylands Library, CH R107.

145 CR xiv (1884), pp.6-7.

146 Royal Commission on the Depression of Trade and Industry, Reports and Minutes of Evidence, PP xxi, xxii, xxiii qq.8149, 8188. Lee was a partner in the textile firm of Tootal Broadhurst, and a Director of the British Alizarine Co. He was on the Council of the Technical School.

147 Victoria University of Manchester, Calendar 1913-1914 (Manchester,

1913), p.919.

148 Owens College, Report of the Council to the Court of Governors, 'Report on the Chemistry Department' for the relevant years.

149 A typical compulsory examination question in 1880 was

"(a) Give a sketch with description of a gas-works plant, and an account of the processes involved.

(b) What indication would the fact afford you as to the working of the gas retorts, that a great deal of carbon bisulphide existed in the gas?

(c) Describe the principles of action and use of the 'conical' and 'throttle-valve governors' for regulating the gas supply."

Owens College, Calendar 1880-1881, p.clxix.

150 Owens College, Council Minutes, 13 January 1882.

151 Owens College, Senate Minutes, 26 April 1884.

152 Owens College, Council Minutes, 4 March 1887. The Council noted that it was "impossible to consider the subject apart from the general organisation of the Chemistry Department."

153 Ibid., 8 July 1887, 29 June 1888.

154 H. Roscoe, 'Chemical Education in this Country and Abroad', Report of the 66th Meeting of the BAAS (1896). CN lxxiv (1896), pp.175-7.

155 Manchester Guardian, 8 September 1887.

156 W. Smith, 'The Aim of Instruction in Technical Chemistry', The Textile Manufacturer viii (1882), p.417.

157 JSCI viii (1889), p.338. The term "scientist" was used rarely at this period, and it is of interest that it was used here dichotomously with "technologist".

158 Oil and Colourman's Journal vi (1886), p.924.

159 Owens College, Senate Minutes, Appendix, Vol. III, p.62 (March 1888).

160 Questions of resourcing, of the threat posed to the position of the chemistry department by the establishment of institutionally separate activity in technical chemistry and of the personal position of H.B. Dixon, who had only recently taken up the Chemistry Chair, all probably had a role.

161 Owens College, Council Minutes, 5 July 1889. Compare note 92 above.

162 Owens College, Senate Minutes, 14 June 1889.

163 Owens College, Senate Minutes, Report of the Technological Chemistry Department Committee, Appendix III, p.192-3 (March, 1890).

164 Bailey (1852-1924) was educated at Owens and in Germany. JCS cxvii (1920), pp.1637-8. Cohen (1859-1935) had worked briefly at the Clayton Aniline Co. before travelling to Germany. JSCI liv (1935), p.1332. Dixon (1852-1930) was educated at Oxford University and taught at Mason College, Birmingham before moving to Owens. JCS (1931), pp.3349-68.

165 Owens College, Calendar 1890-1891 (Manchester, 1890), pp.49-51.

166 Bentz (1862-1925) had worked at the calico printing firm of J.A. Wilson. JPIC (February, 1925), pp.60-1.

167 Owens College, Report of the Council to the Court of Governors (1890), 'Report on the Chemistry Department', p.119.

168 Its main components were "Coal Tar Colours" and "Dyeing and Printing". The "Inorganic" option involved Geology, Mineralogy and Metallurgy, and was thus orientated towards mining rather than manaufacturing chemistry.

169 See the letter book cited in note 144.

170 Owens College, Report of the Council to the Court of Governors

(1890), 'Report on the Chemistry Department', p.118 ibid. (1891) p.158. On Dixon's salary see Council Minutes 17 May 1889.
171 Ibid., (1888).
172 RCTI, Second Report, Appendix 33. On O'Neill (1827-1894) see CTJ xvi (1895), p.251. On Sansone see CR xiv (1884), pp.6-7 and 'Reminescences d'un Chemiste Coloriste et Considérations sur l'Enseignment de la Chimie', Revue Génerale des Matières Colorantes ii (1898), pp.463-6.
173 Manchester Technical School and Mechanics' Institute, first to sixth Annual Report (1883-9). On Sexton (1854-1932) see Nature cxxx (1932), pp.194-5, on Rhead (1864-1940) see JPIC (1940) p.341, on Griffiths see CN liv (1886), p.62, on Snape (1861-1933) see JPIC (1933), p.145.
174 The main chemistry-related evening classes were in Brewing, Metallurgy, Iron and steel, Oils, colours and varnishes, Oils and fats, Soap, Bleaching and printing, Silk, cotton and wool dyeing, and Coal tar products.
175 Manchester Technical School and Mechanics' Institute, Annual Report (1890), pp.11-12. On Knecht (1861-1925) see JPIC (1925), p.362.
176 Liebmann (1852-1927) had worked for Ivan Levinstein. Chemistry and Industry v (1927), p.117.
177 Manchester Technical School, Syllabus of the Departments, Courses of Study, and Teachers, for the Session 1891-92 (Manchester, 1891), p.36.
178 Ibid., pp.36-9. City of Manchester, Proceedings of the Council, 1892-3, 'Report of the Technical Instruction Committee', Appendix C. They were however numerically much smaller than 'handicraft' areas such as plumbing.
179 At Bradford Knecht had described the programme which he was undertaking as follows. "After having become acquainted with some of the ordinary methods of producing colours on wool and cotton, the Student will then devote his time to a strictly systematic series of dye trials, with the object of studying the effects of the different mordants on the colouring matters; of time and temperature in mordanting and dyeing; and of different additions to the dye bath and mordant solution." Bradford Technical College, Calendar (Bradford, 1889-90), pp.67-76.
180 RCTI, Second Report, Appendix 33.
181 On the Technical Instruction Acts see P.R. Sharp, 'The Public Financing of Secondary and Technical Education in Victorian England', University of Leeds Ph.D. thesis, 1973. Idem., 'The Entry of the County Councils into English Educational Administration, 1889', Journal of Educational Administration and History iv (1968), pp.14-24.
182 City of Manchester, Proceedings of the Council, 1892-3, 'Report of the Technical Instruction Committee', p.1298. The Whitworth Institute administered a fund under the will of Sir Joseph Whitworth.
183 On Levinstein (1845-1916) see JSCI xxxv (1916), p.458 and chapter 6.
184 I. Levinstein, 'Address to the Students of the Chemistry, Dyeing and Printing Departments' in Manchester Technical School, Introductory Addresses on Technical Teaching and Its Application to Trades and Industries (Manchester, 1890), pp.45-6.
185 Manchester Guardian 20 September 1890, 23 September 1890. Smithells remarked that as well as industrial plant Levinstein's course would require "some model British workmen tied hand and foot by the rules

of their union; a model foreman dyer, who, armed with his grandfather's receipts, regards your chemist as a mischievous interloper; and, last of all, there should be a model British manufacturer, ignorant of science, distraught by foreign competition, distrustful of all that is new-fangled, dimly conscious that there is something in science that can help him, but fatally impatient of experiment or investigation." *JSCI* xiii (1894), pp.18-21. Evidently a course in academic chemistry would obviate these difficulties.

186 Marquis of Hartington et al., 'The Industrial Value of Technical Training', *Contemporary Review* lv (1889), pp.771-97 (775-6).

187 'The Municipal Technical School and the Owens College'. Owens College, Document Book 10, May 1892. Conference with the Governors of the Technical School, 27 April 1891, Committee Minute Book, 27 April 1891. On Ward (1837-1924) see DNB.

188 Manchester Technical School, *Syllabus of the Departments, Courses of Study, and Teachers, for the Session 1891-92* (Manchester, 1891), p.36.

189 Owens College, *Report of the Council to the Court of Governors* (1895), 'Report on the Chemistry Department', p.118.

190 Owens College, *Calendar, 1896-1897* (Manchester, 1896), p.115.

191 Thorpe (1872-1940) had worked for some time at the Badische Anilin- und Soda-Fabrikation (BASF). *JPIC* (1940), pp.273-5.

192 W.H. Perkin, 'The Training of Technical Chemists', *JSDC* xi (1895), pp.202-9. W.H. Perkin (1860-1929) was the son of the discoverer of mauve. *JPIC* (October, 1929), p.263.

193 See for example Morton, op. cit., p.170.

194 Owens College, *Report of the Council to the Court of Governors* (1896), Appendix vii.

195 Senate Minutes, 24 April 1896. In fact a Senate Committee in 1893 had already decided that this class might "without disadvantage" (to whom was not specified) be discontinued on Saturday mornings and incorporated within the day courses. Senate Minutes, Appendix 4, p.8.

196 Owens College, *Calendar 1896-1897* (Manchester, 1896), p.115.

197 P.J. Hartog, 'The Owens College, Manchester', *Record of Technical and Secondary Education* iv (1895), pp.407-25 (407). Hartog (1864-1947) was at that time a lecturer in chemistry at Owens. DNB.

198 Owens College, *Report of the Council to the Court of Governors* (1900), p.122.

199 Victoria University, General Board of Studies Minutes, 8 February 1900.

200 *Manchester Guardian*, 31 May 1901.

201 Ibid., 8 June 1901.

202 City of Manchester, *Proceedings of the Council, 1900-1*, 'Report of the Technical Instruction Committee', p.2337. On Pope (1870-1939) see DNB.

203 Owens College, Council Minutes, Appendix 13, June 1901, and *Manchester Guardian*, 8 June 1901, where an abbreviated version of the report appears.

204 Ibid.

205 Ibid. On Smith's lectureship the report commented: "A special lecturer in technological chemistry was appointed in 1884, and the lectureship was given up solely in deference to the representations of the Technical Instruction Committee." In fact the Technical Instruction Committee did not exist when Smith resigned and did not take over responsibility for the School till 1892.

206 Owens College, Council Minutes 19 February 1902.
207 Manchester Guardian, 1 August 1901.
208 Owens College, Council Minutes, Appendix 13, June 1901.
209 Senate Minutes, 7 October 1901. Victoria University General Board of Studies Minutes, 24 October 1901, 27 February 1902. On the break-up of the federal University see Fiddes, op. cit., chapter 5.
210 Victoria University of Manchester, Council Minutes, 9 March 1904.
211 Manchester Guardian, 12 January 1905.
212 Victoria University of Manchester, Calendar 1905-1906, (Manchester, 1905).
213 Manchester Guardian, 3 October 1905.
214 Ibid., 5 October 1905.
215 Victoria University of Manchester, Board of the Faculty of Technology Minutes, November 1905.
216 Ibid., 25 April 1906.
217 Victoria University of Manchester, Calendar 1910-1911 (Manchester, 1910), pp.399-408.
218 I. Levinstein, Chairman's Address to the Manchester Section, JSCI xxi (1902), pp.1377-9.
219 The Technical School was represented on Senate by the Professors of Pure and Applied Chemistry, Mechanical Engineering and Electrical Engineering.
220 CTJ, xliv (1908), pp.495-6. Swindin (1880-1976) had taken a more informal route into chemical engineering, described in his Engineering without Wheels, (1962).
221 City of Manchester, Annual Report of the Education Committee, 1913-1914, Appendix A. Victoria University of Manchester, Calendar 1913-1914, (Manchester, 1913), p.957. On Dixon's view of the destinations of students see chapter 5.
222 PRO, Ed.119/27. 'Report to the Board of Education on Visits to the Departments of Applied Chemistry in the Following Four Institutions. King's College, London, Municipal School of Technology, Manchester etc.'
223 City of Manchester, Annual Report of the Education Committee, 1913-1914, Appendix A.
224 Beilby, op. cit. (PRO), p.16. The Institute of Chemistry took a similar view: see Institute of Chemistry, Council Minutes 26 May 1905.
225 JSA xx (1871-2), p.111.
226 Ibid., pp.261-3.
227 Ibid., pp.725-6.
228 Ibid., xxv (1876-7), p.766.
229 Ibid., xxvii (1879), p.471.
230 See above note 72.
231 Technical Education. Report of the Executive Committee to the General Committee of Certain of the Livery Companies of London, (1978).
232 Ibid., pp.2-3.
233 Ibid., p.4.
234 'Scheme of Organisation of the Central Institution', 4 February 1884. Guildhall Library MS 21,834/5.
235 City and Guilds of London Institute, Report by the Council to the Court of Governors (1892), p.2.
236 City and Guilds of London Institute, Report of a Sub-Committee Appointed by the Executive Committee, August 5th 1881, p.3.

237 City and Guilds of London Institute, A Short History of the City and Guilds of London Institute for the Advancement of Technical Education in Report of the Council to the Court of Governors (1899), Appendix A.
238 JSA xxiv (1875-6), p.775-7. On Howell (1833-1910) see DNB.
239 CR vii (1878), p.304.
240 City and Guilds of London Institute, Report for the Year Ending March 10th 1880, p.23.
241 The Times, 26 December 1879.
242 Ibid., 28 December 1879, 3 January 1880.
243 City and Guilds of London Institute, Report for the Year Ending March 10th 1880, Appendix V.
244 R.S. Lineham, A Directory of Science, Art and Technical Colleges, Schools and Teachers in the United Kingdom, Including a Brief Review of Educational Movements from 1835 to 1895 (1895), p.6.
245 The figures for the annual entry during the early period were

1879	16	1884	22
1880	15	1885	19
1881	35	1886	25
1882	54	1887	13
1883	22	1888	12

The entries for 1892 1893 and 1894 were 0, 4 and 0 respectively. These data are taken from the relevant Reports of Council. See Appendix 2.
246 City and Guilds of London Institute, Report to the Governors, 1892, Appendix D.
247 Ibid., 1889, Appendix D.
248 City and Guilds Institute, Minutes of Sub-Committee D, 7 November 1890, 14 January 1891; Report of Special Committee, 6 February 1891.
249 RCTI, qq.450-9, 2862.
250 City and Guilds of London Institute, Board of Examiners Minutes, 30 June 1896.
251 Ibid., 10 November 1896. A.G. Green (1864-1941) eventually held the Chair of Colour Chemistry at Leeds University before moving back into industry. JPIC (1941), p.284-5.
252 City and Guilds of London Institute, Examinations Department, Report on the Work of the Department for the Session 1900-1, (1901), p.91.
253 Typical questions from the 1881 and 1882 examinations are:

"Give an analysis of a good soda ash (or carbonate)."

"Describe the extraction of copper and silver from burnt pyrites in the wet way."

"Describe the working of a decomposing furnace and pan, and state the salt and coals used in 24 hours."

"What weight of soda ash (or carbonate) is obtained from from 100 sulphate, and at what strength?"

"The last sulphuric acid chamber set has become 'pale'. What will result from this, and what would you propose to do?"

Taken from the Calendar for 1881 and 1882.
254 City and Guilds of London Institute, Report of the Council (1880), Appendix VI.
255 City and Guilds of London Institute, Examinations Department, Report on the Work of the Department for the Session 1897-8, (1898), p.38. AE Fletcher (1826-1920) was educated at Universty College London and eventually became Chief Inspector of Alkali Works. JSCI xxxix (1920), p.332R.

256 T. Twining, Phases of Technical Training. A Memorandum for the Use of the National Association for the Promotion of Technical Education (1888), p.28.
257 City and Guilds of London Institute, Examinations Department, Report on the Work of the Department for the Session 1899-1900, (1900), p.41. Bailey, a lecturer at Liverpool University with a Heidelberg Ph.D., typified the academic dominance of the chemical field even in areas of technical education close to the industry itself. Chemistry and Industry v (1927), p.664.
258 LCC op.cit. (1896), p.24.
259 Meldola, op. cit. (1909), p.559. The general emphasis on high level expertise in representations of the chemical industry was not, of course, a novel one. Compare Quarterly Review op. cit. (1888), pp.467-8; Quinton op. cit.; most of the discussion at the Society of Chemical Industry JSCI viii (1889), p.325-51, and especially the contributions of Watson Smith and David Howard. In 1895 Thomas Tyrer summed up the educational needs of the chemical industry in the exhortation: "Educate your masters and exact obedience from the workmen." JSCI xiv (1895), p.1021.
260 PIC (February 1904), pp.8-9.
261 The occupations of Fellows and Associates in October 1902 were as follows:

private practice	30.2%
industry	26.7%
teaching	16.2%
public	7.3%

The remainder were mainly in two or more of these. PIC (1908), pp.15-16.
262 See Russell et al. (1977) on the conflicts in the Institution. There is some discussion of this in chapters 6 and 7 below.
263 Institute of Chemistry, Council Minutes, 13 March 1903.
264 PIC (November, 1905), p.36-7.
265 Committee Minute Books, 'Special Committee re Technological Examinations', 16 October 1903 and 14 November 1903.
266 Council Minutes 11 December 1903.
267 Committee Minute Books, 27 April 1904.
268 Ibid., 16 May 1904, 20 October 1904, 21 November 1904, 18 May 1905. Dyeing and brewing were added to the syllabus.
269 Council Minutes, 30 June 1905.
270 CN cxii (1905), pp.168, 200, 211. CTJ xxxvii (1905), pp.305-6, 355.
271 See the relevant announcements in PIC. The Chemical Trade Journal could scarcely contain its satisfaction at the relative failure of the first examination. CTJ xxxix (1906), p.388.
272 In a letter to the Chemical Trade Journal the examinations were described as asking "a works chemist to submit himself to examination in order to show that he is fully qualified for the position he has probably filled for some years. Yet in the prelude to a scheme to make practical knowledge subservient to theoretical training it will not find favour either with 'works chemists' or their principals." CTJ xxxvii (1905), p.355.
273 "The notion entertained by some teachers that the Institute exists mainly as a qualifying body for public analysts and private practitioners". PIC (April 1913), pp.9-29.
274 See Lord Armstrong, op. cit. (1888). In Bradford the activity of Swire Smith, an advocate of technical education and member of the

Samuelson Commission, provoked a local manufacturer, after some hostile comments on Smith's views, to remark: "Mr. Smith is a spinner; it is to the spinners we must look for the genius that will bring a return of prosperity. If Mr. Smith will set the good example of laying down new machinery...he will do more practical good than can be done by a thousand speeches." T. Illingworth, A Sixty Years' Retrospect of the Bradford Trade Indicative of Some Causes of the Present Depression (Bradford, 1883), pp.40-3. A Bradford dyer remarked dismissively on appeals for more chemical training: "...without an exception the best chemists have never been the best dyers." Bradford Observer 4 December 1875.

275 For an account of the failure of an academically-trained chemist in industry see J. Carter Bell in JSCI xviii (1899), p.442. Bell (1838-1913) was educated at the Royal College of Chemistry. PIC (November, 1913), p.9.

276 City and Guilds Institute, Report of the Council (1892), p.10.

277 See above n.76.

278 See Rothblatt, op. cit. (1968), Roberts op. cit. (1980).

279 University Colleges (Great Britain) Grant in Aid. University Colleges Committee Third Report, PP lx (1905), Appendix.

280 Board of Education, "Report of the Committee on the Co-ordination of Technological Education" (1900). PRO Ed24/36.

281 JSCI viii (1889), p.348.

282 CTJ xliv (1908), pp.425-6; ibid., xliii (1908), p.440.

283 Activity at other institutions tended to fail similarly. See for example Gosden and Taylor op. cit. (1975), p.260.

284 At Owens up to 1900 there were 172 honours graduates in chemistry and 72 in physics. The number of students taking single subject Associateships in chemistry at the Royal College of Science up to 1914 was more than twice that in any other subject. In the period from 1870 to 1900 there 189 graduates with Honours in Chemistry and and 185 with Honours in "Experimental Physics". University of London, The Historical Record (1836-1912) (1912), pp.502-515.

Chapter 5. The Characteristics of Chemistry Students, 1880-1914

A. Introduction

The intention in this chapter is to survey the occupational destinations, and certain other characteristics, of chemical students in a number of important institutions during the period 1880 to 1914. The discussion will focus particularly on the balance between educational and industrial occupations. Addressing this question one is compelled to begin with Cardwell's analysis of English scientific education at this period.[1] The thrust of Cardwell's argument, particularly his quantitative analysis, is to minimize the role of industrial recruitment at the turn of the century. Much of this chapter will unfold against the background of this view, though it will generally adopt a different stance. It is the profile of student destinations rather than the absolute numbers entering any given employment which is of importance in coming to a judgement about the influence of industry on educational activity.

The field of activity under discussion will be divided into evening classes and full-time post-secondary education. Day secondary education in chemistry (where it existed) was not considered a significant qualification in any technical employment. However, though evening classes in 'pure' science may have reached no higher standard, contemporary statements suggest that they could act in a general way as qualifications, perhaps because they could be attended by men already employed industrially. Preparation for the City and Guilds Technological Examinations was also usually undertaken mainly in evening classes. However, full-time post-secondary education ("higher education") constitutes the most significant field. It involved a growing number of heterogeneous institutions, of which a sample has been chosen as representative for the purposes of this chapter. The institutions chosen are:

- -Owens College,
- -University College, London,
- -the Royal College of Chemistry/Royal School of Mines/Normal School of Science/Royal College of Science (this complex of institutions, which eventually merged into Imperial College, will usually be identified as "the Royal School of Mines" before 1880 and "the Royal College of Science" afterwards).
- -the City and Guilds Central Institution (later the Central Technical College),
- -Cambridge University.

It is not appropriate to rehearse the arguments for this list here, and they will be given some attention in the Note on Methodology (Appendix 1). Each institutions is in important respects unique, and the replacement of, say, University College by King's College would alter the balance. Nevertheless it is hoped that they represent an acceptable sample of the available institutions.

The first part of this chapter discusses evening classes. It then moves to survey the evidence concerning full-time students at institutions of 'higher education'. This is followed by an examination of the qualifications of students entering education and industry, and a discussion of salaries. Many of the forces which contributed to the industry-education relationship are more properly examined in other chapters. However the question of salaries fits well within the more statistical material of this chapter. The final section of the chapter draws together the earlier evidence.

B. Evening classes

As with many other areas of English education, assessment initiatives had an important role in codifying knowledge, legitimating certain institutional forms (notably, in this case, national curricula and validation) and helping to systematize provision. National organization of evening classes began with the examinations of the Society of Arts (1856) and those of the Department of Science and Art (1859). Despite the considerable industrial element in the language surrounding these two innovations, the syllabus of each bore the imprint of the mainstream academics who were called upon as examiners (Williamson for the Society of Arts, Frankland for the DSA). They are recognizable as one of the origins of the modern secondary chemistry curriculum.[2] The type of student they attracted also showed considerable overlap.[3] For a number of years the Society of Arts included the occupations of successful examinees in its published lists, and this provides a considerable body of evidence about the student body. The main occupations of students successfully undertaking the Society's chemistry examinations in the period from 1860 to 1870 are shown in Table 1.[4]

Table 1. Occupations of Society of Arts examinees, 1860-1870 (N=598)

Occupation	%
druggists	18
clerks	16
chemical process industries*	8
teachers	5
other	53

*including dyeing, printing, bleaching, soap making etc.

The class of "other" students included a considerable proportion in manufacturing industries other than those with a chemical significance. Overall about 25% of students could be considered as employed in chemistry-related fields, though a large majority of these were involved in pharmacy. Thus the majority of examinees appears to have been attempting to gain or extend their general post-elementary education.

Data on DSA examinees are much less readily available. In a study of the Midland Institute Heward comes to no firm conclusions about the aims of students, but appears to place quite a small emphasis on a direct technical interest.[5] A study of such examinees in Bradford during the period 1870 to 1880 found roughly one-quarter involved in related industrial fields such as dyeing and bleaching, the remainder being clerks, warehousemen and so on.[6] Referring to the evening students at King's College London in 1868 the College Secretary J.W. Cunningham told the Samuelson Commission that they were mainly "clerks, or young men employed in houses of business, or as assistants to engineers".[7]

The provision of evening classes and eventually of technical colleges grew rapidly during the final decades of the century, a growth documented by the NAPTSE and the Association of Technical Institutions.[8] By the latter part of the century it was acknowledged as being more extensive than that of other major European countries, including Germany.[9] However this view was often converted into criticism of its effectiveness compared with full-time high-level scientific education. The City and Guilds Technological Examinations gave an added dimension to the system. The problems with the chemical component of these examinations were discussed above. Later in this chapter some comparisons will be drawn between the activities of these students and those students entering full-time higher education.

Through much of this period of growth of the DSA classes Inorganic Chemistry led the way, despite a temporary eclipse by Magnetism and Electricity. (See Appendix 2.) Alterations in the criteria for funding by the Department (e.g. the change to inspection of Organised Science Schools in 1897) and for maintained schools as a whole, began eventually to reduce numbers, and to increase the significance of evening students. By 1906, of 77,277 papers worked in the, by then, Board of Education examinations 61,469 were from such students.[10] The orientation of the students towards directly industrial activity remained slight. In 1892, as part of a wider review the LCC surveyed Inorganic Chemistry classes (under the heading "Classes bearing on the chemical trades"). Table 2 shows the distribution of student occupations in institutions other than schools.[11]

Table 2. <u>Occupations of London evening students of Inorganic Chemistry, 1892</u> (N=812)

Occupation	%
teachers	34
metal workers	9
chemistry & related	7
clerks etc.	4
pharmacy	4
non-chemical manufacture	3
other	39

Again, though there is some representation from chemical fields, it is quite small. While such students may have had an occupational interest (the character of which will be discussed in the following chapter) clearly they had no key, or even important, role in maintaining the viability of the examinations. In 1895, the commentary and recommendations of the Bryce Commission reflected JFD Donnelly's comment that in the main the Department offered a "distinctly secondary instruction".[12]

C. Higher education before 1880

The corollary of critical comments on the British emphasis on evening classes was the continued canvassing of the need for the high-level education of managers, owners, directors and eventually "expert chemists". It was focused particularly on full-time students in the new university colleges, with Oxbridge coming rather late to the field.[13] Some data are available on the careers and career orientations of chemistry students during the period before 1880. Roberts found the careers of the earliest students of the Royal College of Chemistry to be heavily orientated towards chemically-related industrial and other fields, indicating a diversified but generally practical interest.[14] These students generally attended on an _ad hoc_ basis. These characteristics are consistent with Roberts' view of the College as a catalyst for the conversion of chemical education from a service to a self-sufficient and a self-conscious disciplinary status. The association between the College and the Royal School of Mines from 1853 may have eventually reduced the College's role in this, since in the period from 1859 to 1863 the School of Mines was reorganized more explicitly as a mining school. However the matriculated students working for the Associateship of the School were outnumbered by occasional chemistry students (of the type observed by Roberts) throughout the period leading to the establishment of the Normal School of Science in 1881.[15]

In 1870 Frankland gave a list of the known occupations of past chemistry students at the College to the Devonshire Commission. The ocupations represented are shown in Table 3.[16]

Table 3. Occupations of Royal College of Chemistry Students to 1870 (N=369)

Occupation	%
chemical manufacturer or works chemist	18
other manufacturer	30
public employee	14
academic	10
medical	6
schoolteacher	2
analyst and assayer	4
pharmacy	2
other	14

These figures show some parallels with those of Roberts (though there is overlap for the early years). They are similar to those which can be extracted from the list of the intentions of a much smaller number of current students which Frankland had presented to the Samuelson Committee in 1868.[17] This suggests that, into the final quarter of the nineteenth century, the major support for the Royal School of Mines chemistry laboratory probably continued to come from students whose interest in chemistry was of a 'practical' kind. Indeed the proportion of students intending to undertake industrial activity (though not necessarily as employees) appears to have increased. Few of these students were matriculated (i.e. studying for any formal qualification) and most still appear to have stayed only for such time and followed such courses as suited their immediate practical needs.[18]

In 1868 Henry Cole told the Samuelson Committee that no Associate of the School of Mines was then known to be engaged in schoolteaching and could name only one ex-student so employed.[19] However, in 1872 a scheme was introduced whereby intending science teachers could attend the School for a year or a term free of charge. Initially about 15 teachers were involved each year. (The exact figures cannot be established from the Annual Report.) This inaugurated a shift in the character of the School, towards a Normal School, which was to continue for many years.

Turning to Owens College, the industrial orientation of chemistry students has been suggested at various points in chapters 3 and 4. The first quantitative evidence appears in Henry Roscoe's evidence to the Devonshire Commission. Here he gave a list of the intentions or occupations of laboratory students for the session 1870-71. Their distribution is shown in Table 4.[20]

Table 4. Aims or intended occupations of Owens College students 1870-1

Aim or intended occupation	Day	Evening
chemical manufacturer	17	2
other industrial activity	14	5
science degree etc.	11	-
medicine	3	-
teaching	2	3
metal broker	1	1
other	-	3
unspecified	12	3

The predominance of men with an industrial aim among the day students is clear. However, only six of the students (one of whom intended to follow an industrial occupation) gained a London University degree or Associateship of the College. Indeed the distinction between industrial activity and the aim of gaining a degree is implied by Roscoe's categorization. It appears that there were parallels between chemical activity at the Royal School of Mines and Owens College.

Little information is available about University College, or King's College, London during this period. The University College Chemistry Department had a long-standing association with medical training which has already been noted. In 1844-45 42 out of 45 students studying practical chemistry were medical students and this association was maintained, if in a less extreme form, for some years.[21] In 1870 Williamson indicated to the Devonshire Commissioners that many parents wished their sons to attend for quite specific technical reasons.[22] Evidence to the governmental enquiries suggests that the University College and School of Mines chemistry laboratories were in direct competition for students. Since this competition is unlikely to have referred to students of mining, whose preferred institution was clear, the competition was almost certainly in the type of ad hoc student which can be seen at the School of Mines and is implied by Williamson at University College.

Slightly more information is available on King's College. William Miller told the Samuelson Committee in 1868 that 40 or 50 medical students received a "regular" course in practical chemistry. However only 12 or 14 students from the "Applied Science" Department (the main active higher education department in the College outside medicine) were in regular attendance at the laboratory. Of these, eight to ten were "studying with the express view of afterwards entering manufacturing works".[23]

Little attention needs to be given to Cambridge University at this point. The relatively small numbers of students taking the Natural Science Tripos showed little inclination to follow industrial pursuits. MacLeod and Moseley's published data do not break down NST graduates by their examination subjects. However, for the period 1851-81 they identify only 3.5% as entering industry or business, and 3.7% as showing any subsequent involvement with chemistry.[24]

D. Higher education in chemistry, 1880-1914

In this section data collected by contemporaries will be surveyed, and supplemented by a quantitative survey of the subsequent activities of a sample of students attending day chemistry classes in the period between 1880 and the beginning of the First World War. For this purpose students attending each of the institutions referred to in the introductory section have been identified for periods centring as far as possible on 1880, 1900 and 1910. The original intention was to include a sample of students from 1920. This proved impracticable, partly because certain institutions will not allow access to the relevant records for this period, and for other reasons. These, together with details of the sources for the samples and other methodological issues are discussed in Appendix 1. It is necessary, however, to discuss here some of the reasons for choosing these particular dates.

The period around 1880 saw a considerable change at most of the institutions referred to above. At the Royal School of Mines the shift towards training teachers which has already been indicated was given titular recognition, with the adoption of the the name "Normal School of Science and Royal School of Mines". The former institution, centred at South Kensington, was described as "intended, primarily, for the instruction of Teachers". Other students were to be admitted "so far as there may be accommodation for them".[25] Owens College became the first component college of the Victoria University in 1880, coming very close to being able to award its own degrees and design and examine its own courses. University College saw Williamson replaced by the vigorous William Ramsay, and the establishment of the Chair of Chemical Technology discussed in the previous chapter. Cambridge University, through the division of the Natural Science Tripos in 1881, took a step towards greater specialization, and the co-ordination of its chemical teaching was also improved. Finally, at South Kensington, the City and Guilds Institute was preparing to establish a new high level college, the Central Institution (later the Central Technical College).

About 1880, then, these institutions began to take on, if not their modern forms, at least the transitional characteristics they would exhibit around the turn of the century. Reference has already been made to Cardwell's argument on the relations between education, industry and the 'industrial scientist' in the UK. The question which his analysis invites is that of how an embryonic system such as has been sketched in the previous section could have been converted into one in which (in his view) "the number of raw graduates (in schoolteaching) is comparable to the total number of science and art degrees awarded (during the years 1909 to 1913)".[26] Bud and Roberts have gone some way to answering this question, in terms of the institutional interests and machinations of the mid- to late-Victorian academic men of science and educational administrators. From the other point of view, though tending to emphasize industrial consultancy and make a somewhat discursive use of statistics, Sanderson has undermined the notion that British universities of the period were remote from industry.[27] The response in this chapter to Cardwell's view is that the situation was much more complex and heterogeneous than his argument suggests, and that in key areas industrial recruitment remained of central importance. In order to justify this position it is necessary to offer a complex, and sometimes ambivalent, body of evidence. This is based firstly on the sample of students identified specifically for this study.

The first point to be addressed concerns the formal qualifications which students obtained. These are also the most clear-cut data available, since registers of graduates and associates allow precise figures to be obtained. Table 5 shows the percentages of students at each institution obtaining a formal qualification.

Table 5. Chemistry Students Gaining Qualifications, 1880-1910*
(percentage of students gaining a formal qualification, N=1010)

Year	CGCI**	Owens	RCS***	UCL	Overall
1880	38 (0)	17 (8)	16 (3)	14 (26)	17 (16)
1900	64 (0)	63 (4)	68 (1)	27 (9)	51 (5)
1910	—	83 (0)	—	56 (5)	68 (2)

The figures in brackets indicate the percentages of students gaining a medical qualification.

*Cambridge University has been excluded from this Table because the student sample is based on NST entries.

**Chemistry Department in process of dissolution in 1910. Earliest data for 1886-7.

***1910 data available only for Associates.

There is a predictable increase in the proportion of students obtaining formal qualifications. The main interest is in the size of this effect. Only limited generalization across institutions is possible. For example, students of the City and Guilds Central Institution were required to take an entrance examination and in most cases to follow a formal course, and this appears to be reflected in figures above. By contrast the impoverished and underendowed University College appears still to have accepted many students with little intention of obtaining a formal qualification in 1910. Overall about one-sixth of students studying chemistry obtained some qualification in the period around 1880, rising to one-half at the turn of the century and a substantial majority (assuming University College to be untypically low) just before the First World War. These data indicate a role for relatively informal, perhaps ad hoc students extending well into the twentieth century: on the face of it a continuation of the type of activity which was occurring during the third quarter of the century.

The qualifications were Victoria and London degrees, together with associateships of the Royal College of Science, the Royal School of Mines and the City and Guilds Central Institution. The subject distributions of the Victoria and London degrees are shown in Table 6.

Table 6. Type of Degree Awarded to Chemistry Students, 1880-1910 (percentage of degrees of type indicated awarded by each institution)

Institution	Chemistry	Other Honours	Ordinary Science Degree
Victoria	60	21	19
London	47*	20	33

*Includes 5 students passing Intermediate examinations only.

Honours degrees in chemistry by no means represent an overwhelming majority of those awarded, though those taking such degrees or ordinary science degrees make up four-fifths of each group.[28] Among students who graduated chemistry was only to a limited extent a 'service' subject to other fields at this time.

If Table 5 suggests the need to use data based on all students rather than graduates only when attempting to study the influence of these institutions directly, Table 7 gives some indication of the difficulties involved in this exercise. It shows the raw occupational data which have been obtained for each of the samples.

Table 7. Identifiable Student Occupations, 1880–1910.
(percentage of students at each institution identified in stated occupation, N=1364)

Institution	Date	Student Occupation: Education	Industry	Private practice	Public	Medicine	Other	Unknown
	1880	27	5	0	2	42	18	8
Cambridge*	1900	28	12	1	8	36	9	7
	1909	18	2	0	1	22	1	54
CGCI	1887	21	41	0	0	0	4	34
	1900	4	63	5	11	0	7	14
	1880	7	34	3	3	8	1	43
Owens	1900	34	25	0	6	4	1	31
	1910	25	16	1	4	0	0	54
	1880	21	17	5	5	3	1	47
RCS**	1900	38	16	1	14	1	1	31
	1910	28	33	3	13	0	0	23
	1880	1	21	2	0	26	0	51
UCL	1900	13	6	3	4	9	1	62
	1910	13	11	2	8	5	1	61

*based on NST graduates only
**based on Associates only

A major difficulty in interpreting these data is the often large proportion of students for which no occupation can be identified. Information from other sources casts some light on this. However, using the data only for purposes of comparison (when the students of unknown occupation become less significant), the diversity across institutions is evident. There is also some evidence of random variation, reflecting the need for a larger sample size if reliable estimates are to be obtained. The substantial though declining significance of medicine at University College, London and Cambridge University can also be seen. (The decline is of course only in attendance by medical students at the mainstream chemistry courses.) By contrast the City and Guilds Central Institution exhibits a very considerable orientation towards manufacturing industry. It may be significant, in view of later evidence, that this orientation is at its highest when the percentage of students of unknown occupation has its single lowest value (14%) for institutions other than the Cambridge period covered by Venn.

Cambridge, Owens College and the Royal College of Science show a considerable orientation towards education. At Owens the substantial shift in this direction between 1880 and 1900 probably reflects the establishment there of a Day Training College in 1890 under the regulations of the Education Department. However, in all three cases there is some evidence of a decline in educational destinations during the final period. Industrial recruitment presents a more ambivalent picture. The Royal College of Science, probably for methodological reasons, though these themselves may be of wider significance, exhibits an increasing proportion of students entering manufacturing industry in 1910, in contrast to Owens College.[29] The large proportion of Owens students so identified around 1880 appears to be connected with the establishment of the Society of Chemical Industry (which originated around Manchester) about that time. The breakdown of these data across industrial sectors will be referred to below.

Outside University College and Cambridge, each of which exhibits a considerable medical orientation, education and manufacturing industry are the dominant student destinations observed. This is despite the fact that the Institute of Chemistry's Official Chemical Appointments (first published 1906) allows individuals in public employment to be identified relatively easily. Consultants and analysts in private practice constitute a generally declining proportion (in relative, not necessarily absolute, terms) while public employees show a general increase. By 1927 Alfred Chaston Chapman estimated that only 350 men were independent private practitioners undertaking consultancy and analysis for fees.[30] Many of these individuals moved into independent consultancy after a period of industrial employment. In general, methodological difficulties, often acting differentially across institutions and sectors, have made these data less useful than was hoped in clarifying the occupational significance of chemical education. Heterogeneity across institutions and over time make overall figures doubtful: it is difficult to know how a statistically representative national sample of chemistry students would be constructed, or even if such a sample would be of any value given the large qualitative differences between institutions. Nevertheless, the overall figures show 18% of identifiable students entering education and 22% entering industry. This does not suggest a picture in which preparation for schoolteaching has the overwhelming role suggested by Cardwell. Supplementary information from a number of sources can both cast light on how these data might be interpreted and add further evidence to support this view.

Firstly, data can be added on students' subsequent membership of the major chemically-orientated societies (the Chemical Society, the Institute of Chemistry and the Society of Chemical Industry), and on their publication and patent activity. Individuals detectable by any of these methods may be taken to have a direct involvement with chemistry at the occupational level. Table 8 shows the overall percentages of students falling into this category for each institution during the periods under consideration here.[31]

Table 8. "Professional" involvement of students with chemistry. (percentage of students joining chemical institutions, publishing chemical papers or granted 'chemical' patents, N=1364)

Institution	Cambridge	CGCI	Owens	RCS	UCL
1880	8	33	49	28	17
1900	17	50	24	33	34
1910	12	—	47	69	29

The table shows a broad increase in involvement: the overall percentages, excluding Cambridge, are 27%, 32% and 42% at each date. Again the very high 1880 figure for Owens College appears to be connected with the local formation of the Society of Chemical Industry: 37% of the sample were found to be members of the Society of Chemical Industry. By 1910 these data indicate a very considerable 'professional' orientation among students. Among the individuals falling into this category are about 20% for whom other data have not been obtained. Since these individuals do not appear in the Schoolmasters' Yearbook or Official Chemical Appointments it is unlikely that they were employed in education or as analysts in commercial practice. It is thus probable that they were involved in private industry. On this basis the overall percentages of ex-students employed in industry at each of the institutions would be as follows (figures in brackets refer to percentages detected in education):

Cambridge University	8% (23%)
CGCI	57% (10%)
Owens	31% (25%)
RCS	26% (24%)
UCL	17% (8%)

These figures show a significant increase in the employment of students in manufacturing industry compared with those in Table 7. However, they cannot be considered exhaustive of industrial recruitment. A number of contemporary accounts suggest that a substantial proportion of such students may remain undetected.

In his 1892 survey of London institutions for the LCC, H. Llewellyn Smith was told that, of 120 students in the University College chemistry department, "about 70" (58%) were intending to enter some form of technical employment.[32] On this basis three-quarters of the students whose occupations remained undetected would have entered industrial occupations. There is further evidence to this effect from William Ramsay himself. In 1902, referring specifically to his own research students, he noted that most would enter chemical works of some kind.[33] Figures from Ramsay were also quoted by Robert Blair, speaking to the Education Section of the BAAS in 1910. Ramsay had told him that in the years 1890 to 1910, of 100 students whose occupations he knew, 60 were employed in industry and 25 in education.[34] While this represents only a small sample of the students passing through University College during this period, the similarity to the figure given by Smith to the LCC in 1892 is noticeable.

Further data are also available at Owens College. Philip Hartog commented in 1895 that the increase in the number of college students was due "in great measure to the increasing demand for trained chemists in works, and, to a lesser extent, for trained teachers of chemistry". He particularly referred to the role of Owens in the former.[35] In 1913 H.B. Dixon, who had been responsible for the Chemistry Department at Owens since Roscoe's departure, gave information on the students who had left his department in the previous 10 years, which he put at just over 300. They were employed as follows:[36]

education	c70	(c23%)
"chemical industries of one kind or another"	c200	(c70%)

In the 10 year period 1903 to 1912 218 students obtained Honours degrees in chemistry at Owens College.[37] The number referred to by Dixon must therefore have included other students: perhaps those taking chemistry in the final examinations of the ordinary B.Sc., or students who concentrated on chemistry without taking a degree. In any event these figures give an indication of the senior Professor's understanding of the destination of those students perceived as most closely associated with the Department. Dixon put the current rate of entry into industry at "over 60% of our students". When compared with the figures in Table 7 for 1910 Dixon's figures are consistent with the majority of students of unknown destination entering industry.

It is useful also to compare Dixon's figures with those for Honours graduates in chemistry for previous periods as indicated in the Victoria University Register for 1908. This Register includes details of occupations, and these are shown in Table 9.[38]

Table 9. Occupations of Victoria University graduates with Honours in Chemistry, 1884-1902

Occupation	1884-92	1893-1902
manufacturing industry	14 (42%)	57 (51%)
education	14 (42%)	40 (36%)
other	3 (9%)	9 (8%)
not given	2 (6%)	6 (5%)

Though the first sample in particular is small, and includes a disproportionate number of candidates finding employment as teachers in higher education, the period 1884-1913 shows a relative shift away from education and towards manufacturing industry. In 1902 the chemical manufacturer Ivan Levinstein, referring to industrial recruitment, told the Manchester Section of the Society of Chemical Industry that those who had followed a full course at Owens "find employment so readily that the demand exceeds the supply".[39] In 1897 Levinstein had referred to the "many hundreds" of foreign chemists employed in UK works, and the early twentieth century appears to have seen some systematic replacement of these, as the situation at Levinstein's own works, at Read Holliday and at Joseph Crosfield's suggests.[40]

The Royal College of Science occupies an important place in Cardwell's argument for the overwhelming role of teacher training in the growth of higher level science education. In the period around the turn of the century this institution was approaching the transformation which would lead to the establishment of Imperial College. Its reorganization as the Normal School of Science and Royal School of Mines in 1881 had been followed in October 1890 by the adoption of the overall title "Royal College of Science". The institution was unique at this stage in the amount of public support received by its students. This was supplied through National Scholarships, Royal Exhibitions and Free Scholarships, which varied mainly in their value. All were offered conditionally on the results of the DSA examinations. By 1900 115 places were available on this basis, 35 being competed for each year.[41] In addition the courses of "1 term or 1 year" offered for an indeterminate number of science teachers in training had been continued.[42] Donnelly stated in 1880 that 53 out of 200 students were teachers in training, though the Annual Report indicates that only about 15 out of 100 students in the chemical laboratory were teachers of this type in any given term.[43] This number of teachers was roughly maintained: by the turn of the century about 20 such students were attending the chemistry laboratory (out of 120 students in total) during each term.[44]

In the period from 1880 to 1910 the relative proportions of occasional and "Associateship" students attending the RCS underwent a radical shift, almost a reversal, and a large proportion of the latter were in receipt of public support.[45] The proportion of students intending to be teachers is said to have increased rapidly during this period. Norman Lockyer suggested in 1898 that three-quarters of the students intended to be teachers. He added that while in the past some students, supported on the basis of their claim to be intending teachers, had subsequently entered other occupations, this difficulty had been overcome.[46] This figure of three-quarters was repeated by Prof. Judd in his evidence to the Departmental Committee on the RCS in 1904.[47] However the Committee conducted its own survey into the intended destinations of students during the year 1905-6. The total of 266 students (excluding those from Government departments) gave their intended occupations as follows:[48]

teaching	58	(including 47 "students in training")
teaching or industry	21	
manufacturing industry, mining or metallurgy	132	
unspecified or other	45	

Thus the ranges of percentages of students entering some form of industrial occupation and teaching are respectively:

industry	between 50% and 58%
teaching	between 22% and 30%.

If the analysis is confined to Government-funded students the percentage of intending teachers is between 50% and Lockyer's figure of 75%. Overall, the figures for likely recruits into schoolteaching compare favourably with those for 1900 and 1910 in Table 7. The data are consistent with the view that most students entering teaching are identifiable, whereas a majority of those who enter some form of industrial occupation remains undetected. It may be recalled that the 1910 data for the Royal College of Science were based on Associates only. This appears to introduce little distortion into the figures since few occasional students were in attendance by this date.

Turning finally to Cambridge, it can be recalled that the data in Table 7 are based on graduates examined in chemistry in Part I or Part II of the Natural Science Tripos in the relevant years. Using data on Part II students only, but for the entire period, Roberts has concluded that about 10% of students went into industrial occupations during the period 1882-1904.[49] However, there is evidence that for this much more specialized group recruitment into industry increased markedly during the early twentieth century. The Thomson Committee of 1918 was told that 80 out of 110 men examined in Chemistry in Part II of the Tripos during the period 1900-1916 had entered manufacturing industry.[50] Indeed, the later the period focused on the more extreme the situation appears. HA Roberts, Secretary of the Cambridge University Appointments Board, told a Departmental Committee on teachers' salaries that in 1911 and 1912, of the 24 men taking chemistry in Part II, only 1 entered education. The remainder obtained "technical appointments in chemistry, or appointments in business in which a knowledge of chemistry was valuable."[51]

There is ample evidence in the figures above that the specialist chemistry classes at institutions such as Owens College, University College London and the Royal College of Science, and eventually Cambridge University, were being attended by considerable numbers of students, in some cases a substantial majority, with the intention of working in the industrial field. This poses two questions. The first is statistical, and concerns the inconsistencies between these figures and those produced by Cardwell to support the view quoted above. The second refers rather to the industrial viewpoint: by whom and for what purposes were such students being recruited? The second point is more properly the concern of the following chapter. For the present the discussion will be focused on the statistical question.

Using mainly national statistics published by the Board of Education Cardwell concluded that by about 1910 "at the very lowest" 66% of science undergraduates at the state-aided universities and university colleges were intending to become schoolteachers.[52] In the following section doubt will be cast on conclusions based on this figure from two directions: in terms of national statistics and in terms of the diversity which the figures conceal.

In the period between 1909 and 1912 (roughly corresponding to the period of the final cohort referred to in the discussion above, and that from which Cardwell draws his strongest statistical evidence) 1600 students graduated B.Sc. in pure science at the publicly-aided institutions.[53] Of these, 459 were "recognized students" under the Board of Education regulations for the training of elementary teachers, that is they were legally committed to teaching.[54] This device had already been employed in connection with teachers attending the Royal College of Science, and had been inaugurated more widely in 1890 under the regulations of the Education Department.[55]

In addition, a number of institutions were recognized for the training of graduates for secondary schools, though the students undertaking these courses were not publicly supported. In the period 1909 to 1913 250 graduates were so trained at institutions other than Oxford and Cambridge.[56] However, of these, only 59 held science degrees. Thus a total of 518 students (these 59 plus the 459 "recognized students") who graduated in science during the period may reasonably be anticipated to have entered teaching. In addition considerable numbers of untrained graduates entered secondary schools. On January 31 1909 there were 2568 such teachers.[57] On January 31 1913 the number was 3057.[58] Assuming the difference to come from the relevant cohort of new graduates, it follows that a further 489 of this group entered secondary teaching. Unfortunately the published statistics do not indicate the percentage of these students holding science degrees. If it is assumed that they split in the same ratio as those undertaking training for secondary schools (just under 25% scientists) the number is about 120. If it is assumed instead that they split in the same proportions as students undertaking elementary teacher training (amongst whom just under 50% were scientists) the number is about 240. The two figures would lead to grand totals of science graduates entering teaching (ie the sum of trained elementary and secondary teachers, and untrained secondary teachers) of 638 and 758 respectively. These figures represent respectively 40% and 47% of the total science graduates from the grant-aided universities and university colleges during the period.[59]

These percentages are considerably smaller than those of Cardwell. (This is mainly due to his treatment of arts and science secondary teachers as equal in number, but also reflects the fact that he seems to have underestimated the total number of graduates during the period. In any event his figures are rather less than those which can be obtained by summation from the Reports of Universities and University Colleges for the period.) However, even 40% of graduates entering schoolteaching represents a very high proportion, and one which does not correspond with many of the figures given in Table 7 or in the data subsequently quoted. The discrepancy is best understood in terms of heterogeneities which can only be observed by analysing the figures further. This operates across institutions, across science disciplines and across the type of degree (Ordinary or Honours) awarded. The percentages of science degrees which were awarded to elementary teachers in training varied between 54% (King's College London) and 11% (Bristol University). In general, small, new or underendowed institutions appear to have been more dependent upon grant-aided students. It is not difficult to suggest reasons for this, since the newer institutions would in many cases have small science departments in the major disciplines, and perhaps have been unlikely to attract students with the resources to travel elsewhere.[60] At Owens College, numerically by far the largest of the publicly-aided institutions and producing nearly one-third of the science graduates, only 23% of such students were elementary teachers in training.

In order to indicate further the details of the situation, that at Manchester can be explored more closely. Among those graduates taking either a teaching certificate or a diploma at Owens during the period 1911 to 1913 the degrees obtained were:[61]

Honours Chemistry	17
Honours in another science (including Mathematics)	27
Ordinary B.Sc.	46
Arts	155

Science graduates thus represented 36% of the group, despite constituting approximately 60% of those taking Bachelor's degrees during the period. Among the entire population of students graduating from the science Honours Schools chemists represented 62% of the total, compared with only 38% of the Honours science graduates receiving a teaching qualification.[62] Correspondingly, graduates of disciplines such as Botany and Physics (the latter still offering very little industrial employment) were over-represented.

Turning to the 116 students identified for this study as following a chemistry course at the University in 1910-11, and who could be expected to have graduated during the period under discussion, 31 obtained a teaching certificate or diploma. A significant proportion of enthusiasts did however receive both! These 31 individuals students represent 27% of the total studying chemistry. Among the group of 76 who went on to take Honours degrees in chemistry only 16 (21%) took a teaching qualification. Moreover, while these figures fail to include students entering teaching without a qualification, of the 31 trained teachers referred to above 5 can be found subsequently employed in industry. This nearly matches the number of those who took no teaching qualification and were subsequently identified as teachers.

Contrary to appearances the main thrust of this chapter is not intended to be an investigation of the relationship between higher education and schoolteaching in the period under review. However, the need to explore the details of students entering teaching occurs because of the sigificance for the argument of the balance between educational and industrial recruitment. Some general conclusions can be drawn from the data so far presented. Firstly, it is clear that, among major institutions of the type surveyed here, publicly-funded teacher training represented, certainly, a most significant activity, and the most important source of block financial support. Yet to suggest that it had a dominant position in students' intentions appears unwarranted, and in many institutions the training of future industrial employees seems more significant. Cardwell's national figures both exaggerate the number of teachers and conceal large variations across institutions and disciplines. At a key institution such as Owens College, and especially in the field of chemistry, schoolteaching appears to have been the intended destination of only a minority of students. Similar detailed analyses would be required to construct a national picture. The fairly complete occupational data on those who gained the Associateship of the Royal College of Science suggest that it represents the extreme example of domination by teacher training among larger institutions. Even here preparation for teaching may have reached a peak (in terms of its relative importance) around the turn of the century. At that time teachers represented only a bare majority of identifiable students, and subsequently fell back to a point below manufacturing industry and related activity. In 1913 an informal prospectus for Imperial College remarked that "there has lately been a strong disposition for the best students to avoid this career", ie schoolteaching.[63] The dependence on teaching in the preceding years can easily be exaggerated by ignoring the Royal School of Mines component of the institution, when in fact its students were taught in the same chemistry classes, took a comparable number of Associateships and, for metallurgy students at least, were often to be found in chemically-related industries only indirectly connected with mining.

If any institution demonstrated that an association with teaching was not essential to growth it was the City and Guilds Central Institution which, despite its highly selected intake and rigorous programme, grew steadily while producing only a very small proportion of teachers. In chemistry the Central Institution appears to have suffered because of its more strictly industrial orientation, but there were other causes, as will be discussed in chapter 7. The flexibility still offered by the university colleges in courses and entry, and the buffer provided by their publicly-financed students, may have had an influence here. Ironically it was in those engineering departments where an orientation towards teaching was unimportant that the Central Institution flourished compared with its peers.

Technological activities of this kind in other institutions also merit some attention. At Owens College this chapter has ignored all areas with a directly industrial orientation. Yet the vigour with which the College resisted the claims of the Technical School on its "industrial" students can be recalled. The Technical School, and to a lesser extent the College, had associated with it a considerable body of such students. In the former case this number was much greater than the students committed to teaching at Owens. Of course many of these were evening students of uncertain status: relatively small numbers of day students received degrees and other forms of high level certification. Nevertheless even this group was substantially more numerous than the total committed to teaching. At Owens itself, in the period from 1911 to 1913, 130 students took University Certificates in Technology and a further 37 were successful in the Honours School of Engineering.[64] This can be compared with the 90 science graduates who took Certificates and Diplomas in Education over this period.

It is some respects a meaningless question to ask to what extent any given institution was 'typical' of the university colleges in these and the other aspects under discussion. Owens was certainly not unique in terms of the small percentage of graduates taking formal teaching qualifications, though it was below average. Bristol, Birmingham, Hartley College, Southampton, the East London College (later Queen Mary College) and almost certainly University College, London graduated a smaller percentage of committed teachers during the period 1910-1913. In terms of Owens' technological orientation the situation was similar. In relative terms Birmingham, Leeds, Sheffield and Newcastle (Armstrong College) contained as many or more technological and engineering students.[65] All of this acts to dilute the role of teacher training within the scientific and technical sides of these institutions, especially when it is recalled that most of these students undertook some courses in the 'pure' sciences.

E. Qualifications and Salaries in the Different Sectors

Before attempting to summarize the situation, it is useful to discuss the qualifications of students and the salaries they could expect in the educational and industrial sectors. It has already been established that the chemical activities at the majority of the institutions referred to depended during the 1850s and 1860s on men with a "practical" orientation. The precise nature of this orientation (in particular, whether as employee or owner) is difficult to establish. Reference was often made by the apologists for 'pure' chemistry to manufacturers themselves, and their narrow prescriptions for their sons' curricula. However, evidence from earlier chapters and that immediately following, indicates that paid employment was also a common goal. Whatever their prospects and status within firms it appears that in this early period such men rarely gained a formal qualification. Indeed the only science degree which was widely available, the London University B.Sc., was said by William Ramsay to be considered by employers about 1880 as "too academic", and a positive disqualification for employment.[66]

The balance between undertaking a systematic course leading to a qualification and ad hoc attendance shifted only slowly at all of these institutions, and particularly so at University College. Whether this was a consequence of the congenital poverty of that college is not clear. It was not until 1910 that a large majority of students at Owens College and the Royal College of Science (Imperial College) was receiving a formal qualification. This picture can be supplemented for the later years using the sample obtained for this study, and that used by the BAAS in 1901-2. Table 10 shows the qualifications obtained by students among those individuals in the former group for whom some employment data are available.

Table 10: Qualifications of students and subsequent employment 1880-1910
(percentage of each occupational group gaining stated qualification, N=863)

Employment	Degrees				Associate-ships	No qualification
	1	2	3	Ordinary		
Higher education	49	21	3	4	10	14
Secondary education	20	26	15	20	4	15
Industry	16	14	8	7	15	39
Other	23	21	21	3	5	26

The most noticeable figure here is the large proportion of students (39%) gaining no formal qualification and subsequently employed in industry. While this might be interpreted to mean that industrial employment represented a 'sump', there are reasons for thinking this to be an incorrect interpretation. One has already been referred to. It seems likely that formal qualifications had differing significance and perceived relevance in the educational and industrial spheres. However, even within these data the situation is somewhat distorted by the large numbers of 'industrial' students not gaining qualifications. Among students gaining degrees, 36% of those entering industry gained Firsts, compared with 24% of students entering schoolteaching. Thus it would be more reasonable to suggest that distribution of the qualifications of students entering industry was polarized in relation to those entering schoolteaching, with relatively more of the latter gaining Thirds and Ordinary degrees. Focusing only on the period around 1910, when the majority of all groups gained qualifications, 42% of graduates detected subsequently in industry (N=71) gained Firsts, compared with 16% of those entering schoolteaching.

The only useful survey of men employed in chemical and chemistry-related industries undertaken at the time was that of a Committee of the BAAS in 1901-02.[67] This survey was based on a selected sample of the membership of the Society of Chemical Industry, the latter totalling about 3700 at that time, and some weight has been placed on it in demonstrating the absence of trained men in industry. The Committee wrote to all members apparently "in a position as manager or chemist in a works", and this was judged to be about 1000 individuals in all. Of these, about half replied—a total of 502 men. Among those replying 212 had been educated in a university or university college, and, of these, 75 were graduates and 147 were not. In addition 165 men had been educated as day students in technical colleges and 85 as evening students. The striking aspect of these figures is the balance between graduates and non-graduates among university or university college students. The interpretation to be placed on this depends upon the view taken of the non-graduate students. There is evidence here of the existence of the body of 'unqualified' men which has been referred to at intervals, and which plays some part in explaining the discrepancies observed in evidence about the destinations of students.

The absolute numbers involved are also of interest. It is not clear whether the raw total of 75 United Kingdom graduates identified includes Associates of institutions. From the sample of men obtained specially for the present study, and referring only to those for 1880 and 1900, it was possible to identify 103 individuals with either degrees or associateships who were employed in manufacturing industry. There are ample sources of error in this figure. Perhaps one third of the 1900 cohort could be expected not to have been in employment at the time of the BAAS survey. The survey itself takes only a static view of employment when in fact men would move into and out of industry (though this would have compensatory effects). The movement into consultancy later in careers would be expected to have reduced the observable total of employees. Nevertheless the discrepancy between the BAAS figure and the data presented here is gross (bearing in mind that the figure of 103 refers to only two periods of time and four institutions, and excludes the Scottish universities entirely). The British Association figure can be compared also with that for Owens College. The total number of honours graduates in chemistry recorded in the College Register as entering manufacturing industry from this single institution in the period 1884 to 1901 was 71. This excludes the much larger number of men graduating with ordinary degrees (and of course the still larger number leaving with no qualifications).

It seems necessary to question whether the BAAS sample is representative. The final sample consisted of about one-seventh of the total membership of the Society of Chemical Industry (though the foreign membership was substantial). The questionnaire was sent to approximately one-third of the UK membership. It is not clear on what criterion the committee selected this group for its survey, but it seems certain not to have included all of those in technical employment even within the Society.[68] Nor is it clear that the entire membership was representative of absolute numbers working in chemically-related fields. Bleaching, dyeing and printing constitutes an important area outside the chemical industry proper in which chemical knowledge could be deployed. A comparison between the membership lists of the Society of Chemical Industry and those of the Society of Dyers and Colourists for 1905 reveals only limited overlap. Of the first 100 members of the latter only 36 were also members of the former.[69] Again the extent to which this situation was reflected in other sectors is unknown.

Of the men specifically selected for the present study who were employed industrially only one half were found to be members of the Society of Chemical Industry. Among the industrially-employed Owens Honours graduates in chemistry previously referred to only 40% were members, on the basis of the 1905 and 1915 membership lists. Overall, it seems unlikely that the BAAS data are reliable indicators of numbers of industrial employees. Even for graduates Dewar's supposedly "generous" suggestion of multiplying the figures by three may be a considerable underestimate, or at least should be treated as a guess by a contemporary with an axe to grind. Similarly the figures offered by Cardwell, and those offered by Pike in his earlier study seem to have little foundation: they certainly cannot be made the basis of theories of the dynamics of British higher scientific education.

Before turning to the question of salaries, it is appropriate to say something of the City and Guilds examinees. While this may seem to be more obviously connected with evening classes, it was suggested in the previous chapter that the reason for the failure of the chemistry-related examinations was due to the absence of a constituency of skilled artisans in the industry. The demands made by the examinations were such as to place them in in direct competition with the new university colleges. In the early years of the examinations the Institute published lists of successful examinees (no records of examinees for the later years appear to have survived). The points just made can be illustrated by reference to the 73 students who passed the examination in Alkali Manufacture during the period 1880-84.[70] Among these men at least 4 went on to gain university degrees or Associateships. Proportions of examinees roughly comparable with those among Owens College students also went on to become Fellows of the Chemical Society and the Institute of Chemistry, members of the Society of Chemical Industry, to publish papers and to take out patents.[71] Approximately one-third were identifiable subsequently in the chemical industry (usually as managers or senior foremen), though six found employment as schoolteachers. After the first few years of the examinations it appears that men of this type saw little potential benefit in undertaking the highly constrained City and Guilds examinations. Some progressed within industry after some kind of secondary (perhaps DSA) study, while for others attendance at institutions such as Owens College became the requisite qualification.

Turning now to salaries, it can first be noted that complaints about the poor salary of both the works chemist and the teacher were common throughout the period under discussion. However, information on the latter is generally scarce. Public reference to it is most frequently in the context of polemical pieces, which must be treated as such. By contrast teachers' salaries, particularly in maintained schools, are relatively well-documented. In 1905 the average salary of certificated male teacher in public elementary schools was £116. For Head Teachers the average was £164.[72] In the Higher Elementary Schools established under the 1901 Code (providing a "predominantly scientific" curriculum) the figure was £149. No breakdown is possible between graduates and non-graduates.[73] Endowed schools fared little better. The average salary of non-resident masters around 1909 was said to be about £120.[74] The period was one of rising salaries, if from a very low base. In 1908, when the LEAs established under the 1902 Act were taking action to improve salaries, the situation in Manchester was as follows (unfortunately average salaries are not given):[75]

secondary teachers (2 schools): £140-£200 (over 10 years)

higher elementary teachers (5 schools):

graduates £90-£170 (over 14 years)

non-graduates £80-£160 (over 14 years).

By 1914 the average salary of graduate schoolmasters was £225.[76]

There is much variation in these figures, but the evidence on industrial salaries is both more sparse and more difficult to interpret. As early as 1868 the Select Committee on Scientific Instruction was told by Robert Clapham and Lyon Playfair that chemists who reached positions of "sub-manager" could anticipate a salary of £150 early in their careers, and even £300 to £400 quite quickly. It was only the routine analyst who was constrained to about £100.[77] In 1876 a letter to Chemical News suggested that salaries for works chemists of £100 to £150 were the norm, and argued that these were inadequate.[78] In 1887 correspondence in the Chemical Trade Journal during one of the regular controversies over foreign chemists claimed that Germans answering an advertisement in the journal were willing to work for salaries between nothing and £65.[79] Their underlying aim appears to have been to gain experience in Britain. On the other hand the average requirement of British respondents averaged £190. In 1896 an advertisement from "B.Sc., Ph.D." seeking work as an "assistant chemist" requested a salary of £50.[80] Frank Clowes told an LCC Sub-Committee in 1902 that starting salaries were "about £70 per year without sufficient prospect of advance", while Hurter stated that the starting salary for chemists at the United Alkali Company was £150.[81] In 1907 FA Freeth, then aged 23, received a starting salary at Brunner, Mond of £200, though he had previously earned just £108 as analyst in a tobacco factory.[82] Brunner, Mond paid the five senior foremen in 1880 an average of £159 p.a. (£130-£208).[83] In 1902 the Manchester organics firm of Levinstein paid E.H. Bagnall, an Owens M.Sc., a starting salary of £200 running to £260 over 4 years, together with 4% commission on the profits on any patentable discoveries.[84] Bagnall was aged 27 at this time, having graduated in 1896. His starting salary was thus well above that which a higher grade school teacher could expect to earn at any stage in his career, even some years later. Levinstein was not noted for being over-generous with his employees.

For men who reached senior positions in production proper the possibilities were considerable. In 1892 Joseph Hawliczek, an Austrian Ph.D. with experience at the Brunner, Mond works was being paid a salary of £1,250 by the United Alkali Co., plus a retaining fee, plus £250 p.a. if the annual profits exceeded £10,000.[85] The chief chemist to the United Alkali Co. received a salary of £1,000 in 1892, and this was later raised to £1,500.[86] At Brunner, Mond itself, the four senior managers in 1890 each received £1,200 p.a., together with one and one half percent for every half-year dividend payment over 7%. Among these the general works manager, Gustav Jarmay, was aged only 34.[87] Despite the rising salaries of school teachers during this period, an informal prospectus produced by Imperial College about 1913 commented that "although in some cases the salaries (in schoolteaching) at first compare favourably with those in the careers noted above (industrial careers), the prospects offered are, as a rule, poor..."[88] During the First World War HA Roberts, Secretary of the Cambridge University

Appointments Board, told a Departmental Committee that initial salaries in industry ranged up to £300.[89] They eventually reached figures from a few hundreds up to well over £1000 and sometimes well beyond. In the immediate post-War years the Institute of Chemistry gathered statistics from its members on salary, and found that the mean salary for those in teaching was £285 p.a., while for those in industry it was £410.[90]

If any summary was to be attempted on the available evidence, it would be that industrial salaries underwent a reduction during the period around the turn of the century when the flow of science graduates began to increase, but that this reduction was focused more especially on men entering as analysts at a fairly low level. Even at their worst these salaries were comparable with starting salaries in teaching. For those who moved even slightly beyond this situation the rewards available were well beyond any but a very small minority of teachers. This is reflected in the advice of HA Roberts in 1914 to Cambridge graduates that it was essential "to make a mark" in industrial chemistry: otherwise it offered "but a poor career".[91]

One area which has not so far been discussed is that of the distribution of students across areas of manufacturing industry. This question was in fact one of those which it was hoped to answer by undertaking the survey of students which has been referred to at intervals in this chapter. The balance between the chemical industry narrowly defined and other forms of chemistry-related industry was of particular interest. It has not proved possible reliably to assess the relative importance of industrial sectors in the employment of students. This is due to the diversity of sectors represented, in relation to the size of the practicable sample and the rate of detection of students. Table 11 shows the breakdown of the industrial activities in which students were found to be engaged for students from the 1880 and 1900 samples. The two earlier periods have been combined for this purpose, but students graduating or otherwise qualified in non-chemical fields have been excluded. The 1910 sample has been excluded in order to eliminate, as far as possible, students whose area of employment was unlikely to have been decided before the beginning of the First World War.

Table 11. Distribution of industrially employed students across sectors, 1880-1900.

Sector	N	%
Textiles	14	9
Metals	11	7
Brewing and distilling	10	7
Inorganics, acids, alkalis	7	5
Unspecified chemical mfr.	8	5
Fine chemicals, food	7	5
Organics	5	3
Cement, ceramics	5	3
Other (specified)	37	26
Other (unknown)	40	27
Total	144	100

It is evident that the chemical industry, narrowly defined, had no over-riding role in the employment of trained men. The diversity of the industries indentified for the 26% of students in other sectors is considerable, ranging from rubber through to railways, and it seems likely that those indentified in firms of unknown type would add to this. (In general these men are merely identified as "works chemist" or by the names of firms only.) A word of caution is in order here since, though this information has been obtained largely from sources indicating a 'professional' chemical interest, it is still possible that firms may have recruited men to fill non-chemical functions. (See Appendix 1.) Nevertheless, the implication of these data is that students leaving higher education after studying chemistry entered a very wide range both of firms and sectors, in many of which, it seems probable, they were the only chemist. Though there is some similarity in the profile to be seen in Table 11 and that obtained from the BAAS survey (see Appendix 2), the small numbers in any given sector and the variations which are evident indicate that a considerably larger sample would be required for a reliable profile to be produced.

F. Conclusion

Reference has been made in this chapter to Cardwell's view on the role of industrial recruitment in the growth of science education. The overall thrust of his argument can be illustrated as follows:

> the professional scientist is, in the first instance, the product of the educational system; to a much less extent is he the product of industrial practice and economic organisation.[92]

Depending on the meanings attributed to the phrases "product of the educational system" and "professional scientist", this statement may be unexceptionable enough. However, elsewhere Cardwell takes his view further: "the industrial scientist is to be regarded as the internal product of the educational system".[93] He argues that, in some respects, educational provision in Britain recapitulated the path of Germany, say, fifty years previously. On that path, he claims, "the ultimate deciding factor...must have been the educational machinery; the necessity of staffing the universities, polytechnics and schools".[94] Yet R.S. Turner has shown, empirically rather than on _a priori_ grounds, that future secondary school teachers (as he says "this most obvious of clientele") were rare among Germany university chemical students around the mid-century, and that pharmacists, medical students and industrial chemists(!) were present in greater numbers.[95]

Cardwell's view appears to be that educational activity in science, and more especially its growth, was an inward-looking process, industrial recruitment a kind of 'spin off' and industrial 'demand' negligible.[96] In this chapter it has been argued that the situation was more complex. The nineteenth-century growth in higher education in chemistry involved largely practical, often industrial, motivations. Most students gained no formal qualification. By the early twentieth century elements of this picture were still in place. Such empirical data as can be mustered show more students detectable entering industry than education, but in reality an 'overall' picture is almost meaningless. Heterogeneities across institutions and over time are too marked to allow any simple picture to stand. This would apply even if an attempt was made to save Cardwell's hypothesis by pointing only to the growth points in educational provision. Nevertheless, in important institutions such as Owens College, there is no evidence to suggest that the underlying orientation towards servicing manufacturing industry which had grown up in the chemistry department from the 1860s had been overturned. This applies both in terms of the intended destinations of the most committed chemistry students and of the ideological underpinning of the activity.

Cardwell's approach is constrained by its orientation towards 'mature' forms of the education-industry relationship: towards graduates and research laboratories fully institutionalized within firms.[97] The tendency to give little attention to other students leaving high level institutions, and other routes by which trained men entered industry, represents the situation as overly 'dichotomous' and without intermediate forms. It is only within such a perspective that Cardwell can suggest that "the beginning of true applied science has been dated, with some precision, as occurring between 1858 and 1862".[98] From this perspective also the only career available on any scale for 'professional scientists' in the UK during the period under consideration would be in education. However this leaves a major problem in categorizing the considerable numbers of men who moved from higher education to industry during this period. Overall, it is not clear that there is any need to impale oneself on either of the horns of the dilemma which Cardwell offers--either that "until the universities were producing the specialist industrial demand could not make itself felt" or that one can "explain professional scientific training by reference to industrial demand".[99] The relationship was conditioned rather by specific industrial and educational circumstancs.

An important element in any account of these circumstances is the character of internal changes within industry and career patterns there. The assimilation of the products of higher scientific education into industrial firms must be seen as problematic. Industrial firms set the terms on which trained men were employed, and determined their subsequent trajectories. The 'industrial scientist' was in this sense an internal product of the industrial sector. The process took place within the forces of employee/employer relations and a shifting organizational situation. Chapter 6 therefore explores more directly the involvement of trained men within the chemical industry.

Notes to Chapter 5

1 Cardwell, op. cit., (1972), chapters 6 and 7. Data are also presented in R.M. Pike, 'The Growth of Scientific Institutions and Employment of Natural science Graduates in Britain, 1900-1960', M.Sc. thesis, London University, 1961.

2 Cole remarked to the Samuelson Committee in 1868 that "...when the Board accepted those subjects of teaching, they were all thought, in a greater or lesser degree, to have a bearing on industrial occupations." SCSI, q.111.

3 The Society of Arts examinations in subjects explicitly overlapping those of the DSA were ended in 1870. Despite pressure for their retention, they quickly tailed off to commercial subjects only. JSA xviii (1869-70), p.685; ibid., xxxv (1876-7), p.768.

4 Drawn from the relevant volumes of the Society's Journal.

5 C. Heward, 'Education, examinations and the artisans: the Department of Science and Art in Birmingham, 1853-1902', in MacLeod, op. cit. (1982), pp.45-64 (58).

6 Donnelly, op.cit., p.104.

7 SCSI, q.3333.

8 NAPTE, Technical Education in England and Wales, (1889). Association of Technical Institutions, Are Our Industrial Leaders Efficiently Trained? (A Comparison of Technical Education at Home and Abroad) A Pamphlet Prepared by the Council of the above Association, (Bristol, 1901). Meldola suggested in 1909 that 130 institutions had been established as a direct result of the technical education propaganda of the late nineteenth century. Meldola op. cit. (1909), p.574.

9 Association of Technical Institutions, op.cit., pp.5-7.

10 Report of the Board of Education for the Year 1904-1905, PP 1906, xxviii, p.58. See also the relevant DSA Annual Reports and Appendix 2.

11 LCC, op.cit., (1902) Appendix E. The institutions on which these data are based are: Bow and Bromley Institute, People's Palace, Toynbee Hall, Hackney Institution, Working Men's College, Queen's-park Institute, Westbourne-park Institute, Regent St. Polytechnic, Onslow College Chelsea, Woolwich Polytechnic, Addeys School, Goldsmith's Institute, Morley Memorial College, Finsbury Technical College, City of London College, St. Thomas Charterhouse School of Science and Art, Birkbeck Institute. For some of the institutions it seems likely that some day students were also included.

12 Royal Commission on Secondary Education, I Report of the Commissioners, PP 1895 , xxi, p.28, p260, qq.1070, 1182-3. For a general account of the DSA examinations see H. Butterworth, 'The Science and Art Department Examinations: Origins and Achievements', in MacLeod, op.cit. (1982), pp.27-44.

13 In 1868 Huxley remarked to the Samuelson Committee that "our older universities ...are hardly to be trusted with scientific education". SCSI, q.8013.

14 Roberts, op.cit. (1973), Table 12. She gives the following distribution, which refers to the period 1845-1853:

manufacturer	13.4%
pharmacist	10.3%
physician and surgeon	10.3%
academic	10.0%
brewer	4.4%
public employee	4.4%
analyst	3.8%
engineer	3.3%
agricultural chemist	1.6%
unknown	34.8%

15 Normal School of Science, First Annual Report, PP 1854, xxviii, p.177. DSA, 10th Annual Report, PP 1863, xvi Appendix V. See also Appendix 2 below.
16 RCSI, q.5683.
17 SCSI, Appendix 18. The intended occupations were: chemical manufacturer, 9; brewing, 6; mining, 4; "professional chemistry", 3; engineering, 1; teaching, 1; sugar refining, 1; church, 2; law, 1; medicine, 1.
18 The Registrar, Trenham Reeks, told the Samuelson Committee that those intending to become "chemists or manufacturers" "generally enter specially for chemistry...they would only enter for one course of lectures perhaps". SCSI, q.1193.
19 ibid., q.882.
20 RCSI, q7365.
21 Roberts, op.cit. (1973), p.181, and see below Table 7.
22 RCSI, q.1172.
23 SCSI, qq.3243, 3248. F.J.C. Hearnshaw, The Centenary History of King's College London. 1828-1928, (1929), p.254-8.
24 R.M. MacLeod and R. Moseley, An Anatomy of an Elite: the Natural Science Tripos and its Candidates, 1850-1914, SSRC Research Report HR 1963, (1976), Tables 1E and 1F. R.M. MacLeod and R. Moseley, 'The "naturals" and Victorian Cambridge: reflections on the anatomy of an elite, 1815-1914', Oxford Review of Education vi (1980), pp.177-95.
25 Science and Art Department of the Committee of Council on Education, Prospectus of the Normal School of Science, and of the Royal School of Mines, South Kensington and Jermyn Street (1881), p.5. The emphasis elsewhere is a little different. In the negotiations leading to the establishment of the Normal School of Science the School was to be "a Metropolitan School or College of Science, not specially devoted to Mining but to all Science applicable to Industry, and with a special organization as a Training College for Teachers". Correspondence between the Science and Art Department and the Treasury as to the organization of the Normal School of Science and Royal School of Mines PP 1881, lxxiii, p.3. A detailed account of the origin of the Normal School has been given by Bud and Roberts, op. cit. (1984).
26 Cardwell, op.cit.(1972), p.217.
27 Bud and Roberts, op. cit.(1984). Sanderson, op. cit. (1972).
28 These data reflect the relatively greater proportion of chemistry graduates generally at Victoria compared to London. See note 285 to chapter 4. Other data about the position of chemistry relative to other disciplines at the institutions under review here might be

considered relevant. Among the the NST sample, 82% of those taking Part I were examined in Chemistry compared with 20% of those taking Part II. At the City and Guilds Central Institution during the period from its foundation to 1912, 124 Diplomas were granted in chemistry, 675 in Civil and Mechanical Engineering and 451 in Electrical Engineering. At the Royal College of Science, for students entering before 1890, 47% of all single subject Associateships were in Chemistry. For the period 1910-1914 the figure was 46%. The nearest competitor in each case was Physics with 18% and 20% respectively. The sensitivity of disciplinary importance to institutional context is sufficiently apparent. For the origins of this information see Appendix 1.

29 The 1910 data for the Royal College of Science are based on Associates only, and the relevant Register contains occupational data, unlike those of other institutions at this time. Here and elsewhere all Mining and Metallurgy students apparently taking only a basic course in chemistry are excluded.

30 A. Chaston Chapman, The Growth of the Profession of Chemistry during the Past Half-Century (1927), pp.17-18.

31 The percentages of students detected in each of these categories at each institution were:

Category	Cambridge	CGCI	Owens	RCS	UCL	Overall
SCI	2	32	15	14	9	13
CS	6	21	10	18	10	11
IC	4	15	15	24	11	12
patent(s)	2	13	6	7	4	5
paper(s)	5	18	11	9	7	9

32 LCC, op. cit. (1892), p.72.

33 LCC, op.cit. (1902), p.23.

34 R. Blair, 'The Relation of Science to Industry and Commerce', Nature lxxxiv (1910), pp.345-53 (348). Blair was Education Officer to the LCC.

35 Hartog, op.cit. (1895), p.424.

36 Institute of Chemistry, Conference of Professors of Chemistry, held at 30 Bloomsbury Square, London, W.C., on Friday, 17th October, 1913 (1913), p.38.

37 These data are taken from Victoria University of Manchester, Calendar 1913-1914 (Manchester, 1913), pp.869-84.

38 Occupations have been determined using Victoria University, Register of Graduates up to July 1st, 1908 (Manchester, 1908). Unfortunately it has not been practicable to compile similar data for students taking chemistry in the Ordinary B.Sc. degree. The figures can, in passing, be compared with those students from the Chemistry Department considered to have obtained "important appointments" (the phrase is that used to describe this list in the College's report to the Board of Education) for the years 1903 to 1909. These were employed as follows:

education	41%	
chemical manufacture	32%)	44%
other manufacturing	12%)	
other	15%	(N=163)

Owens College, Report of the Council to the Court of Governors for the relevant years. Academic appointments make up the majority of those classified under education, and the figures are a commentary on what was considered "important" by the College authorities.

39 Levinstein, op. cit. (1902).

40 Musson, op. cit. (1905), p.166. On Levinstein see chapter 6.

41 Board of Education, South Kensington, London SW. Directory with Regulations for Establishing and Conducting Science and Art Schools and Classes PP 1900, xxvi, p.33 et seq.

42 Ibid., p.345.

43 Correspondence between the Science and Art Department and the Treasury as to the organization of the Normal School of Science and Royal School of Mines PP 1881, lxxiii, p.18. DSA, Annual Report, PP 1880, xxv, pp.597-8.

44 The manner of reporting makes it difficult to establish the number of individual students over each year, so numbers are given here for the first term.

45 See Appendix 2.

46 J. Norman Lockyer, 'A Short Account of Scientific Instruction', in Education and National Progress. Essays and Addresses 1870-1905 (1906), pp.75-104.

47 Departmental Committee on the Royal College of Science (including the Royal School of Mines) and Questions Connected Therewith, Final Report. II Minutes of Evidence and Appendices, PP xxxi, 1906, q.2393.

48 Ibid., Final Report I, p.3.

49 G.K. Roberts, 'The Liberally-educated Chemist: Chemistry in the Cambridge Natural Science Tripos, 1851-1914', Historical Studies in the Physical Sciences xi (1980), pp.157-83.

50 Committee to Enquire into the Position of Natural Science in the Educational System of Great Britain, Report of the Committee appointed by the Prime Minister to Enquire into the Position of Natural Science in the Educational System of Great Britain, PP 1918, ix, paragraph 170.

51 Report of the Departmental Committee for Enquiry into the Principles which Should determine the fixing of Salaries for Teachers in Secondary and Technical Schools, Schools of Art, Training Colleges and other Institutions for Higher Education (other than University Institutions) Volume II. Summary of Evidence, PP 1918, ix, p.107. In 1912 W.J. Sell, University Lecturer in Chemistry at Cambridge, remarked that "During the late years a rapid change has been observed in the type of career adopted by graduates who have specialised in chemistry in the University. Formerly the greater proportion of these became teachers. Within recent years, however, it has become unusual...and posts are obtained by nearly all of them in connection with the chemical industries." W.J. Sell, 'The Chemical Laboratories of the University of Cambridge', Chemical World i (1912), pp.85-9. It was slightly earlier than this that Brunner, Mond began to recruit Oxbridge men: see chapter 6.

52 Jenkins has come to similar conclusions using some parallel data, though from the perspective of the supply of teachers, and with greater qualification of his conclusions than Cardwell. E.W. Jenkins, From Armstrong to Nuffield. Studies in Twentieth-Century Science Education in England and Wales (1979), pp.219-21.

53 These figures have been obtained by summation from the tables of degrees awarded within individual institutions, to be found distributed through Board of Education, Reports for the Year 1909-10 from those Universities and University Colleges in Great Britain which are in Receipt of Grant from the Board of Education, Cd. 5872 and the equivalent double volumes for 1910-11 (Cd. 6245 and 6246) and 1911-12

(Cd. 7008 and 7009). They refer to English institutions only.

54 These figures are obtained by summation of: "Results of University Degree Examinations taken by Students in 1910" (Table 121) in Board of Education, Statistics of Public Education in England and Wales. Part I. Educational Statistics, 1909-10, Cd. 5843, and the equivalent tables in the volumes for 1910-11 (Table 116) Cd. 6338 and 1911-12 (Table 116) Cd. 6934. They exclude Oxbridge and Welsh data.

55 R.W. Rich, The Training of Teachers in England and Wales during the Nineteenth Century (Bath, 1972; first edn. Cambridge, 1933), p.226. H.C. Dent, The Training of Teachers in England and Wales, 1800-1975 (1977), pp.32-3.

56 These figures are obtained by summation of Table 125 "University Degrees held by Students who Completed a Course of Training during the Year" in Statistics of Public Education...1909-10, op. cit. Cd.5843, and the equivalent tables (Table 120, Cd. 6338 and Table 120 Cd. 6934) for 1910-11 and 1911-12. The use of identical years to those above for these postgraduate students has no significant effect on the findings, and is more meaningful in terms of the treatment which follows of numbers of graduate teachers.

57 Statistics of Public Education...1909-10, Cd. 5843, Table 44.

58 The figures for England (which are not given separately for this year) have been obtained by subtraction of those for Wales (Statistics of Public Education in Wales (with Monmouthshire). Part I. Educational Statistics, 1912-13, Cd. 7930 Table 38) from those for England and Wales (Statistics of Public Education in England and Wales. Part I. Educational Statistics, 1912-13, Cd. 7674 Table 38).

59 All of these figures assume no transference between Oxbridge and the independent sector on one hand and the grant-aided university colleges and the maintained sector on the other. In this respect they follow Cardwell, and without this assumption little or no use can be made of public statistics.

60 The potential elementary teachers were, as Tilden put it, an "impecunious class". Departmental Committee on the Royal College of Science, Second Report q.2506.

61 See note 38 above. Taking those institutions as a whole which broke down their reports of degrees obtained during this period into Ordinary and Honours degrees, out of a total of 163 Honours degrees in science awarded only 19 (12%) went to Recognised Students.

62 These data are taken from the summary of graduates given in Victoria University of Manchester, op.cit. (1913).

63 Imperial College of Science and Technology (otherwise untitled informal prospectus, c.1913), pp.17-20.

64 Victoria University of Manchester, op.cit. (1913).

65 See the summary data in the reports referred to in note 53, e.g. Cd.7008, 1911-12, pp.xxviii-xxix.

66 Royal Commission on University Education in London, Minutes of Evidence, PP 1910, xxiii, q.2256.

67 'Statistics Concerning the Training of Chemists Employed in English Chemical Industries. Report of the Committee, Consisting of Professor W.H. Perkin (Chairman), Professor G.G. Henderson (Secretary), Professor H.E. Armstrong, and Mr. G.T. Beilby', in Report of the Seventy-Second Meeting etc. (1903), pp.97-8. See Appendix 2. The 1907 Industrial Census provides information only on the numbers of salaried and waged employees. PP 1910, cix, p.231.

68 A survey of the 1900 membership with surnames beginning A-C yielded the following breakdown of stated occupations:

	N	%
analyst or assayer	83	12
manufacturing chemist	72	11
chemist	52	8
engineer	30	5
chemical works manager	26	4
technical chemist	25	4
merchant, drysalter	25	4
consultant	12	2
lecturer etc.	10	2
public employee	10	2
chemical engineer	9	1
pharmaceutical chemist	8	1
higher education	8	1
works chemist	3	<1
student	2	<1
foreign	166	25
other	125	19
unspecified	8	1

Those clearly not industrial employees (merchants, drysalters, consultants, public employees, lecturers, students and those in higher education) represent about 10% of the total.

69 Based on members with initial letters A-C. In 1901 William McMurtie estimated that 80% of US chemists were employed in industry, but that only one-third of these were members of the American Chemical Society. 'The Condition, Prospects and Future Educational Demands of the Chemical Industries', *Journal of the American Chemical Society* xxiii (1901), pp.71-89.

70 Taken from the *Report of the Council to the Governors* for the relevant years.

71 The percentages identified were as follows:

SCI	38%
CS	10%
IC	10%
patent(s)	8%.
paper(s)	10%

These figures can be compared with those in note 31.

72 *Statistics of Public Education...1905-6-7*, Cd. 3886, Tables 16 and 17.

73 Ibid., Table 26.

74 C. Norwood and A.H. Hope, *The Higher Education of Boys in England* (1909), p.239.

75 City of Manchester, *Sixth Annual Report of the Education Committee 1907-1908* (Manchester, 1908), pp.158, 204-5. P.H.J.H. Gosden, *The Evolution of a Profession. A Study of the Contribution of Teachers' Associations to the Development of School Teaching as a Professional Occupation* (1972), pp.23-30.

76 *Report of the Committee on National Expenditure*, PP 1931, xvi, p.50. It is not clear how this figure was arrived at.

77 *SCSI*, qq. 7010-14, 1146.

78 *CN* xxxii (1876), pp.178-9.

79 *CTJ* i (1887), p.116.

80 CN lxxiii (1896), p.222.
81 LCC, op.cit. (1902), p.19.
82 Biographical Memoirs of Fellows of the Royal Society xxii (1976), pp.105-7.
83 CCRO, DIC/BM8/1/10. Wages Books. Entry for July 1881.
84 CTJ xxxix (1906), pp.549-50.
85 Ibid., xix (1899), 7 January 1899.
86 Minute Book of the Board of Directors, CCRO DIC/UA3/2/1, entry for 19 December 1890.
87 Brunner, Mond, Minute Book of the Shareholders Meetings, CCRO, DIC/BM3/12, entry for 18 August 1890. On Jarmay see JPIC (1944), p.186.
88 Imperial College of Science and Technology, informal prospectus c.1913, pp.17-20
89 Report of the Departmental Committee for Enquiry into the Principles which Should determine the fixing of Salaries for Teachers..., PP 1918, ix, p.107.
90 Institute of Chemistry, Council Minutes, entry for 21 January 1921.
91 H.A. Roberts, Careers for University Men (Cambridge, 1914), p.18.
92 Cardwell, op. cit. (1972), p.244.
93 Cardwell, op. cit. (1972), p.240 and 'The Development of Scientific Research in Modern Universities: a Comparative Study of Motives and Opportunities' in Scientific Change ed. A.C. Crombie (1963), pp.661-77 (676).
94 Cardwell, op. cit. (1972), p.241.
95 R.S. Turner, 'Justus Liebig versus Prussian Chemistry: Reflections on Early Institute-building in Germany', Historical Studies in the Physical Sciences iii (1982), pp.129-61.
96 This may seem to be a distortion, but compare the following account of a "smooth-running" educational system, which culminates in the quotation already given: "Young men and women, educated at primary and secondary schools are vocationally trained at a university to return to the former as teachers; they therefore perpetuate the principle. But some of these students--a small minority perhaps--will have talent above the ordinary and will want to do research at the university. A proportion of these will normally be retained as university teachers; but as supply generally exceeds demand in this case, those who do not become university teachers must either revert to school teaching, or abandon science, or become industrial scientists. From this point of view therefore the industrial scientist is to be regarded as an internal product of the educational system". Cardwell, op. cit. (1972), p.240.
97 Cardwell, op.cit. (1972) pp.15-16. and op. cit. (1963) p.671.
98 Idem., op. cit. (1972), p.237.
99 Ibid., p.246.

Chapter 6. Technical and Scientific Personnel in the Chemical Industry from the Mid-Nineteenth Century.

In chapter 2 the role of chemical knowledge in the calico-printing and alkali industries until the mid-century was discussed. During the earlier period a considerable amount of activity was described which involved men with some chemical training, though with few standardized forms of employment. This chapter explores the activities of trained men from the mid-century until approximately the beginning of the First World War. During this period the foundations were being laid of the more formal mechanisms for the recruitment and employment of such men in the later twentieth century.

In the previous chapter the occupations and destinations of chemistry students were surveyed systematically so far as possible. The situation within industry cannot readily be explored in a parallel way. Large scale data across sectors are lacking: the first industrial census was not undertaken until 1907, and contains little of use, while the normal census of population was too imprecise to be of value.[1] The contents of this chapter will refer mainly to the areas of alkali manufacture (and associated inorganic fields), organics (especially dyestuffs) and, to a limited extent, explosives. It is difficult to obtain a complete picture, even within individual firms, of the education and functional specialization of personnel or of the network of authority. Information on each of these areas in the industrial archive is very limited, and this makes any account of the situation more speculative than would be wished. (See Appendix 3: 'A Note on Sources'.)

In this chapter accounts will firstly be given of the situation in a number of individual firms, representing the main components of the chemical industry. These accounts vary in length and complexity, but an attempt will be made to cover the major firms in the areas referred to. They will inevitably include some more interpretative material, but, so far as possible, this and more general discussion will be confined to the latter part of the chapter.

A The Alkali Industry

The history of alkali manufacture during this period is dominated by the decline of Leblanc soda and its replacement by ammonia soda. The period of decline of the older process was lengthened by its role in chlorine manufacture, a rearguard action of technical innovation and the development of ancillary processes. The first commercially and technically viable ammonia soda works in Britain was set up by Brunner, Mond & Co. in 1874. At that time total soda production was approximately 300,000 tons per annum. By 1920 no Leblanc soda was being produced in Widnes.[2] The Leblanc process mainly involved batch working and much labour controlled by individual manual workers. It had long been associated with the production of large quantities of semi-solid, liquid and gaseous waste products. No useful theoretical understanding of the chemistry of its key stages was gained during its commercial lifetime.[3]

About 1870 the English alkali industry was still split between Merseyside and Tyneside, though the shift away from the latter had already begun.[4] On Merseyside proper (that is to say excluding the works of Kurtz and Crosfield at St. Helens) the major works were those of Gaskell, Deacon & Co., John Hutchinson & Co., the Runcorn Soap and Alkali Co. Ltd., James Muspratt and the Widnes Alkali Co. Ltd.[5] On Tyneside, important works included those of Allhusen (later the Newcastle Chemical Co. Ltd), Chas. Tennant and Co. and the Jarrow Chemical Co. In Scotland Tennant's St. Rollox works on Clydeside was dominant.

Gaskell, Deacon & Co.

Gaskell, Deacon is illustrative of a technically-innovative firm during the early part of the period. The original partnership between Holbrook Gaskell and Henry Deacon was established in 1855. Both had an engineering background, though Gaskell (at one time a partner of the engineer James Nasmyth) appears to have had a mainly commercial interest in the firm. Deacon had served an engineering apprenticeship with the firm of Galloway & Co. and with Nasmyth and Gaskell.[6] He worked at Pilkington's glass works in St. Helen's, and as a manager for the alkali manufacturer John Hutchinson in 1851, before joining Gaskell. The partnership of individuals with, respectively, a mainly commercial and a mainly technical competence was a quite common situation during the period.

Deacon took a direct responsibility for management and development. His chemical knowledge was a result of self-tuition and attendance at Faraday's lectures at the Royal Institution. In the 1850s he attempted to operate an ammonia soda process, and he took out patents in other chemical processes with the St. Helen's engineer Thomas Robinson.[7] It is illustrative of the occupational flexibility of the period that Robinson, the engineer, had begun life as an apothecary's apprentice. Deacon's major technical initiative was his process for chlorine recovery by catalytic air-oxidation of hydrochloric acid, which was patented in 1868.[8] He offered a theoretical interpretation of this to the Chemical Society, and claimed that ideas of chemical affinity had guided him in developing it. However Georg Lunge commented of this in 1880 that "(i)f the truth be told, the somewhat pretentious theoretical investigations of Deacon, so far as can be seen, have had next to no influence in promoting the practical working out of the process."[9]

It is difficult to establish how much technical and scientific help Deacon obtained. In any event, at least three academically educated men were employed in the works by 1870: Eustace Carey, Ferdinand Hurter and William Jekyll. Carey had studied at the School of Mines, Hurter in Germany and Jekyll at Owens College. In addition the engineer and photographer Vero Charles Driffield was employed in the works from 1871.[10] After Deacon's death in 1876 Carey and Hurter appear to have carried the major technical responsibility between them, though it is impossible to decide exactly how it was divided. Other men were trained within the firm, but there is no record of their origins. Thus Fred Brown, the assistant manager at the Gaskell Deacon works within the United Alkali Company in 1907, trained under Hurter, as did F Wright.[11] A letter in the Brunner, Mond archive from Hurter indicates that he had encouraged an under-manager (one Charles Ridd, a "controller" of the Deacon plant) who had done well in the DSA examinations to go to Zurich to study.[12] The routes (or at least potential routes) into more senior positions within the firm appear to have included both academic training and more traditional apprenticeship, as well as a combination of both. The movement of immediate family into such positions was not displaced, and Henry Deacon's son, Henry Wade Deacon, was also active in the firm after studying chemistry at King's College London.[13] The extent of his technical interest is not clear, but he was a member of the Institute of Chemistry and the Society of Chemical Industry before retiring in 1891. Holbrook Gaskell's son also retained an involvement.[14]

While it is impossible to reconstruct the division of labour at Gaskell, Deacon in any detail, it appears that a broad division between technical control and development work/general laboratory services existed between Carey and Hurter. Hurter himself began in a more analytical capacity in 1867. He assisted Deacon in the development of his chlorine process but his 'research'-orientated notebooks (which begin with work in this area) date only from 1871.[15] It seems that men such as Jekyll, Ridd, Wright and Brown were employed initially to work in the laboratory in a more routine capacity under Hurter, and this situation characterized the firm until its absorption into the United Alkali Co. (UAC)

Hurter himself occupies an idiosyncratic position in the history of the heavy chemical industry. He went on to become Chief Chemist to the United Alkali Co. in 1891. His notebooks reflect a systematic theoretical examination of processes within the Leblanc industry extending over many years, attempting to apply ideas drawn from physical chemistry. He published some of these. In a eulogy of Hurter his sometime collaborator Georg Lunge remarked delicately that Hurter's scientific weapons "were, perhaps, too fine for the broad questions at issue".[16] Ludwig Mond was said to have "had little regard for Hurter's chemistry, pure or applied".[17] Hardie and Reader have suggested that Hurter's advice on electrolytic techniques undermined the commercial prospects of the United Alkali Co. There is evidence in other conflicts of opinion of what Lunge called Hurter's "tendency to conservatism in technological questions".[18] Hurter will be referred to later in connection with the UAC.

James Muspratt & Co. and related firms

The history of the works associated with the Muspratt family is complex. James Muspratt's first English works was established in Liverpool during the early 1820s.[19] He was involved in a brief partnership with Josias Gamble at St. Helen's, and operated a plant there till the 1850s. He also opened a works at Widnes, and members of the family later operated works at Flint in partnership with J.K. Huntley. The Liverpool, Widnes and Flint works were in operation from the mid-century, under varying management. James Muspratt himself had originally been apprenticed to a pharmacist, but all of his sons (James Sheridan, Richard, Frederick, and Edmund) received a chemical training at Giessen.[20] Each of them was involved technically with the works at some stage, though only Edmund appears to have maintained a long-term interest. Frederick undertook research into the Leblanc process with Joseph Danson, a student at the Royal College of Chemistry, and this was communicated to the Chemical Society in 1849.[21]

During the mid-century such technical activity seems to have remained largely in the hands of the family, though it is unlikely that its members undertook everyday analytical work. In the period 1839-44 a plant at Newton-le-Willows was managed by James Young, and employed a chemist, William Hart. Hart's training is unknown, but Young had been employed at Glasgow University and University College London.[22] Young undertook some development work in connection with Muspratt's attempt to operate the Dyar-Hemming ammonia soda process, and his departure stemmed in part from a disagreement over the possibility of a partnership within the firm. Hart's existence is recorded fortuitously, and the same applies to Martin Murphy, who was also employed in the laboratory at one of the works. Murphy had trained for the priesthood in Ireland, and was employed, originally as an assistant to James Sheridan, during the period 1845 to 1855. He subsequently joined the latter at his College of Chemistry in Liverpool.[23]

Edmund Muspratt suggested that the Widnes and Liverpool works in the mid-century "were left entirely to the management of foremen".[24] He himself took over some responsibility for them in the mid-50s on his return from Giessen, and Richard and James retained a role, but it is difficult to establish the precise extent of their involvement.[25] During the mid-century period the firms continued to employ analytical chemists. Josiah Kynaston was trained at James Sheridan's Liverpool College and subsequently became chemist at the Flint works about 1860. While here he undertook analytical work on the Leblanc process, and published on the subject.[26] In 1870 the firm recruited its first German chemist, Konrad Jurisch, to be in charge of the Widnes laboratory, and Jurisch was allowed to develop his activities into 'research' on the operation of the plant. He undertook work on technical problems, and carried out systematic investigations on the Deacon process, which were published.[27] Another German chemist, Fritz Vorster, was employed by the firm at about the same time. He too was an ex-student of the Royal College of Chemistry, while another ex-student, T.H. Wilson was stated in the list given by Frankland to the RCSI in 1871 to be employed by Muspratts.[28] Vorster published material of a similar type to Jurisch.[29]

Jurisch left the firm to return to Germany during the 1880s, but by this time chemists were employed consistently. Georg Eschelmann, another German Ph.D., was recruited about 1883, and worked on the development of a process for producing potassium chlorate. He was helped by an ex-student of the Royal School of Mines, Charles

Higgins.[30] Two other men with a university education were recruited: G.H. Bostock, who had been a student of Bunsen and was employed in the laboratory about 1888, and Menrig Davies, from University College Liverpool, who was employed as a chemist at the Liverpool works before moving on to manage a works of the United Alkali Company.[31] It seems unlikely that this list exhausts those who were employed by the firm. The move into process management which many of them made, or their publication of academic papers, is the main reason for their identification. Chemists occupying a more routine position, such as Wilson or Murphy, are much less likely to be identified. Nor had recruitment of men who had undertaken some form of higher education replaced more traditional mechanisms. Men are recorded as reaching managerial positions within the United Alkali Company after starting with Muspratts straight from school in very junior positions (for example, as a letter carrier).[32] It is significant that none of these men worked manually on the process proper.

The two firms just discussed show considerable parallels. In each case academically-trained employees were introduced into the firm alongside members of the family who had been scientifically educated. The practice of educating sons in this way appears to have been widespread. In 1887 George Davis claimed that some years ago no-one entered manufacturing chemistry without a good chemical education.[33] While this was perhaps an exaggeration, it seems that it was frequently true of second generation chemical entrepreneurs. Of course these individuals would not have been tied to a laboratory bench undertaking analytical work. Such work was associated with a transient body of externally-trained men, though these laboratories also employed numbers of men who were 'apprenticed' within the works. Trained employees only appear to have a long-term association with firms where they moved into managerial positions, or even partnerships. There is little indication that academically-trained men were recruited because of any general policy that they were essential for process control: men who had joined firms as boys continued to move into managerial positions. Thus the motivation for the recruitment of chemists was based more on the perceived immediate significance of analytical competence. However their situation allowed the possibility of expansion beyond this activity. Both of the firms undertook a good deal of systematic research and development work, though the former serviced the latter directly. The situation of such men was fluid, stemming in the first instance from recruitment as "chemists" for quite specific purposes in analytical work, their subsequent utilization on an ad hoc basis and more or less fortuitous movement into process management.

Runcorn Soap & Alkali Co. Ltd.

Of the firms above only Muspratt Bros. & Huntley became limited liability companies. There were 44 such companies listed by the Chemical Trade Journal in 1887. One of the earliest was the Runcorn Soap and Alkali Co., formerly J. & T. Johnson, registered in 1865.[34] A discussion of this company will serve to illustrate the points just referred to and any differences from private companies.

Johnson's had begun as a soap manufacturer which produced its own alkali. The first recorded chemist at the older firm was Edward Davies, who had served an apprenticeship with Frederick Crace Calvert. In 1864 he set up his own analytical practice in Liverpool, suggesting that his work at Johnson's was largely analytical. The plant was managed at this time by two men from the soap-making trade, Neil Mathieson and Duncan Mackenzie.[35] After the firm's reorganization none of those on its board of directors appears to have had any technical involvement with the firm excepting the managing director, Charles Wigg.[36] Wigg was a member of the Society of Chemical Industry and took out a patent for bleaching powder manufacture in 1873. The firm recruited a series of analytical chemists after its foundation but these, like Davies, moved on quite quickly. Josiah Kynaston was employed during the period 1866-7, and he was followed by Charles R.A. Wright. Wright published papers on the alkali manufacture during the period, but later evidence suggests that his role was largely analytical.[37] Wright was followed by Edward William Parnell, who had studied at Wiesbaden with Fresenius.[38] Parnell was said to have declined an offer to remain at Wiesbaden as assistant, and worked for the Runcorn firm for a number of years. He succeeded in moving from analysis to process operations, eventually becoming Managing Director of the Desoto Alkali Co. and developing the Parnell and Simpson causticizing process in 1877-8.[39]

Other individuals were employed in chemical work at the firm during the period. E.J. Bevan (later of the well-known consulting partnership of Cross & Bevan) was employed there from 1872-6, but this was before he attended Owens College.[40] Archibald Campbell, who had been a student at the Andersonian and a chemist at Tennant's works in Glasgow and on Tyneside, was employed there from 1878.[41] Overall the firm had a rapid turnover of men, and there is little record of technical publication or innovations associated with those who can be detected during their employment with the firm. This includes, apart from those with formal training, others of more traditional background such as Edward Aaron and apprentices such as John Knowles. Knowles took the Society of Arts examinations in 1878.[42] It is not until the late 1880s that the firm is recorded as employing more than one individual at a time with a chemical training. These were Julius Raschen, a German Ph.D., A.G. Haddock (later Haydock) who had been apprenticed to Edward Davies, and William Norris Jones, who had been a student at Owens College, and attended Watson Smith's classes in Chemical Technology.[43] It is likely that some of this late burst of recruitment was connected with the fact that at about this time the firm was attempting to establish an ammonia soda plant.[44]

Identifying differences between Runcorn Soap and Alkali and the previous firms is a somewhat speculative exercise. Nevertheless the apparent remoteness from technical involvement of the directorate, the more rapid turnover and failure to progress within the firm of the junior chemical employees and the comparatively late recruitment of scientifically qualified staff can all be noted. Overall, however, the similarities are more pronounced than the differences. The comments made earlier about Muspratt and Gaskell, Deacon apply broadly to the Runcorn firm.

Looking generally at the Leblanc industry before the formation of the United Alkali Company in 1891, perhaps the most extreme form of recruitment which is encountered is that of men trained in Germany or elsewhere in Europe. In the early period this mainly involved foreign nationals, though later the balance shifted towards British students who had visited Germany. There are records of many such foreign chemists. One of the earliest recruits was P.V. Pauli, who was employed at the Union Alkali Works of Evans & McBryde from July 1860.[45] In 1862 Pauli developed a process for purifying caustic soda by fusing, indicating that the chemist at even quite a small works could be involved in technically innovative work.[46] Others observed in this decade are Ludwig Mond and Henry Brunner (the brother of Mond's eventual partner) at John Hutchinson's works, and elsewhere, Hurter, Lunge, and Louis Schad.[47] The 1870s saw Jurisch and Vorster at Muspratt, Jacob Grossmann at Gamble, Gustav Schack-Sommer at the Newcastle Chemical Co. Ltd., and Finkelstein and Steffenhagen also on Tyneside.[48] A few British nationals with German training such as Affleck of the Jarrow Chemical Co. and E.W. Parnell can also be traced. The flow continued into the 1880s and 1890s.[49] The exchange of personnel between Germany and Britain during the nineteenth century is well-known.[50] It extended beyond the chemical industry, but it was there that the movement of German nationals into Britain was most marked. It was not confined to Leblanc soda firms.

The accounts above show that German employees do not exhaust the recruitment of chemists. In 1875 Georg Lunge told the Newcastle Chemical Society that when he had arrived 10 years earlier to work for the Tyne Alkali Co. he had been the only chemist at the works. However large plants now employed "a staff of several chemists".[51] Lunge himself had "given up the laboratory for the outdoor work of the manager". The employment of "chemists to analyse" as the Alkali Inspectorate called them in 1871 was widespread by the early 1870s.[52] Their qualifications appear to have been diverse. It is unlikely that Lunge intended his comment to mean that all of those referred to would have qualifications equivalent to his own, and it can perhaps be assumed that many would have served apprenticeships. In 1868 Robert Calvert Clapham told the Samuelson Committee that about 50 apprentices were then passing through the laboratories associated with Tyneside alkali works, and that many had good prospects of becoming sub-managers.[53] It was from this group rather than from process workers that such junior managers were recruited. Men of this type would later take DSA examinations, and those of the City and Guilds.

The practice of employing even highly qualified chemists was not limited to 'progressive' works. An account of life at what was, at best, a run-of-the-mill works appeared in the Chemical Review in 1878.[54] The author was British and had attended a German university. He found employment, somewhat unwillingly, in an alkali works. His work was

> to make determinations of soda-ash, of copper, sulphur, and silver, in short analyse everything, as my future employer said, "that came in and went out", to which he might have added, "and every intermediate stage".

The description of his activities includes reference to the laboratory (located under one of the lead chambers), the ignorance and narrow-mindedness of the owner, and the prevalence of sharp practice and simple deceit in analytical activity. The works itself is represented as little more than a shambles.[55] The chemist was not involved in the production process proper. The conditions of work of men employed as chemists were evidently both materially and intellectually poor. Although it refers to a different chemical sector, the description by J.B. Cohen of the situation at the Clayton Aniline Co. is worth quoting:[56]

> We worked there in a noxious atmosphere of fumes and in indescribable filth...More unhealthy, dismal and repulsive surroundings it is difficult to conceive.

Extant process records reflect the repetitive nature of the work, and a review of a new analytical technique late in the century remarked that[57]

> (t)o be placed amid smoking chimneys and compelled to spend month after month determining the same element in similar material is a necessity dire enough to hatch anything.

The movement of men from English institutions into the alkali industry started in the 1870s, and was led by students from the Royal School of Mines and Owens College. A number of examples of men of this type have been given in the firms discussed above. Men who joined other firms from the Royal School of Mines before 1880 include CG Cresswell (Chance Bros.), GE Davis (Bealey, Gamble), HL Edwards (Hay Gordon), JK Hill (Mort, Liddell), B McNeill (Chance Bros.) and RC Woodcock (Bede Chemical Co.). It is noticeable that many of these men stayed only briefly with the firms referred to: indeed it is only from their subsequent activities that they are usually recorded.[58] This tendency reflects that already observed in the firms discussed above. It is possible, from the 1870s onwards, to find an undercurrent of men moving from educational institutions into the alkali industry in an analytical capacity, but not entering on a stable career in that role. Many left employment within industry for analytical or other consultancies. Others were promoted to managerial positions. The lack of institutionalization is reflected in the fact that firms often employed men with formal qualifications or training alongside others who had followed internal 'apprenticeships'. It was not uncommon for individuals to attend the School of Mines or Owens College after a period in a works laboratory.[59] In 1882 Tennants gave the Royal Commission on Technical Instruction a list of all of those employed at St. Rollox in their "chemical department" from 1870: 19 men were identified. Among these, seven had attended day classes (mainly at the Andersonian and Glasgow University), while the remainder had attended evening classes at the Andersonian and the Mechanics' Institute.[60] Of the early names on the list only one, who had become a process manager at St. Rollox, was still at the works. The remainder had moved on to managerial positions elsewhere.

To pursue this discussion would lead prematurely into the general issues which are addressed in the final section of this chapter. For the present it can be noted that the position of chemically trained men was in practice an ambivalent one. In many cases they deployed the relatively arcane knowledge of analytical chemistry for a highly constrained purpose, and with limited involvement in the process proper. The discussion now moves to Brunner, Mond & Co., the firm which posed the major British threat to the established techniques (both physical and organizational) of the alkali industry.

Brunner, Mond & Co.

Brunner, Mond & Co. was established in 1873 with a view to exploiting the technical changes which had rendered the production of ammonia soda commercially viable during the period 1860-70. Attempts to replace the Leblanc process by other methods of soda production had been made since its inception. Of these the ammonia soda method had proved the most consistently attractive.[61] This can be traced to its chemical simplicity, and its limited energy and raw material demands compared with other methods. The first attempt to operate the process commercially in Britain seems to have been that of John Hemming and Harrison Gray Dyar at Whitechapel in 1838. Both Hemming and Dyar were men with considerable scientific knowledge, but their claims for their process were evidently exaggerated, particularly in the key area of the rate of ammonia loss.[62] The plant was nevertheless sufficiently promising to attract James Muspratt, and Henry Deacon also attempted to render the process viable during the 1850s. Numerous other Continental and British attempts are recorded in the sources cited above. The cumulative effect of these innovations was partly responsible for the success of Ernest Solvay in setting up a viable plant in Belgium during the mid-1860s. The chemical simplicity of the process is clearly deceptive. Lunge remarked in 1880 that "the process is less a chemist's than an engineer's business", but this formulation is less informative than his earlier comment:[63]

> (Solvay's) process is an attempt to combine the elements of continuous, self-acting circular process, avoiding manual labour to the utmost.

Ludwig Mond came to the Solvay process from a background in traditional alkali manufacture, though he had worked in other forms of manufacturing chemistry.[64] He had left Heidelberg University without taking a degree, but found a more congenial environment in the pressures and more concrete demands of manaufacturing industry. It was suggested earlier that he was by no means the highly trained man of science of some contemporary representations.[65] Mond worked at the Widnes alkali works of John Hutchinson from 1862, but his status was that of a semi-independent consultant.[66] Hutchinson already employed Henry Brunner as chemist. Brunner had been educated at Zurich Polytechnic, and went on to become a partner and process manager in the firm after Hutchinson's death in 1865.[67] Mond's intentions were always entreprenuerial. He had some success in licensing his sulphur recovery process, which addressed a central commercial problem of the Leblanc industry. He considered setting up a Leblanc works in partnership with John Tomlinson Brunner, the brother of Henry and a senior commercial employee of the Hutchinson firm. However, recognizing the possibilities of the ammonia soda process, he chose rather to obtain a licence to work Solvay's patents in Britain. In 1873 the partnership began to construct a plant on an undeveloped site around Winnington Hall in Cheshire.

When Mond began operations at the Winnington site the technical staff apparently consisted of himself and a German chemist, A. Mebus, with an education similar to his own. The latter is variously described as chemist and works manager. There was also a foreman, James Lowery, who had previously worked for the Widnes Foundry Co.[68] In addition Mond received considerable help from members of the Solvay family. He also employed an engineer called Forrer and a consultant engineer, Samuel Horrocks.[69] The process was at the limits of what was technically feasible at the time. Mond remarked that "the whole plant is essentially one single unit connected by four pipelines and hundreds of cocks which come to a standstill on the slightest disturbance or blockage".[70] The problems were of a novel kind, and the solutions _ad hoc_. At first Mond slept in the plant, and during the frequent early crises had this to say of his two subordinates:[71]

> Mebus and Lowery are no better friends, and Lowery gives me a deal of trouble—he will have to go...
> I cannot run the risk of sacking Lowery at once. Mebus can do very well in fair weather, but Lowery is invaluable during a crisis.

The early years at Winnington involved practical solutions to immediate problems. The work can loosely be called chemical engineering, though activity involving boilers and compression engines came within the ambit of traditional mechanical engineering. Any idea that the operation of the process involved radical departures in the application of academic chemical knowledge (or any other form of academic knowledge) is clearly incorrect. Analytical chemistry retained its status as a useful tool, and appears to have operated much as in the Leblanc industry. In some cases routine analysis was the responsibility of foremen.[72]

Whether for reasons of cost or otherwise (the firm's capital base was severely stretched during the early years) Mond does not appear to have employed a full-time analyst. However, after a few years the works began to operate at a profit and its future commercial position became more secure. The conflict between ammonia soda and Leblanc soda dates from this time. However, the ancillary problems of the ammonia soda process were considerable, and in 1877 Mond began to devote attention to these. One element of this was the recruitment of a laboratory chemist. Mond took up the references of a student at the School of Mines in the following terms.[73]

> He would have to do the routine work of daily analyses in the laboratory; this would take little time however, and I am therefore looking for a young man who would be able to work under my control on various problems such as: the cause of ammonia loss in ammonia soda manufacture; the utilization of waste products in producing hydrochloric acid and finally on testing various new suggestions for producing ammonia from atmospheric nitrogen.

A shift can be seen here, from analytical to wider-ranging work, in the process of occurring. Mond could find no English chemist to occupy this post, and it was filled by Gustav Jarmay, a Hungarian who had trained at the Zurich Polytechnic.[74]

The staff at the works remained quite stable until about 1880. A few individuals are recorded as having being recruited during this period, but they were mainly foreign, and connected with Brunner, Mond's agreement to run the rival ammonia soda plant which had been established at Sandbach by Richards, Kearne & Gasquoine.[75] From about 1880 onwards there is evidence of considerable recruitment and reorganization, though not all of those involved were eventually employed. A Swiss, Henry Schellhaas, was appointed Chief Engineer in 1880.[76] DB Hewitt was recruited at about the same time, apparently being allocated a general technical role with a view to joining the

Board. Hewitt had been managing partner at Bealey's chemical works for a number of years, and he would join the board at Brunner, Mond in 1885. Nevertheless, despite his seniority, he spent some time in Brunner, Mond's laboratory.[77] Gustav Jarmay transferred from the laboratory to be works manager at Winnington around 1880, though it is unlikely that this was an instantaneous shift. Edward Milner, an original partner, was appointed to manage Sandbach in 1882. Jarmay joined the Board in 1889 and Schellhaas in 1892. Other chemists and engineers were being recruited at a lower level. A German chemist, Arthur Gossman, was employed briefly in 1879.[78] John Watts was recruited straight from Owens (though with some doubts on Mond's part) in 1881.[79] The firm made enquiries about a chemist called Ehrhardt, working for Vivian's at Swansea.[80] An assistant engineer of unknown background, Thomas Johnson, was recruited in 1880. GH Beckett from the Royal College of Science was employed briefly from 1882.[81]

While it is relatively easy to establish that these men were recruited, the way in which they were employed is much more problematic. These changes occurred during the period of the firm's shift to limited liability, which eventually took place in 1881. With the establishment of the process as technically and commercially viable Mond partially withdrew from the day-to-day running of the works, and the appointments which have been referred to may have been part of this process. The records are sketchy, but a major motivation in this appears to have been the desire to undertake more wide-ranging research. His biographer has suggested that the financial resources made available by the shift allowed him to embark on a "scheme of research...and to recruit trained scientific staff".[82] Mond's partial withdrawal from direct control became a physical removal in 1884, when he and his family moved to London. DB Hewitt joined the Brunner, Mond Board the following year. The structure of authority at the works thus went through Edward Milner and, especially, Hewitt to Schellhaas and Jarmay in engineering and production matters respectively.

It has already been observed that Mond had identified as priorities for research the key resource and by-product problems in the ammonia soda industry. He established a laboratory at his London home to attack these questions. A number of assistants were recruited to this laboratory during subsequent years, though at first they came mainly from Germany. Heihrich Hirtz, Carl Langer, Freidrich Quincke, Bernhard Mohr (later More) are recorded as working there during the period 1884-1900, as well as MD Cowap, Frederick Bloomer, John Gall, John Shields and Mond's son Robert.[83] A letter exists from PF Frankland (the son of Edward Frankland, and at that time Demonstrator at the Normal School of Science) recommending Trenham Reeks for a post, but he was evidently not appointed.[84] This laboratory liaised with larger scale development work at Winnington for many years. Thus, for example, in 1894 Mond indicated that Langer should go to Winnington to supervise large-scale experimental work on chlorine manufacture.[85]

The later 1880s saw further recruitment of chemists to the works proper. Henry Glendinning, an early recipient of the Owens College Certificate in Technological Chemistry, was appointed to a post in 1884.[86] Charles Ellis (Glasgow U. and Bonn), Georg Eschellmann (late of Muspratts'), Karl Markel, P. Naef, AW Tangye, Adolf Staub, Robert Mond and JFL Brunner were all employed at Winnington or Sandbach during this period.[87] Again there is no formal record of the personnel structure of the works and the way in which it operated can only be sketchily reconstructed from the surviving minute books and correspondence.

By 1891 there were 9 managers and sub-managers at the Winnington works.[88] Thomas Johnson was in general charge of the ammonia soda process under Jarmay.[89] In one letter the character of this authority received particular attention, with Johnson indicating that he was responsible to Jarmay, though keen to stress his need to take independent decisions. His authority ran directly to the individual foremen in charge of plants rather than passing through senior foremen such as Herbert Capes:

> This entails that I shall receive my reports in future direct from the process foremen...and give my orders direct to process foremen instead of to Mr. Capes.

The existence of other separate departments based on process operations is indicated by the Directors' Minutes, but their precise character is unclear.[90] They evidently had a distinct financial status, and although no detailed financial information has survived it appears that the breakdown was quite fine.[91]

The reference to more than one account for experimental work is of interest: the distinction between London and Winnington in this respect has already been mentioned. Overall, a wide range of types of 'research and development' work occurred, though with limited 'institutional' recognition. At the largest scale of experimental work, it has been suggested that Mond, somewhat ruthlessly, used the Sandbach works for full-scale plant experiments. Some existing comments give support to this view.[92] In any event the operation of the plants was carefully monitored, with Mond using analytical and other data to maintain control from London and even while on extended visits to Rome. Johnson and to a lesser extent Jarmay were under constant pressure to maintain production and ammonia losses at optimum levels, and technical parameters and apparatus were still under scrutiny by Mond in the 1890s. Any failure to report data or the results of such alterations was severely criticized.[93] It is not easy to distinguish this type of work from day to day plant operations under changing conditions, but it is evident that neither at the Winnington or Sandbach works was the production process allowed to operate without modification.[94] Least of all was control allowed to fall into the hands of foremen, as sometimes happened in the Leblanc industry. The early situation with Lowery was not repeated.

More radical, smaller scale innovatory work was also constantly in progress. While the exploratory work might go on in Mond's London laboratory, the Directors' Minute Book at Winnington records a steady stream of activity during the 1880s and 1890s in connection with the production of caustic soda, Mond gas, sodium bicarbonate and chlorine.[95] Mond is also reported to have undertaken work on nitrogen fixation with the Polish chemist Josef Hawliczek at Winnington during the 1880s, using gases from the Solvay towers.[96] There is however no reference to this in the minute books, reflecting both the difficulty of keeping track of the full range of activity which was undertaken and its relative lack of institutionalization. Men moved between laboratory and process activity in both directions, rather than following only the more common route from laboratory to plant.[97] There is no evidence to indicate that the Winnington laboratories were independently constituted to undertake service work for the investigation of plant operating problems. It seems that such work was directly under the control of Mond: certainly his letters contain direct references to the activities being undertaken, and the personnel who ought to be responsible for them, well into the 1890s.[98] The question of the shifts from an authority structure based on the founders is discussed below.

The laboratory facilities at Winnington and Sandbach expanded in a way that matches the recruitment referred to. In 1886 new offices, including a "private laboratory", were built at the former works.[99] This appears to have been intended to complement both existing facilities and Mond's own laboratory in London. New offices and a laboratory were built at the Sandbach works in 1896, and the office space freed was used to expand the existing laboratory.[100] The facilities at Winnington were expanded in 1893 and again in 1899.[101] It was in relation to a suggestion that the expanded laboratory should occupy separate premises that John Brunner made the remark quoted previously about the benefits of proximity between departments. At only one point do the records give any numerical statement about the staffing of these laboratories. In October 1892 the total of men employed in the Winnington laboratories was 25 and that at Sandbach 6.[102] These totals exclude laboratory boys, of whom 5 were employed as early as 1881, but certainly include numbers of men carrying out routine analysis and having relatively few qualifications.[103] Some evidence exists concerning men of the latter type, as for example Charles Moore, who was apprenticed with Campbell Brown at Liverpool Royal Infirmary before being employed at the Globe works in St. Helen's and then at Brunner, Mond from 1887 to 1899.[104] In 1888 the total Winnington works staff (as opposed to manual workers) was 61, of whom 22 can be identified as foremen.[105]

Numbers of academically-trained staff continued to grow during the 1890s, with the recruitment of both German and, increasingly, British trained men. They were not recruited directly into process management but rather, in the first instance, to the laboratories. One, GA Ashcroft, who held the Owens College Certificate in Chemical Technology, was dismissed because of his analytical incompetence.[106] In general it still appears that Germans such as Carl Hoepfner were recruited for more innovatory work.[107] By the second half of the decade the numbers were sufficiently large to allow the establishment of a social club for senior members of the technical staff, housed at

Winnington Hall. Reader has discussed this, and unfortunately records of the club are more detailed than any of the technical and scientific operation of the works. The first general meeting of the club took place in 1897, and gives some indication of the origins of the senior technical staff. It was attended by 5 men with German or Continental education, together with others from Owens College, the Andersonian, Cambridge University, and the City and Guilds Central Institution.[108] As the decade passed the balance between German and British universities shifted only slowly. There is no record of any formal recruitment procedure, but HA Humphrey was said to have been selected from a field of 200 to become Engineering Manager of the refined bicarbonate plant in 1892.[109] Most major British institutions sent men to the firm around the turn of the century, but during the first decade of the twentieth century men from Oxford University became predominant.[110] The earliest recruit from the ancient universities without a family connection appears to have been AV Cunnington. Cunnington had however spent some time at Zurich Polytechnic after taking a first in the NST in 1897.[111] He was recruited first to the analytical laboratory at Winnington, and was Chief Chemist by 1907. The precise duties which went with this title are not clear but, as will be seen in connection with FA Freeth, appear to have allowed scope for, if not the duty of, quite fundamental research.

When Brunner, Mond became a limited company in 1881 Mond and Brunner had been appointed Managing Directors for life. As has been seen, Mond did not allow his physical distance from Winnington to prevent him from maintaining a direct involvement with its operation. Analytical and other data were a key element in this. Letters which exist for the period from Mond's departure in 1884 to the mid-1890s deal with operational details of plants, recruitment of staff and the transfer of existing personnel. The recipients include Jarmay, Milner, Johnson and Hewitt, and in 1894, even while in Rome, Mond continued to have final authority on the appointment of trained staff and larger decisions concerning plant operations.[112] There is only tenuous evidence of difficulties and tensions which this entailed. By the late 1890s the correspondence had ceased (or none has survived). However, even as late as 1899 it was necessary to get Mond's formal agreement to leave decisions on new laboratories and offices to the Directors, while

HA Humphrey needed to apply directly to Mond for promotion.[113]

Reader has described how the firm began to recruit commercial and financial staff which complemented those on the technical and scientific side.[114] The early twentieth century saw the two founders replaced at the most senior level by Roscoe Brunner and Alfred Mond, though neither of these two men were technically orientated.[115] It is at this time that there is evidence of technical control at Winnington falling explicitly into the hands of a structure manned by the men whom Mond had appointed, with little 'family' representation. The weekly directors' meetings were supplemented in the late 1890s by minuted managers' meetings. This group became the main forum for technical decisions.[116] The membership of this group, initially seven, grew until by 1919 it included 21 individuals.[117] Even then there is no direct evidence of the existence within this group of any functionally-based division of authority, though it seems likely that such a division was in existence by this time. In a parallel development

the weekly directors' meetings (now under the general leadership of Roscoe Brunner and Alfred Mond) shifted away from everyday matters to larger strategic concerns (particularly, by the post-War period, synthetic ammonia).[118] In part this was a consequence of the increased scale and diversity of Brunner, Mond's operations, a process which had been accelerated by the War.

It does not appear, however, that the managers' meeting was associated with a more complex authority structure. During the early 1880s individual managers produced reports personally for Hewitt or Mond, rather than for the Director's meetings. There is no evidence of the Managers' meeting operating as a new tier of authority, beneath the Directors' Meeting, by the time of Mond's withdrawal. Though this was of course formally the case, in practice the Directors received no reports from it, and the meeting acted as a replacement, about 1898-9, for the supreme technical authority previously held by Mond himself. Technical decisions which had been addressed (and apparently recorded) mainly at a personal level were now addressed in this forum. Nor was there a 'functional' division of labour: 'research', for example, continued to be undertaken on an individual *ad hoc* basis. (The relationship between technical and other forms of authority at first operated in a more problematic way at Synthetic Ammonia and Nitrates.

When independent managers' meetings were convened at Billingham in the 1920s Winnington construed this as an attempt to usurp authority.[119])

It was not till some years after the turn of the century that the more fundamental research activity which had previously been the prerogative of Mond to instigate and direct came to be more formally focused in the Winnington laboratory under salaried employees. Even then the process was a somewhat haphazard one. In 1907 FA Freeth was recruited to the laboratory. Freeth had worked as an analyst in a tobacco factory immediately after leaving Liverpool University. His starting salary at Brunner, Mond was £200, and he was apparently given a free hand, on succeeding AV Cunnington, to supplement his analytical work by undertaking phase rule studies on inorganic systems.[120] He had a team of routine analysts (with the kind of limited qualifications which have been referred to at intervals), and other graduates such as HE Cocksedge and Wallace Akers joined the work. The laboratory was at least informally distinct from the analytical laboratory by Akers' arrival in 1911.[121] Freeth's work was of fundamental importance in placing the understanding of the ammonia soda process, and the other inorganic systems in which the firm was interested, on a sound theoretical basis. The reason for the leeway which he enjoyed is not obvious. It may partly have been due to Brunner, Mond's sheer commercial success, so that financial constraints were quite small. The general operation of Solvay-related firms may also have had a part to play: Reader has indicated that their technical dominance stemmed in part from the creation and sharing of a database of process-orientated technical information.[122] In 1911 Freeth was offered the chance to shift into process management ("then the road to advancement in Brunner, Mond") but he declined. Eventually Freeth was to hold the title of Head of Research at Brunner, Mond, and the shift to this more fundamental research activity at the plant itself probably marks the final elimination of the technical influence of Mond.[123]

Though the extent to which Brunner, Mond's 'research' was independent of the analytical laboratory is problematic, the limited activity which did exist had a key role in the firm's growth and technical development. Thus, in 1911, when Brunner, Mond was looking to diversify into ammonium nitrate production, it was to Freeth's research activity that Henry Glendinning (himself a representative of the early group of scientifically qualified men appointed by Mond) first turned for the generation of the basic physical knowledge and early development work.[124] Similarly the Oxbridge graduates who entered the firm in the immediate pre-War period found their initial employment in this area. By the beginning of the War the firm was recognized as possessing the most developed scientific staff in Britain.[125] Alfred Mond indicated that this group was the firm's main source of personnel for senior positions.[126] Brunner, Mond was involved in a diversified range of activity extending into organics, and it was largely through the deployment of this 'research' staff that it was able to attack novel technical problems, to display formidable technical virtuosity and to generate large scale profits.[127]

The extent of "fundamental" research was of course limited.[128] One of the problems in relation to such activity was its appropriateness for publication. Brunner, Mond had established, through Freeth, a connection with the Dutch school of physical chemists. After the War the firm attempted to gain a foothold in the new cryogenic laboratory at "Leiden" (sic), and Freeth hoped that "with a little diplomacy we could keep this laboratory to ourselves".[129] Freeth's FRS was obtained despite a poor publication record, and he was given credit for unpublished work. From the first Mond had devoted considerable attention to maintaining the secrecy of the details of his plant and operating methods. In the period from 1874 a sequence of rival attempts to establish ammonia soda plants in Britain occurred.[130] All were more or less failures, though that operated by GL Murgatroyd in 1893-4 was thought to be a potential threat.[131] It seems that no firm could hope to recapitulate the development work which Brunner, Mond (and the Solvay group generally) had undertaken, still less when under commercial pressure from Brunner, Mond itself. Nevertheless, the knowledge of operating conditions which even a foreman could carry to such firms was considered potentially damaging to Brunner, Mond. Siegfried Pick, who managed the Sandbach works during the late 70s subsequently appears as consultant chemical engineer to the Cheshire Alkali Co.[132]

In the more formal situation of the 1880s all senior employees were expected to sign a document, copies of which have not survived, but which was apparently concerned with taking employment with rival firms. Debate occurred as to who should sign.[133] Men like Glendinning and Markel signed as a matter of course. Any doubts, as in the case of one Henry Yeomans, who is otherwise unknown, were usually resolved by requiring men to sign. During 1889 there was some debate over the need for foremen to sign. Later it was discovered that one recently discharged and relatively junior foreman, James Allman, was working with Hawliczek on Mathieson's ammonia soda plant, and it was subsequently stated formally that, in all cases, signing "the agreement" was a "sine qua non of (their) appointment as foremen".[134] The need to prevent foremen finding employment elsewhere recurred at intervals. In 1899 two men were retired on half pay "with a call on their services" acknowledged to be to prevent them finding other employment rather than with any view to recalling them.[135]

Secrecy was stressed still more for senior staff, and an atmosphere of distrust was not uncommon. In 1888 the German Georg Eschelmann left to work abroad, and suspicion fell on one of the Owens recruits, AW Tangye, whom Eschelmann had apparently attempted to persuade to leave with him. Tangye was interviewed by Hewitt, and claimed that "before he knew Eschellmann was leaving he had often talked to him about the Ammonia Soda Process...but that since he knew he was about to leave he had not done so."[136] Tangye had been working with Eschellmann on chlorine recovery using a nickel catalyst, and Mond was later compelled to purchase a related process which the latter had patented. Georg Lunge (by now Professor of Technical Chemistry at Zurich Polytechnic) was said to have been banned from visiting Winnington when he published an account of the ammonia soda process in his well-known textbook after a visit to the works.[137] Secrecy remained the norm in regard to the ammonia soda process well into the twentieth century. Freeth, for example, was not allowed access to operating details of the plant until some time after his first employment, and Humphrey had to ask permission of Jarmay to collect data for some personal investigation.[138] In earlier chapters, it was seen that the secrecy of innovations was often referred to in relation to the construction of curricula. This issue was by no means merely rhetorical, and it was considered of central importance not merely in small-scale traditional works, but in the most technically advanced heavy chemical firm in the country.

It has been noted at intervals that Brunner, Mond recruited considerable numbers of men for more routine analytical work. From 1890 the firm had compelled most of their young workers (up to 19 years) to attend the local evening classes at Northwich, and from 1904 arranged for apprentices to attend for two afternoons per week.[139] Unfortunately no further details of the activity involved have survived. It may have been part of the wider range of innovations, such as paid holidays and sickness benefit and an eight hour day, which Brunner, Mond introduced, and which placed the firm in the vanguard of "welfare capitalism", rather than having a narrowly technical significance.[140] The comments of Alfred Mond to the Royal Commission on Welsh University Education in 1917-18, indicate that the local technical institution was of less significance than the firm's own training. In any event he made it clear that such part-time education, and the group at which it was directed, were viewed in a very different light from that of the firms' graduate recruits.[141] The role of such training for the firms' engineering employees may have been less constrained.

By the beginning of the First World War the extent of functional specialization within Brunner, Mond, while undoubtedly increasing, was still relatively limited. The available evidence suggests that the organization consisted of a single hierarchy based around educational background rather than one which expanded into different kinds of approximately equivalent technical/scientific knowledges. It centred on the recruitment of university-trained men and their induction through the laboratory into more senior managerial positions within the works. Freeth's rejection of this move seems to have been exceptional. The structure involved the social element of membership of the Winnington Hall Club, and, for a few, the pinnacle of appointment to the Board of Directors. The strongest differential in the works, so far as scientific training was concerned, was between this group and those described by Alfred Mond as trained for routine work, who "would never get any further".

The discussion now turns from Brunner, Mond, with its technical and commercial success, to the United Alkali Co., the major function of which would be to manage the decline of the Leblanc industry.

The United Alkali Company

In 1891 the Leblanc industry underwent a massive financial reorganization, with the amalgamation of nearly all of the main firms to form the United Alkali Company.[142] The resulting firm operated 47 plants and was capitalized at £8.2m—the largest chemical firm in the world. The amalgamation was essentially defensive. It aimed to provide a strong basis for the defence of existing Leblanc plant by a combination of threats of undercutting ammonia soda and the production of by-products, notably chlorine (as bleaching powder). The prospectus of the new company also promised increased efficiency by the application of the most efficient methods to all plants. However the new Board of Directors was mainly orientated to representing the geographically diverse interests encompassed by the company.

The administrative structure which emerged contained committees of both local and national directors, together with professional managers overseeing individual districts. Thus, for example, the district manager for Tyneside was TW Stuart. Stuart had progressed via Edinburgh University and a position as works chemist at Allhusen's to become works manager at Tennant's Tyneside works.[143] The St. Helen's district was managed by JR Wylde, who had been apprenticed at the Widnes Alkali Co. and married the senior partner's daughter.[144] The extent of the bureaucracy constructed did not meet with the approval of some shareholders, and as the economic position of the firm worsened it was claimed that it was "overrun by officials and superfluous men".[145]

The differing backgrounds of Stuart and Wylde reflected that of the main body of UAC plant managers. There was no shift in management at the individual plants immediately after the amalgamation.[146] Among the early works managers of whom something is known nine had begun in works after, at most, a secondary education, often beginning as assistants within laboratories. A few can be detected taking the early

Society of Arts and City and Guilds Technological Examinations.[147] A further seven had received some kind of full-time academic education in chemistry: two had German Ph.D.s, one had attended Owens College, one the Royal School of Mines, one Edinburgh University, one had trained at JS Muspratt's College of Chemistry and one at the Newcastle College of Science and Art.[148] It is clear that there had been no standardized route into managerial positions within the Leblanc industry during this period. The analytical laboratories nevertheless had an important role both for academically trained men or those who had been "apprenticed". Most individuals of both types had spent some time in analytical work, but none had come through manual work in the Leblanc process.

The Company was not content to follow existing practice in its approach to laboratory activity. As part of the formal structure necessary to integrate their diverse empire the Directors decided to appoint Ferdinand Hurter as "head of the laboratory department" in December 1890, and commissioned him to report on the requirements of the company in this area.[149] Hurter advocated a Central Laboratory, and gave an analysis of its functions which reflected many of those which would become commonplace in the twentieth century (original research, development, the investigation of patents and customers' complaints, and the standardization of analytical work).[150] It seems unlikely that Hurter, with his generally conservative outlook, was doing more than formalizing activities which were already to be found in the laboratories associated with the works. Of these Hurter remarked that they were "too small to accommodate both the works requirements and the requirements of the research department". It is possible that Hurter's intention was to ensure that the research facilities were not associated directly with any plant. The new laboratory was to have a technical library, and it is of interest that Hurter suggested that the existing library of the Gaskell, Deacon works formed a good basis for this. The Directors gave Hurter immediate approval to proceed.[151]

The Central Laboratory had an original staff of 12, of which five had German or Swiss qualifications.[152] In addition, and paralleling the situation at Brunner, Mond, there was a number of men with a lower level UK background, employed mainly for analytical purposes.[153] The laboratory grew slowly, recruiting mainly graduates, and developing a particular relationship with Liverpool University and Owens College. However, it also recruited from the Royal College of Science, Manchester College of Technology and from Germany.[154] It appears to have fulfilled the programme which Hurter mapped out for it, though without conspicuous success for the company. Its operations were bureaucratically controlled, and detailed records were kept of all the activities to which individuals were allocated. The staff successfully developed a number of new processes, though of a fairly minor kind.[155] In the key area of electrolytic techniques Hurter's advice was to have "disastrous" consequences for the firm.[156]

In 1896 Hurter gave an account of the work of the laboratory to a London County Council Special Sub-Committee on the teaching of chemistry.[157] He made clear that he saw no need for his recruits to have received a German training. They spent their whole time in research activity or work of a closely related kind. They needed to receive "a thorough preparation in analytical work". Apart from its research function, the Central Laboratory acted as a clearing house for works chemists: "(a)s vacancies occur in the several works they are filled by the assistants in the central laboratory". There was no set time before men were "drafted into works". Hurter's comments on the role of these men once they entered works are not easy to follow. He remarked that

> In such works as he is connected with the scientific chemist forms the head, and is not expected to do the daily routine testing, this being left to men who have not been through a university course. The men who do the routine work attend classes under the Science and Art Department.

Hurter does not mention the works managers, and reference has already been made to the other more clearly hierarchical division to which he does refer. It seems unlikely that men leaving his laboratory, without works experience, went directly into process management. Nevertheless some of those who passed through the Central Laboratory eventually moved into managerships or assistant managerships at works. Examples include GC Clayton, Arthur Wareing, Oliver Heslop, SJ Willcox, Arthur Carey and TS Norman. Max Muspratt had followed a modified version of this trajectory, by becoming a director with special responsibility for technical operations after his time at the Central Laboratory. It is not certain, but appears probable, that he spent some time in works.[158]

Though it cannot be judged whether it was the only route to works management the Company had established a mechanism by which graduates from the laboratory could be fed into the works proper in some capacity. Eustace Carey indicated the importance of this route in 1909.[159] Some idea of the later stages of this process can be discerned in comments by WL Rennoldson, manager of the Company's Tennant works on Tyneside. In 1902 he noted that

> A works chemist often has other duties to perform than analytical work; frequently he is asked to devote all attention to a department of the manufacture with the view of finding out the cause of some more or less mysterious trouble existing.

Rennoldson himself had followed the route from analytical chemist to works manager.[160] These remarks are in conflict with those of Hurter: evidently the works chemist did undertake analytical work, and was not the "head" of the works. Elsewhere Hurter noted that the chemists were expected to produce standard solutions for use in routine activity. It is possible that he was using "head" in the metaphorical sense, not uncommon at the time. In any event, the activity to which Rennoldson was referring was clearly moving some distance towards intervention in processes directly, rather than indirectly (the latter by acting as a source of information for the manager proper). In a number of cases individuals are recorded as being both works chemist and assistant manager.[161]

It is possible to gain a fairly complete picture of the management of the Company's Fleetwood ammonia soda works at the turn of the century from the reminiscences of WW Gleave, who was recruited to the works laboratory from the Runcorn Technical Institute in 1901 at the age of 15.[162] The works manager was RH Davidson, who had been trained at the Golding, Davis Leblanc works, but was without formal chemical education.[163] The Chief Chemist was AE Hetherington (University College, Liverpool and Heidelberg), but the works also had a Chief Analyst, Thomas Bazley, perhaps reflecting the comments of Hurter to the LCC. Bazley had been trained at the Hazlehurst Leblanc works. In addition, experimental work was carried out by two engineers, T. Houghton and "young Holbrook Gaskell". The latter was the grandson of the first Holbrook Gaskell (a partner in Gaskell, Deacon), and had graduated in the Mechanical Sciences Tripos from Trinity College Cambridge in 1900.[164] The Fleetwood works may have been exceptional, but this was a fairly complete managerial structure on the technical side. Hetherington had passed through the Central Laboratory.

Engineers as well as chemists were recognized within the Company's central administrative structure. An Engineering Department was started under EJ Duff in 1895. It recruited engineers from the City and Guilds Central Technical College during this period, to supplement the more traditionally trained men attached to each works.[165] Holbrook Gaskell became Chief Engineer in 1914. By 1908 a Central Engineering Department parallel to that in chemistry was housed in Widnes.[166]

In 1908 Max Muspratt gave some indication that the tensions of bureaucratic organization had been consciously addressed within the company, in a paper to the Society of Chemical Industry entitled "The individual and the corporation in the chemical industry".[167] The paper evidently drew on his experiences with UAC, and he sketched the administrative structure which was necessary. He stressed the role of trained men in co-ordinating complex internal and external operations, referring particularly to the areas of chemical, engineering and statistical activity. However this structure continued to be subsumed by that of authority within the works. Men in supervisory positions were now "more likely to be recruited from those who work with their brains...".[168] In any case it seems likely that Muspratt's account was as much prescriptive as descriptive. The available evidence suggests that the more dated UAC technical operations, and the Company's origins hindered the wholesale replacement of traditional process managers by academically-trained men. Many managers in the early twentieth century were of the former type, and this contrasted with the situation in Brunner, Mond. Moreover, many of those reaching the more senior managerial positions with an academic background had personal connections with the earlier firms, a situation which again contrasted with that in Brunner, Mond.

The firm paralleled Brunner, Mond in the stratification which it developed in its recruitment of "chemists". In 1906 it still retained 12,000 employees, and of these 150 were so described.[169] Of course this does not mean that it employed 150 graduates: a large proportion of these men would have been those identified by Hurter as having taken DSA examinations (or their educational equivalents in 1906). By the early twentieth century this body of analysts appears to have been recruited from the new technical institutions.[170] In some cases men of this type were encouraged to undertake further study. Indeed it is probably only by this mechanism that there is any record of them as individuals. WW Gleave (see note 162) followed this route, as did another individual, Stanley Bowman, who attended Rutherford Technical School in Newcastle-upon-Tyne, before joining the Company as an assistant chemist in 1906, at the age of 18. He eventually became an Associate of the Institute of Chemistry in 1920.[171]

The only systematic information about such employees to have survived dates from 1923, when the firm produced a report on the laboratory chemists in its Widnes and St. Helen's district for the Dyes Advisory Committee.[172] The report indicated that this region employed 42 "degree and college trained men" and 96 "qualified chemists", at a total of 12 works, including the Central Laboratory. The "qualified chemists" were employed in lower level and more routine work. Most of the "degree or college" men were concentrated at the Central Laboratory and the Pilkington-Sullivan works (the latter having three men employed full-time on research, though all of its men were so employed during the post-War slump). Most of the other works employed only "qualified chemists", the direct descendants of men men like Gleave and Bowman, their qualifications consisting of City and Guilds Certificates or those from local colleges. The National Certificate system had not been in existence sufficiently long to generate this number of men.[173] Moreover the employment of this group had probably increased since 1907, when the Company had claimed to employ 150 chemists of all types (the figures for 1923 refer to only one region).

It had been common up to the turn of the century and before to employ "university men" (not necessarily graduates) in routine capacities. (The comments of Mond in note 141 can be recalled.) The technical schools and colleges were meeting an expanding demand in this area. That this shift was placing pressure on the Institute of Chemistry is indicated by the formation in 1917 of the National Association of Industrial Chemists, with its class of non-graduate entry.[174] The United Alkali Company, along with other companies, ensured that much of its chemical work was undertaken by men with minimal chemical knowledge under supervision, and its distinction between "degree and college trained men" and "qualified chemists" reflected this. It seems likely, but cannot be shown, that supervision was exercised in some works by chemists who had moved into managerial positions and who were not included in the data cited above.

Alkali manufacture was the archetypal heavy chemical industry. However, even during this period synthetic chemistry on an industrial scale occurred in many other forms. The following section turns to another major component of the chemical industry known to have recruited trained men from an early date: the manufacture of organic chemicals, especially synthetic dyestuffs. Here the techniques and historical development were substantially different.

B. Synthetic Dyestuffs

The origin of the production of dyestuffs from coal-tar products is not as chronologically precise as is sometimes suggested. Earlier activity than that of Perkin has been documented, but little was commercially significant.[175] Perkin was the first to convert a suggestive laboratory reaction into an industrial process by solving the problems of raw material supply, scaling up for commercial production and persuading dyestuff users to switch to his novel material. It has been suggested, on the basis of Perkin's own accounts, that the solution of these problems represented his main achievement.[176]

Perkin's commercial success was followed by a stream of new dyestuffs, patents and litigation. The basic technique involved seems to have been to treat likely looking coal-tar products with any available reagent and see what emerged. Patents were attempted which would cover wide swathes of such activity, and duly criticized.[177] In the first fifteen years or so Britain led the field in this activity. Germany did not overtake the UK in British dyestuff patents until the late 1870s, though when the change came it was dramatic.[178] A number of small British firms was established to exploit the novel materials obtained. To a remarkable extent the technical and scientific men associated with this activity had received some chemical training at the Royal College of Chemistry. Perkin suggested that there were six coal-tar colour works in the UK in 1868 (he also suggested that there were 17 such works in Germany, which makes the patent record still more surprising).[179] The six works he had in mind were probably Perkin & Sons, Simpson, Maule & Nicholson, Read Holliday & Co., Levinstein & Co., Williams, Thomas & Dower, and Roberts, Dale & Co. A few small firms such as Dan Dawson & Bros. and JC Bottomley were also in existence at that time.

GF Perkin & Sons was the first firm to manufacture dyestuffs synthesized from aniline. WH Perkin was educated at the Royal College of Chemistry. His bother, TD Perkin, and father were both builders, but the former did undertake some technical activity.[180] In addition Perkin employed or worked with a number of men with some chemical training, most of which had been received at the College of Chemistry. JT Brown, (Sir) Alexander Pedler, C Greville Williams and Robert Williamson all spent some time at the works, while BF Duppa apparently worked with Perkin on a more informal basis.[181]

Perkin and his co-workers continued to produce new dyestuffs and bring them into production throughout the existence of Perkin & Sons, culminating in the production of artificial alizarin in 1869. However, Perkin withdrew from the industry in 1874. The reasons for his withdrawal, according to his sons, were his distaste for the constraints of commercially-orientated research, and the difficulty in recruiting skilled organic chemists.[182] The closest Perkin himself came to commenting publicly on the situation was in his Presidential Address to the Society of Chemical Industry in 1884. He noted the absence of research chemists, as opposed to men with analytical knowledge, but went on to comment on the division of labour in German works. In a curious aside, given his earlier remarks, he noted that many heads of firms were unwilling to sub-divide activity in this way: "(t)hey forget that others, less well-qualified perhaps, but more narrowly occupied may do the work well".[183] It is possible to speculate on whether Perkin had himself in mind. If so, he was perhaps recognizing that the development of new institutional structures within firms was an essential concomitant of expansion, in an industry dependent for its growth on the continuous production of new products, and the integration of large numbers of relatively small scale chemical operations. While the Germans followed this route, though with more hesitation than is sometimes suggested, Perkin evidently refused it, and he was not alone.[184]

The firms which grew up in parallel with Perkin operated in a similar way, though with a generally greater reliance on the recruitment of German chemists. The Lancashire firm of Roberts, Dale & Co. was established in 1852, and manufactured chrome yellow and oxalic acid.[185] The firm shifted into the manufacture of synthetic dyestuffs quickly, and employed the German chemists CA Martius and H Caro in the years around 1860, apparently undertaking systematic research activity. Martius had spent some time with Hofmann at the Royal College of Chemistry. Three other German chemist were associated with the firm: Griess, Leonhardt and Koepp, though the first was not employed at its works.[186] The firm also had some connection in later years with Owens College. Dale's younger son, RS Dale, was a student there, and subsequently published work with Carl Schorlemmer, the eventual Professor of Organic Chemistry. The firm patented a process for alizarin manufacture with Schorlemmer. Dale's younger son, John, studied briefly in Manchester, and also undertook research work with the firm before his early death in 1871. It also employed William Dancer, a graduate of Owens and pupil of Bunsen.[187] Nevertheless, despite early successes, it does not appear to have maintained its technical or recruitment momentum, and to have relied, after the departure of the Germans, on the technical activity of Dale's son and Dale himself. Nor did it specialize, as the Germans did, in dyestuffs and their intermediaries. At the time of a large explosion in the works in 1887 RG Dale was described as both manager and chemist to the firm.[188]

The firm of Simpson, Maule & Nicholson was established in the early 1850s to manufacture organic materials. All three of the founders had attended the Royal College of Chemistry, though George Maule and EC Nicholson had also served apprenticeships, the former with the same pharmacist as Edward Frankland.[189] The firm manufactured nitrobenzene for Perkin after failing to obtain a licence for the production of mauve, but was able to shift into the more lucrative field through its own innovations in roseine, magenta and other colours. It shifted from its original Locksfield site to an expanded works at Hackney Wick in 1860.[190] It employed a number of men from the Royal College of Chemistry during these years. David Price (who had also studied at Giessen) developed the roseine process which the firm used in 1859. Another Price, AP Price, also with a German Ph.D., worked with Nicholson on magenta in the early 1860s.[191] Simpson, Maule & Nicholson also employed William Spiller, Frederick Field, Henry Lowe and RE Alison (all of whom had been students at the Royal College of Chemistry). Two were associated with new colours (Spiller's purple and Field's yellow).[192] The firm operated Henry Medlock's famous arsenical patent for producing magenta for a time.[193] Details of the employment of the men referred to are unclear, and some may have been partners. In any event, the corporate effort of the firm was effective, and it was claimed to be the largest dyestuff manufacturer in the world during the mid-1860s. However, in a striking parallel to Perkin, all three partners had withdrawn from the industry by the late 1860s. Simpson left first, and the firm traded for a while as Maule & Nicholson, but in 1868 the business was sold to the partnership of Brooke, Simpson & Spiller.[194]

This firm too had an association with the Royal College of Chemistry. One of the named partners, William Spiller, was the same ex-Royal College of Chemistry student who had been associated with the earlier firm and another technically-active partner, WC Barnes, may have spent some time there. Richard Simpson was the brother of the George Simpson of the earlier firm, but is otherwise unknown. Edward Brooke was a Manchester chemical manufacturer, and was subsequently joined by his brother Arthur as Managing Director.[195] The firm has received a bad press because of the limited technical interest of its directors. It entered the industry during the period when the early pathbreakers were retiring. The available evidence suggests that it was willing to recruit chemists and allowed them to undertake research of a fairly free-ranging kind. John Spiller, another ex-Royal College of Chemistry student, joined the firm shortly after its establishment, and it also employed an analytical chemist of unknown academic training, Benjamin Nickels, from 1869.[196] When the firm took over the works of Perkin & Sons in 1874 it also retained the chemists Stocks and Brown.[197] It recruited RJ Friswell, another Royal College of Chemistry man, in 1874, and an attempt was made to recruit the young James Dewar.[198] Raphael Meldola was employed from 1877 to 1885, and published some of his work. He was replaced by AG Green.[199] Thomas Royle, originally from the Royal College of Chemistry, acted as works manager during this period.[200]

Green and Meldola both made significant discoveries of dyestuffs during their time with the firm (Meldola's blue and rosaniline sulphonic acid, and Primuline respectivly) and both later contributed to the firm's reputation for degrading the UK industry.[201] Green later gave an account of the firm's operations in which he indicated that it possessed reasonable research laboratories, and a "semi-scale" laboratory, together with six chemists.[202] He emphasized the absence of any separation between research and process work, but added that he himself was only made aware of the extent of German competition when he visited the north of England introducing Primuline. The planning of commercial production from laboratory ideas was undertaken by "the chemist who had made the discovery, the head chemist, and—as there was no engineer-- the foreman fitter". In practice Brooke, Simpson & Spiller appear little different from the the other firms which survived the early period of synthetic dyestuff manufacture. Their major difference from Perkin & Son was that they were still manufacturing dyestuffs. Like Perkin they were not willing or able to follow the Germans in developing functional specialization servicing commercial policy. During the remaining years of the century Brooke, Simpson & Spiller continued to recruit chemists on a small scale from the UK institutions, and at the turn of the century it still employed five chemists, while retaining Green as consultant.[203]

The final firm associated with early activity was that of Williams, Thomas & Dower, established in Brentford in 1868. C Greville Williams left Perkin in order to set up the works in conjunction with Edouard Thomas. Both men were ex-students at the Royal College of Chemistry.[204] It was a small but active firm which recruited Otto Witt, PGW Typke and RE Alison from the College of Chemistry and Antonio Sansone from Zurich.[205] It was, along with Brooke, Simpson & Spiller, awarded a Gold Medal at the 1878 Exhibition: they were the only UK firms to be so recognized. In 1877 CG Williams retired from the firm, and it was reorganized as Williams Bros. and Thomas & Dower.[206]

A few other small firms such as Dan Dawson & Bros. also existed around this period. The atmosphere of this early period has already been described. UK activity was heavily derivative of the influence of Hofmann at the College of Chemistry, and involved a highly personalized set of relations. All of the firms just described operated in a broadly similar way, interchanging their small pool of chemists, suffering from the early retirement of apparently key personnel, and not undertaking the qualitative shift undergone by the German firms This situation had numerous causes. The synthetic dyestuff industry was far from typical in its knowledge demands, particularly the need for the organization and constant renewal of that knowledge. While the difficulties can be abstractly rendered as the supply of trained men, the reality was more complex. The earliest synthetic dyestuffs were produced more or less by chance, using combinations of known reagents. As the early stages passed the possibilities of this activity grew less, and the need for synthetic activity to be guided by theoretical speculation grew. Witt's theory of chromophores and auxochromes was perhaps a response to this challenge. Kekule's benzene structure also had an important role. The deployment of this type of knowledge over a wide range of substances grew increasingly demanding of personnel time and, more importantly, organization. Each new dyestuff and intermediary posed similar problems, leaving aside the demands of moving to commercial-scale production. Perkin's luck and his early focus on a single product had to be replaced by organization over an ever-widening area, in a notoriously volatile and dynamic market. It was not by coincidence that it was in this commercial context that organizational structures adapted to gathering and focusing knowledge over an expanding range of products (necessarily also scientific entities) were first constructed.

No UK dyestuff firm developed substantially in this direction before the First World War. The two firms which came closest, and which survived to form the basis of the post-war British dyestuff industry had comparatively little association with the Royal College of

Chemistry and the early personnel, but were located within the textile areas themselves. They were Read Holliday & Co., of Huddersfield, and Levinstein & Co., of Manchester.

Read Holliday & Co.

Read Holliday began as a coal-tar distiller in the 1830s, but moved into the sale of patented oil-burning lamps. He appears to have been a technical opportunist, and this was characteristic of the firm for many years.[207] His early recruitment of chemists was orientated towards more efficient distillation. After a visit to Paris gas works in 1850 Holliday recruited a French chemist named Potier to his Turnbridge works. He also retained CB Mansfield as a consultant on coal-tar distillation at about this time, precipitating the crisis in Mansfield's view of his scientific career previously referred to.[208] The firm expanded and operated a number of distillation plants during the 1850s throughout the north of England and in London. There is no other record of Holliday employing chemists during this period, though it may have been that Mansfield, an acknowledged leader in the field, gave the firm some technical edge. The shift in emphasis towards synthetic dyestuffs was a natural enough consequence of the firm's location in a textile district, and began with the production of aniline and related products for the embryonic industry.

Read Holliday had five sons. Of these, only the last, Robert Holliday (1855-1901) is known to have received a high-level scientific education, at Bonn University and the Royal College of Chemistry. However at least two others were also involved in technical activity and took out patents. None of the brothers joined the firm until their 20s. Thomas Holliday, the eldest, began at the works in 1860, at the age of 20, and his brother Charles joined in 1863 aged 21.[209] It was at this time that the firm began manufacturing dyestuffs, by exploiting patents. Litigation on questions of patent infringement followed during the 1860s, and the firm succeeded in breaking Medlock's arsenical patent for the production of magenta.[210] During the mid-1860s the firm began to patent its own dyestuffs, and to purchase and operate Continental processes.[211] There is no record of any attempt to recruit chemists. The firm also demonstrated its directly commercial instincts by opening a plant in the USA for the production of aniline and magenta in 1864.[212]

It is not until the late 1860s that Read Holliday is recorded as recruiting trained chemists, and these were Continental in origin. From this date a trickle of men was employed, apparently in a role combining research work with production. Albert Chatelaine, Alfred Wolf and a chemist called Scheitling were involved in the production of novel dyestuffs during the period from 1868 to 1880.[213] In addition many of the distillation works were sold. The firm concentrated this work in Wakefield, while the Turnbridge works increasingly focused on dyestuffs and other manufactured organic chemicals, working under the general direction of Robert and Thomas Holliday. The Continental chemists were supplemented by some men with a British training after a friendship between Robert Holliday and Raphael Meldola, which developed while the former was at the Royal School of Mines. Meldola and FW Streatfield were employed as consultants, and Gilbert Morgan was employed in the laboratory in the late 1880s. LG Paul (a Tubingen Ph.D.) was also employed at about this time.[214] It appears from Morgan's account of the activities at this period that the main function of the chemists was to test processes obtained or copied from other sources. The firm's general policy had been to purchase "processes which were hawked around by Continental chemists", with mixed results. It had copied AG Green's Primuline within a year of its discovery.

Continental recruitment continued on a small scale. Morgan indicates that the staff consisted of 2 Germans, 1 Swiss and 1 Austrian around 1890. These men can be identified as PRE Seidler and KB Elbel, Henry Bindschaedler and Josef Petraczek respectively. All were involved with production as well as research activity, but most took out patents in conjunction with the firm. In addition there were numbers of "assistants" who had received their training at the newly established Technical College. A few names have been recorded: the brothers Joseph and James Turner and Harry Dean, each of whom rose eventually to be described as Head Chemist, while the Continentals came and went.[215] Moreover it was one of these men, Joseph Turner, rather than the Continentals, who took over responsibility for the firm as the members of the Holliday family died. In 1890 the firm became a limited liability company. The Board of Directors consisted of Huddersfield men with no recorded technical connection with the firm.[216] As the brothers died the firm went into a commercial decline, and in the late 1890s it passed through near bankruptcy, but was saved by the manufacture of picric acid for the Boer War. A recruit to the firm from the Yorkshire College at about this time described its commercial operations around the turn of the century, particularly the claims of novelty made for common materials, as close to fraudulent.[217]

The firm's technical position was no better. Its Chairman was Joseph Turner, who had begun as a laboratory boy. Robert Holliday had turned his attention to acetylene production (via the Read Holliday Acetylene Co., thus continuing the opportunistic tradition of the family). It ceased to employ foreign chemists, and would not do so for some years. Its patenting activity was also declining.[218] The firm's recovery from this position appears to have begun with the recruitment to the Board of a third generation Holliday, LB Holliday, the son of Thomas. He had been educated at Bonn University and became Managing Director in 1901, shortly after his return to England.[219] However it was Joseph Turner who represented the firm before the Departmental Committee on Alcohol in 1905, and his somewhat incoherent evidence appeared to irritate the committee members. He stated that the firm had just recruited two foreign chemists, the first for five years.[220] It was also at about this time that Read Holliday began to recruit steadily from the Yorkshire College and other British institutions.[221] At the same time it began to increase its recruitment from the Technical College, and its apprentices were said to constitute "the backbone" of the College's Dyeing Department.[222] It appears that students of this type went into the laboratory or the dyehouse, rather than into production proper.

Read Holliday undertook no radical development of its organization during this period. By the beginning of the War the firm was better known for the production of general chemicals and organic intermediaries than dyestuffs themselves. It appears to have been selected as the basis of British Dyes Limited in 1915 more on the basis of its manufacturing potential than for any well developed research or scientific capacity which it possessed.[223] Cardwell has suggested that Read Holliday was the first UK firm to establish an industrial research laboratory, about 1890, though his evidence for this is not given.[224] In fact the firm appears little different from other UK firms of the period: certainly any activity which was begun in the 1890s was not maintained. During 1915, when Leeds University was negotiating a special relationship with Read Holliday, AG Green thought that Turner was "bitterly opposed to the introduction of men of science into the business, fearing lest their knowledge compared with his ignorance should lessen his authority...".[225] It needs to be recalled that Green was not the most disinterested of witnesses, since he would later become involved with Holliday's main competitor, Levinstein. Overall, it seems improbable that Read, Holliday was the first British firm to establish a formal research laboratory.

Levinstein & Co.

Ivan Levinstein came to the UK in 1865, after spending some time at Berlin University and the city's Technical High School, already in possession of a patent for an aldehyde green. He began manufacturing magenta in a private house (after the fashion of Dan Dawson) and eventually set up a partnership with some elder brothers. Production expanded in an ad hoc manner, to the extent that adjoining houses were purchased as required. There is no record of Levinstein employing any chemists before the 1870s, though it seems unlikely that he operated alone. His commitment to dyestuff manufacturing as such may be called into question, as he founded and edited the Chemical Review during the early 70s.[226] From about the time of his relinquishing the Review the first chemists are recorded, all recruited from Germany, and their appearance was accompanied by clashes with German dyestuff firms.[227]

By the early 1880s a considerable number of German chemists had been employed, and one of them, Rosicki, had taken over the role of works manager.[228] Little is known of their activity, and they took out few patents while at Levinsteins. Nevertheless, they undertook some research activity, and Klepl in particular is associated with Blackley Red. Levinstein later fought and lost a long patent action with BASF over this dyestuff.[229] By the mid-1880s some Germans had already moved on from the works, and this flow of Germans into and out of Levinstein's works at Blackley and later Crumpsall was to be characteristic of the firm. While the German firms developed relatively stable personnel and expanded into limited liability companies with formally organized research programmes and elaborate sales and service mechanisms, Levinstein & Co. remained a private partnership controlled more or less directly by Levinstein himself. Some of the chemists leaving the works remained in Manchester, and were eventually dubbed "Die Gesellschaft der ehemahligen Levinsteiner".[230]

The first batch of chemists all left during this decade. Rosicki was replaced as works manager by Leonhard Limpach, who had been a student of Wislencus and worked for Meister, Lucius & Bruning. During the late 1880s the expansion of the firm at Crumpsall put a considerable strain on Levinstein's capital, and in 1890 he reorganized it as a limited company. Two German firms, Agfa and Bayer, supplied a large part of the capital, and had effective control. Reader has discussed possible reasons for the this brief incursion by the Germans into Britain.[231] The two firms lent Levinstein a number of chemists during this period, and other personnel changes continued. Limpach resigned as works manager in 1892 and was replaced by one of the chemists from Agfa, J. Hirschberger. A number of other men, almost all of them German or Swiss, are recorded as passing through the works during the 1890s, but it is again not possible to gain any clear picture of their precise employment.[232]

In 1897 Levinstein gave a brief account of the works personnel to the Society of Chemical Industry.[233] There were, he said, 18 "head chemists", 12 "assistant chemists" and 15 "youths, apprentices etc." Of the chemists 8 were employed in research, though it is not likely that this meant as a full-time activity, and it was the vertical rather than the horizontal stratification which Levinstein stressed. The differing competencies in the organic and inorganic sector (and perhaps those of the chemical engineer) were also recognized, since Levinstein had retained George Davis, a consultant chemical engineer discussed in the following chapter, to construct the sulphuric acid plant, which produced 400 tons of acid per month. The works also had its own mechanical engineers under a Chief Engineer. Levinstein noted the absence of highly trained chemists in Britain, and referred to the "many hundred foreign chemists" employed in British works.

In common with some other firms, it was at the turn of the century that Levinstein began to switch to the recruitment of mainly British-trained men. From the late 1890s the firm recruited a number of chemists from the two Manchester institutions in which he had been active. Both the Technical College and Owens College supplied men, though those which can be detected attending the Technical School were mainly evening class students, and described themselves as apprentices. More will be said of these in a moment.

By the turn of the century Levinstein was recruiting men regularly from Owens College, apparently confining himself to those receiving Firsts in Chemistry.[234] There is no record of his employing men from other UK institutions, with the exception of Martin Feilman (later Fyleman) who had attended University College, Nottingham, but who had also subsequently studied in Switzerland as a Great Exhibition scholar.[235] A similar route was followed by Levinstein's own son Herbert, who took a First at Owens, after a secondary education at Rugby, and a Ph.D. at Zurich. Herbert Levinstein replaced Hirschberger as works manager about 1907 after a period of research and patenting activity under Mensching.[236] Herbert told the Departmental Committee on Alcohol in 1905 that the firm employed about 20 graduates.[237]

An impression of the situation at this time can be gained from two sources. EA Littlewood, an assistant chemist recruited from the Manchester Technical School, has left this account of the period from 1903:

> Until 1908 several research chemists came in rapid succession and their work seems to have been directed to "getting around" German patents. I remember Hoffa, Neef (Naef?), Maron and others. Their work was always kept a close secret from the works chemists and we assistants were told to give them no information about works processes.[238]

The situation was thus apparently little changed from earlier years. One of the "works chemists" was EH Bagnall (who held a First in Chemistry and an MSc from Victoria University after studying at Owens College), and there is an account of his activities as a result of his death in a works accident. This precipitated litigation on the question of whether or not he was a "workman" within the terms of the Workmen's Compensation Act (1897), under which his widow would have been entitled to compensation. Hirschberger told the court that Bagnall was required

> to turn on steam, and to put taps on for blowing over liquor which was in boxes. He was dressed like a common workman and wore clogs. He did no research whilst in the employment...He had to see that the daily manufacture was carried out. He took samples to the laboratory to test and see they were all right. His work was sometimes done by the foreman...For five-sixths of his time he was in the works, and for one-sixth in the laboratory...[239]

Bagnall's salary was £200 rising to £260 over 4 years, with a commission of 4% on any patentable improvements or inventions he originated. He was employed under a restrictive contract, which required him

> (n)ot to endeavour to obtain any information relating to any kind of the company's business which is not especially entrusted to him.

He had graduated BSc in 1897 and MSc in 1899, and moved directly to work for Levinstein. After three years he had taken over general responsibility for overseeing the manufacture of sulphur colours. It is not clear how he was employed during the three years before he moved on to the contract and activity just described. It can be surmised that he spent part of his time gaining familiarity with works-scale operations, and the remainder learning and carrying out the analytical activity for which he was still responsible at the time of his death.

It appears from Littlewood's account, which describes the situation at about 1905, that Bagnall was one of about seven men with responsibility for individual groups of dyestuffs. By this time all of this group of process controllers appear to have had an English (Manchester) education, except Hirschberger and Herbert Levinstein. Research activity at about this time was under the general charge of Ernest Naef. It thus seems possible that the majority of the graduates referred to by Herbert Levinstein in 1905 were employed for some of their time in research. If so the situation was not dissimilar to that described by his father in 1897, though with a slight expansion of research. The flow of chemists to which Littlewood referred came to an end about 1907, when Levinstein junior replaced Hirschberger. The Swiss chemist Max Wyler then took on some general responsibility for research. Wyler stayed with the firm and its successors, and described himself as "the last Continental chemist in the motley procession of tried and untried colleagues".[240] The combination of the younger Levinstein and Wyler appears to have stabilized the situation.

From this period the firm began to recruit more widely from British institutions. The London colleges, Cambridge, the Royal College of Science for Ireland and, especially, the colour chemistry department at Leeds University began to contribute men to the works.[241] The Leeds department changed in character at about this time. It had previously been under the control of JJ Hummel, whose background was in dyeing. With the appointment AG Green from the Clayton Aniline Co. in 1903 the name of the Chair was changed to include Tinctorial Chemistry, and the public emphasis shifted towards "the structure and characteristics of the dyes".[242] The change, coinciding with the increasing reponsibility and influence of Levinstein junior in the works, may have precipitated the flow of men from Leeds. In general chemists recruited from institutions of university standing earned about £120. They could hope for a move into process control, in charge of foremen under the works manager, and this was associated with a substantial increase in salary of the kind received by Bagnall.

Like Read Holliday the firm was also recruiting "assistant chemists" aged about 18 from local technical colleges, particularly Salford Royal Technical Institute and the Manchester Technical School. These men worked in the laboratories at salaries of about £70, and in some cases went on to attend evening classes. A number of students of this type are recorded in the registers of the Technical School about the turn of the century. The average age of men identified in this way was 19.[243] There is no later record of these individuals in connection with the firm. It is perhaps significant that two students of which there is such a record were full-time at the Technical School, and gained its Associateship or, later, the M.Sc. Tech of the Faculty of Technology of the University. They were Lionel Blumenthal (later

Blundell) who is listed by Littlewood among the technical staff, and Thomas Horner, who was a member of the first fully constituted research department.[244] Thomas Jones, a students whose status at the Technical School is unclear, went on to become the firm's Chief Colourist. Despite this there appears to have been a considerable amount of fluidity about the likely destination of the part-time men. A number of the apprentices can subsequently be found in more senior positions in other firms, and in the Institute of Chemistry, though in some cases they appear to have entered full time education at some intermediate stage.[245] Others such as Harry Hampson, who joined from the Salford institution in 1904 remained in relatively junior positions.[246] A rare record of four men beginning apprenticeships in 1914 is suggestive of a less fluid picture by this time, since none of these individuals reached more senior positions or joined the Institute of Chemistry. However the effect of the First World War must be borne in mind here.[247]

Though the firm undertook much research activity, this work was not fully separated from process operations until after the beginning of the First World War. At this time the firm recruited AG Green from the Leeds department, and placed him in charge of research, with a separately constituted staff of 13 men. Green was however at first only employed part-time, with the remainder of his time spent at the Manchester Municipal College of Technology. The new department was staffed by three men from Leeds, and one each from the Manchester College, the City and Guilds Central Technical College, the Royal College of Science for Ireland, Edinburgh University, one other London graduate and four of unknown origin.[248] Some were already employed by Levinstein, but others were recruited specifically for the department or very close to its establishment. The formation of the department was precipitated by the demands made by the war and by the perceived threat from the formation of the Government-funded British Dyes Ltd. (BDL) BDL took steps to expand research activity under WH Perkin jun. and MO Forster, though this was focused on research "colonies" at universities. It is striking that the embryonic research organization within Levinstein had not been formally institutionalized before the direct challenge emerged.[249]

The other dyestuff firms which existed around Manchester and elsewhere at this time reflected Read Holliday and Levinstein on an even smaller scale. They certainly undertook research and recruited chemically trained staff. Thus, for example, AG Green was employed at the Clayton Aniline Co. both as research chemist and works manager around the turn of the century.[250] The British Alizarine Co., essentially a specialized service company for the turkey red dyers and calico printers who dominated its board, has left a useful account of the distribution of the activities of its employees.[251] The substantial balance towards junior laboratory chemists acting in an analytical capacity seems to have reflected that at other dyestuff firms.

C. Explosives

So far as explosives are concerned, Miles has provided a fairly detailed account of the situation at Nobels.[252] The works at Ardeer in Ayrshire was founded in 1871. It was staffed originally by men recruited mainly for laboratory work: the manufacture was of course a comparatively novel one. Nobel relied on men he had trained himself for process management, notably Alarik Liedbeck and later George McRoberts.[253] In January 1877 the firm shifted to limited liability. From this time Nobel himself was less involved in day-to-day control. This meant that troubleshooting activity could not easily be referred to him, and investigatory laboratory and development work began to be undertaken independently. Further chemists were recruited in the late 1870s, as men like Kater, who had gained experience in the process itself and the handling of explosives, moved into management.[254] Nobel seems to have put relatively little reliance on men with a foreign background, though CO Lundholm was brought from Sweden to a managerial position in 1879.[255] Otherwise the men recruited had received their training at the Andersonian.

About 1880 chemists began working on research activity under the direction of a salaried management, and this may have been the earliest example of this situation in the UK. By 1888 a research department had been constituted independently under Joseph Sayers.[256] Sayers had been educated at the Andersonian (by then the Glasgow and West of Glasgow Technical College). This activity was however small-scale: Miles suggests that a maximum of three trained men were involved in research (of a technical kind) and nine on analytical activity and direct process control about 1888. The former two departments were fused in 1894. The association between the firm and the Andersonian was a long-term one. A notebook of GG Henderson, Professor of Chemistry at the Andersonian, shows a steady stream of men moving from the college to Nobels during the period from the early 1890s. The college's Calendar for 1892-3 shows six men being recruited to Ardeer in that year alone.[257]

This resulted in a steady numerical expansion of the chemical staff at the works, and by 1909 it employed 35 chemists.[258] During the intervening period research had been undertaken in an atmosphere of secrecy, with individually allocated activity being preferred to a corporate research programme. In 1909 the organization was restructured under William Rintoul into something resembling a modern system, including a library and information service under GH Beckett.[259] This process was taken further in 1914, when three equal managerial positions in relation to process, research and commercial activity were created. It is particularly significant for this study that Rintoul restructured recruitment policy. Men were no longer recruited from the Andersonian, and a policy of employing graduates on a 'track' leading to more senior positions was inaugurated. These men were inducted into the works or research by an initial period in the analytical laboratory. Servicing this group were larger numbers of students employed as assistant chemists, recruited in the first instance from the higher grade schools, but later from the Glasgow Technical College. Eventually the latter group came to be associated with training for the National Certificate.[260]

D. Conclusion

In this final section the main themes within the previous accounts of specific firms will be drawn together. It can be noted first that the recruitment of chemically trained men into firms was a commonplace from the mid-1860s onwards, and that the works chemist was well established as an occupational category in public discussion of the chemical industry by 1880. However, then and in the subsequent period, the use of the term was fluid. It encompassed both Ferdinand Hurter on £1500 a year in a purpose-built research laboratory, and the "greenhorn" described by George Davis in 1887.[261]

As has been implied, the distinction between the "works chemists", narrowly understood, and men in charge of industrial processes proper, has an important place in an account of the situation of academically trained men in chemical works. When introducing systematic practical education in chemistry at the mid-century Hofmann had presented the analysis of materials as the major mechanism by which chemistry could influence manufacturing industry.[262] This apparently unremarkable activity continued to be represented as a key innovation so far as the "application of science" was concerned for a number of decades. In fact, as was indicated in chapter 2, it had a long history. Nevertheless the analytical laboratory constituted a key institutional space in the late nineteenth century and beyond for the trained chemist wishing to obtain work in industry.[263]

During the 1870s it was normal for alkali works of any scale to employ at least one chemist, and often more than one. MacLeod has noted the influence of the Alkali Acts of 1863 and 1874 in this respect, but there is no direct evidence that this intervention had a crucial role.[264] Textbooks on the alkali industry, and the heavy chemical industry generally, include as their main "scientific" content analytical information and the key points at which to obtain and deploy it. It was here that the chemical formulae and equations which studded such books gained operational significance. On the evidence of such contemporary accounts quantitative analysis was employed to maintain knowledge of the increasingly large scale internal and external chemical transactions occurring at works.[265] Occasionally it was also used as an "objective" criterion for payment of manual workers.[266] An analyst of no experience of the works processes could be employed to undertake this activity. However analytical standards among both consultants and employees were often a matter of doubt or public controversy. The Gaskell-Deacon works used consultants to check its own chemists' results.[267]

In chapter 3 it was observed that the scientific knowledge defined by academic practice was largely represented as a 'cognitive' insertion within the traditional forms of the industrial hierarchy, with the highest place reserved for the scientifically-trained entrepreneur. Yet the usual situation for a trained men (unless he had a family connection) at that time was in fact as an employee, initially with a limited functional specialization. Hofmann had represented analytical activity as a tool in the hands of entrepreneurs and principals. These groups, however, made use of the tool on their own terms. The differentiation between process management and servicing analytical chemistry can be seen as the first element of the complex stratification and functional specialization which accompanied the integration of academe and industry. It was manifested whenever chemical knowledge was introduced into works. Moreover the routine analyst was in a position of low status and salary, and little authority.

While this attenuated role for trained men found few echoes in the language of the apologists for scientific and technical education, entrepreneurs quickly demonstrated the unreality of any notion of chemical knowledge available for deployment in a 'neutral' way. As the available knowledge was appropriated by firms, an alternative version of what it was to be a chemical practitioner was constructed. Though this involved an alteration in the personnel structure of the chemical firm itself, this shift was limited. After the early emergence of the analytical chemist, further change was slow.

The most obvious route for expanding routine activity was into what can be loosely described as laboratory research. It was observed earlier that in 1877 Ludwig Mond contemplated expanding the work of his future assistant in this direction. However Mond, with his emphasis on independently constituted if technically orientated research, cannot be considered typical. The same applies to Muspratt's. It was seen earlier that a few analysts in works were publishing accounts of processes from an early stage, focusing on the details which could be gleaned by the laboratory analysis of samples or even the laboratory replication of processes. Some chemists could find themselves deployed in more radical innovative research and development work, either in processes with an important role in improving the Leblanc cycle, such as chlorine and sulphur recovery, or in relation to the various chemicals produced on a small scale in most works. The methodology and organization of development in these areas was not in essence different from that in earlier decades. though the initial impetus could come from novel chemical reactions or reagents.[268] Analytical data could offer little in the way of theoretical insight into the dynamics and controlling characteristics of even laboratory chemical processes. Problems of scale ensured still greater difficulties at the commercial level. Overall the relationship of the chemist and the academically-derived knowledge he wielded to industrial practice (in a wide sense, that is to say, including its organizational and class aspects) was full of tensions and ambivalences.

Research was not recognized as a functional specialism for many years. In the cases referred to above (n.268) the men involved in innovative activity were also active in everyday process management. The chemist, narrowly understood, was distanced from the process as such. For such men the most likely route to advancement was not into laboratory 'research' in any formal sense, but rather into direct process control and works management. In 1874 John Morrison, referring to the chemical works manager, told the Newcastle Chemical Society:[269]

> Most of us are of laboratory descent—men who, with a strong love to the calling of our choice, have early yielded to the discovery that we could never look to analytical chemistry other than as a sort of pis-aller — a kind of out-at-elbows trade -- forming simply a stepping-stone to an indefinite something better. That at first undefined something, however, speedily resolved itself into a managership, and a managership, therefore, became henceforth the summit of our most ardent hopes.

The trajectory which Morrison was describing constituted the major concrete aspiration of trained men as represented in the routes observed in this chapter. The stability of this situation in the nineteenth century is indicated by comments made by Georg Lunge in 1897, though there are some differences in emphasis.[270] For Morrison, in the earlier part of the period, it was possible for the chemist to look towards a full managership or even a partner- or directorship as his ultimate aim. Lunge's comments suggest that the chemist at the turn of the century could only look towards managing "some part of the process itself". Reviewing the situation in 1910, The Times Engineering Supplement remarked that[271]

> While it must be admitted that in the United Kingdom there are a large number (sic) of persons occupying useful and responsible positions who have received a proper training in chemistry, it frequently happens that they are not recognized as chemists, but occupy managing positions or are looked upon as engineers.

Acknowledgement of the low status and rewards of analytical chemists, though involving a distinction between such men and manual workers, began at an early stage. The character of their work was recognized as being highly constrained, based on routine and repetitive analysis of unchanging materials. In 1866 William Crookes' Chemical News printed a spoof advertisement for an analytical chemist required "occasionally to wait at table", and had to reassure outraged readers that it was an attempt to highlight the poor situation of chemists.[272] The flow of complaints about that situation increased steadily over the years. By 1914 it was described as being "a little less than a typist".[273] Though the standard of menial activity had changed, the message remained the same. The chemist was said to be "treated as a mere analytical machine", and his work to be suitable for "poor relations and younger sons".[274] The former remark was made by JH Davidson in 1881, but a further comment made in the same piece ("The chemical technologist--or, as he is commonly called, the works chemist...") is indicative also of the important tension which surrounded this occupational category.

Academics had some part in this decline, at least in its public formulation. While, for Hofmann, analysis had been a key chemical tool, by the late nineteenth century analytical activity was commonly represented as the merest veneer of scientific competence. In 1892 Alexander Crum Brown could distinguish in his Presidential Address to the Chemical Society between "routine work" such as "analysing", and "research".[275] In 1900 the American CF Chandler, in his Presidential Address to the Society of Chemical Industry, was warning of the danger that "purely chemical studies" could qualify the student only for analytical work in the laboratory.[276] By 1910 it could be said that "under the name of chemist enough rubbish has been supplied to (the chemical manufacturer) to break down his faith in the panacea. Twenty years ago...the English schools turned out only analytical machines."[277] To some extent the shifts in academics' views may have been due to their following industrial opinion, or refashioning their ideas in the light of technical conditions. There were comments about manufacturers having unreal expectations of chemists and communicating their disappointment but it is difficult to unearth many concrete examples.[278] It seems likely that as important to the shifting academic view was the changing institutional basis of educational activity. As practical chemical instruction became more widely available the characteristics of chemical competence were redefined so as to differentiate institutions. This was discussed in chapter 4.

There were certainly examples of trained men partially specialized in process management, in research and development and in analytical work by the turn of the century in certain firms across the full range of the chemical industry. However most of this activity was embedded in a hierarchy which still led into process and works management. The dichotomy between process control and analysis which was established so quickly remained recognizable well into the twentieth century. In 1927 the analytical laboratory was still seen as a major starting point for university chemists in industry.[279]

By the early twentieth century control of works involved the deployment and integration of larger and more diverse bodies of personnel, but formal bureaucracies, if they existed, have left few traces. The clearest potential example occurs in the case of the United Alkali Co., but even here detailed evidence does not exist. The initial thrust of the activity was directed less towards constructing an instrumentally efficient management, than to managing the decline of and balancing the interests within, a diverse and ramshackle empire. A strategy of placing academically-trained men into works positions was operated through the Central Laboratory, which acted as a clearing house. However this activity appears to have been ineffective in the over-diversified and often outdated technical operations of the Company.

The situation at Brunner, Mond was in some ways the reverse of that at the United Alkali Co. Formal specialization is less visible (which is not say that it did not exist) and the firm had no structural and few commercial problems. Activity was bent towards maximum technical efficiency. While the firm did not possess the high profile of formally-independent research activity represented by the Central Laboratory there is every indication that technical and scientific problems were addressed effectively in an ad hoc way. Unlike that at the United Alkali Co. the key process at Brunner, Mond was under little competitive pressure, and operated within a substantial (if still theoretically undeveloped) knowledge base, so that the relatively clumsy 'bolted on' Central Laboratory mechanism was not employed for problems of a technical kind. Such evidence as is available suggests that the analytical laboratories acted as a kind of clearing house for trained men, but that delocalized development work was the main emphasis. Research of a more fundamental kind, begun under Mond himself, lapsed on his withdrawal, but the relatively uncontrolled regime operated within the analytical laboratory appears to have allowed Freeth's phase rule studies to emerge painlessly, if somewhat fortuitously, and they were quickly exploited. Nevertheless, the "laboratory" (even the embryonic research laboratory) and the "works" occupied different levels, as reflected in Freeth's experience. His willingness to remain in the laboratory and his fortuitous field of expertise seems to have contributed significantly to the growth of an independent, specialist research function within the firm, in the years before the First World War, some 20 years after the United Alkali Co. The differences between Brunner, Mond and the United Alkali Co. indicate the different outcomes which commitment to a knowledge-based system could have under differing technical and historical conditions.

Nobel followed a slightly different trajectory. Here the remoteness of the firm from its main technical initiator appears to have encouraged the formation of functional divisions in the salaried staff quite early. However, the establishment of a stable and formally-recognized research department was postponed for many years, so that around the turn of the century the firm occupied a state somewhat similar to Brunner, Mond, with differentiation on an ad hoc basis. Like Brunner, Mond this appears to have been sufficient to maintain Nobel's technical edge over its competitors. Again like Brunner, Mond and the United Alkali Co, the analytical laboratory acted as a clearing house for chemists in the works proper.

The organics firms exhibited some of the characteristics just referred to, but in forms again modified by their technical and economic situation and their size. 'Research' found a place more readily and constituted a greater proportion of the activity undertaken by trained men. Little of this appears to have been separate from the organization of production proper, and few if any men spent their whole time on it. A more common model seems to have been that individuals of relatively senior standing and with some management function 'followed through' a new process from its initiation (which may have been the need to imitate a competitor) to production. The manufacture of many different products and their intermediates demanded a fairly complex subdivision of activity, though the organization of of this was achieved by one or two individuals rather than by an administrative structure. As with the heavy chemical firms the supervision of analytical work and quality control occupied some of the time of process controllers. The examination of the dyeing characteristics of products led to a further important location for laboratory-based activity in the organic dyestuffs field, and trained men found employment in the dyehouse.

Overall, it seems that the development of the organizational mechanisms and functional specialization by which the control and development of industrial processes came to be focused on academically-trained men was sensitive to context. The same judgement must also be made of the influence of the major shift in financial organization which accompanied the process: that from private firms to limited liability companies. By the First World War most of the significant British chemical firms were of the latter type. The impact of the shift was by no means uniform. So far as firms like Brunner, Mond and Levinstein were concerned, with forceful and technically active founding partners, the movement to limited liability may have allowed capital expansion and thus some recruitment, but the shifts towards a salaried management had to await the withdrawal of the founder. At the United Alkali Company financial reorganization was contemporaneous with other forms of integration. While new technical and scientific structures certainly accompanied the changes, they and the limited liability framework were equally a consequence of the attempt to integrate many firms. At Nobel's there is some evidence that the early shift to limited liability and the presence of salaried managers accelerated the growth of more differentiated technical and scientific activity, including research. However this effect cannot be separated from the firm's special circumstances, notably geographical remoteness and decentralization, in relation to its founder. Overall, contemporaries tended to present the shift to limited liability and salaried senior management as threat to technical innovation in terms of individuals' responsibilties. References to the wider organizational or financial concomitants of the new industrial form were rare.[280] In a rare example FM Perkin, speaking from the perspective of synthetic dyestuffs, highlighted the financial impact, and contrasted the German firms' access to finance capital for research and development with that of their UK competitors.[281]

Aspects of these changes to which little attention has so far been devoted are the tensions of authority and 'class' which stemmed from the fact that 'chemists' were almost always employees. There is evidence of a collective consciousness among chemists from the early 1870s onwards. The Tyne Social Chemical Society was established in 1870 for "chemists and managers".[282] It reasserted this in 1872, responding to a proposal that it form the nucleus of a general society orientated towards chemical industry with the remark that it was "a society of managers and chemists only, and not for manufacturers".[283] Accounts of early attempts to establish such societies in south Lancashire in the mid-1870s suggest that there was hostility between employees and owners both in relation to an attempted society in St. Helen's and to the Faraday Club, the latter based initially at Widnes and St. Helen's.[284] George Davis was compelled by his employer David Gamble to confirm that the "secret society" was "a combination of chemists having no interest but their own profession, and (which) had no adversaries...".[285] The preliminary meetings in Widnes during 1879 which led eventually to the formation of the Society of Chemical Industry attracted about sixty individuals, most of them apparently salaried chemists and managers. However, this activity now appears to have bridged the gap between owners and employees.[286] Indeed there is a suggestion in an account by John Hargreaves of hostility in the reverse direction. In attending a meeting of the new society (which was chaired by James L. Muspratt) George Davis intended to "smash it up" for reasons which are obscure.[287] The disappearance from view and eventual relaunch of the Society as a national organization by a collection of academics and entrepreneurs confirmed the successful redirection of the efforts at collectivity among employees along narrowly technical lines.

The Society of Chemical Industry cannot be thought of as a professional body for industrial chemists. The obvious candidate for this position, the Institute of Chemistry, was itself very young, and dominated by conflicts between academics and consultant analysts. Industrial chemists appear to have wielded little power within it. This may have been because many had no formal qualification, but it is also likely that it reflected distinctions in resources and status. Moreover those works chemists who succeeded in making the shift into management were occupied in activity to which the Institute, with its perennial concern about analytical standards, was only peripherally relevant. Those who made the other available shift, into analytical consultancy, occupied a very different sphere, modelled rather on the independent "collegiate" professions, in which framework the Institute operated.[288] The issue of the organization of industrial chemists did not surface again until just before the First World War.

Industrial chemists were in a weak position in relation to their employers. Most aspired to positions within the traditional authority structure of the firm. The reconstruction of older technical and authority relations into a more complex network, which could have provided alternative routes to promotion within firms, occurred uncertainly, and was constantly being assimilated into the, essentially one-dimensional, hierarchy of decision-making authority.

The most complex form of physical technology was at Brunner, Mond, where the works operated, in Mond's words, as "a single unit", rather than in the organic firms. The attempts to control the physico-chemical and engineering aspects of Mond's "single unit" called into existence a diverse body of trained staff. However, at Brunner, Mond the works was not organized to put the process into the control of an impersonal structure of technical employees. Over-riding financial and commercial imperatives continued to be transmitted directly and personally. The early utilization of chemical knowledge as routine analysis was slowly developed, and joined with other knowledges, but largely within this framework.

It is appropriate to recall here, from chapter 3, the increasing use around the turn of the century of a language in which "organization" began to be represented as the key to the control and development of the production process and of innovation. In 1896 Georg Lunge put it in a crude, intermediate form when he remarked of the German firms that[289]

> (a)t their colossal works they need specialists for each branch, and they cannot do without a staff of fully trained engineers, so that their chemists are not called upon to do any but strictly chemical work. Some owners of works may not even like their chemists to get too much insight into the practical and mechanical part of the manufacturing operations, for reasons which need not be dwelt upon here.

WH Nichols, the American President of the Society of Chemical Industry, gave an account of works organization in 1905 which indicates a thrust towards functional specialization within a more overtly 'neutral' framework.[290] The notion that technical and scientific knowledge was merely the subject matter on which a higher level organizational and financial understanding would operate began to be common.[291] It became explicitly acknowledged that it was not merely analytical work which could be routinized. Most scientifically trained men could be "sappers working intelligently, but under orders", by which mechanism it would be possible to "make the most of mediocre ability".[292] The metaphor of the industrial army came regularly into play.

If the position of trained men developed within a fine balance between formal and informal structures, functional specialization and simpler decision-making hierarchies, that of the manual workforce was clearer. In general the industry required relatively little skill of its workforce. Even the skills deployed in the saltcake and black ash furnaces were generally acknowledged to be closer to strength and endurance than authentic psycho-motor skills. The thrust within these oldest components of the Leblanc cycle was to replace manual with mechanical action, and to concentrate control within furnace operators.

It was a commonplace of the time that chemical workers needed mainly to follow instructions.[293] This was easily transformed into a commentary on their educational needs, despite the gloss about the need for an 'intelligent workforce'. Within the Leblanc sector the relevance of educational activity was particularly problematic, since the key processes were so unpleasant as to be physiologically destructive, particularly in terms of exposure to corrosive gases. Physical involvement with them was an unlikely occupation for anyone with significant educational aspirations.[294]

This situation is reflected in the fact that there are few examples within the chemical industry proper of manual workers reaching positions beyond fairly low level foremen, and in the very limited contribution of workmen to innovation, observed by Muspratt and others. Throughout the industry the movement was towards making foremen themselves receptacles and transmitters of instructions rather than allocating them an active role in decision making or development.[295] In some cases foremen had not passed through the process stage at all at a manual level, but had come via laboratories. The situation can also be related to the absence of evidence of conflict over the control of chemical processes in the works itself. There is a literature of such conflicts within the engineering industries.[296] There are some indications of operative-based conflicts within the chemical industry, but they appear to have been easily won by owners of works. Few locations existed within the industry where craft-based skills could be defended.[297] John Glover summarized the approach to one such area in steel manufacture, and its connection with the role of science, when he argued in the 1870s that the use of a spectroscope would[298]

> make the difference between conducting a process on an empirical or on a scientific basis; they now trusted to the acquired skill of a workman; if they could introduce an instrument which would give scientific accuracy to the progress or completion of the processes, it would make all the difference between empiricism and science.

The impetus of the chemical industry was towards processes which could be controlled within a framework of knowledge and practice accessible only outside the constraints of craft-based technology and manual skill. At a strategic level, shifts towards the type of intractable operations most clearly represented by the furnacing within the Leblanc industry were avoided. New processes which could be conceived, developed and directly monitored using laboratory activity were explored. Even within the core of the Leblanc industry, in the manufacture of saltcake, more radical shifts than mere mechanical furnacing were developed, as in the Hargreaves process, where sulphur dioxide and steam were reacted directly with common salt.[299]

Within the chemical industry many innovations were generally qualitative in character--new substances or reactions conceived entirely within the material substrates of the laboratory, based around techniques which required independent and explicit preplanning, controlled and monitored by laboratory analytical work and quantifiable communicable characteristics. Indeed this communicability in standardized terms contributed to the ease with which quite novel chemical operations could be transferred from plant to plant, both with the approval of operators (as in the centralized operational knowledge of the Solvay industry) and without. While the laboratory might give little predictive control over chemical processes, or guidance in the problems of scaling-up, ontologically the industry was striving to be a projection of the laboratory. Everyday categories, or those of manual skill, had little purchase on such operations.

In a study such as this it is not possible to assess the impact of recruitment and organization of trained men on firms' economic performance. It can be remarked however that any such effects were focused on the organic sector, and this may have led to their exaggeration. In a paper published in 1896 Carl Duisberg stated that 83 German chemical firms employed 448 "College matriculated" chemists (426 with doctorates).[300] Of these, 227 were in 23 organics works. By contrast, in heavy chemicals there were 57 men in 13 works, an average of just over four men per firm. It is not appropriate to amalgamate the diverse body of data which has been used as the basis of the present study to produce comparable figures, because of the time scale they cover, and because there is no way of deciding their statistical representativeness. However, for the heavy chemical industry, the situation in Britain appears not so dramatically different, quantitatively at least, from that presented by Duisberg in Germany. In addition it appears that, while the picture is a complex one, in economic terms the UK heavy chemical industry did not undergo the dramatic relative decline of its organic equivalent.[301]

Turning from a focus within firms towards their institutional relations with the educational system, it can be noted that by the early twentieth century a substantial educational structure was in place in the UK. Some part of this issue has been addressed in chapter 4. The framework of industrial employment into which institutions fed was determined by the circumstances of individual firms and sectors in ways relatively unconstrained by the men involved, by the manual workforce, or by academics or other interest groups. The technical education movement is well-known to have been treated with suspicion by organized labour, which frequently viewed it as a mechanism for placing the control of recruitment and training in the hands of employers.[302] However workers in the chemical industry possessed relatively little power or organization. By the turn of the century the firms discussed here recruited men both from university-level institutions and technical colleges. The earlier flexibility with which the universities had trained men to varying standards was replaced by an increasing differentiation. The expanding technical colleges became, in the chemical sector, orientated towards supplying the lower level analytical personnel which had been defined both within the educational and the industrial sectors.

Men working at lower levels in the industry tend to be historically invisible. The few individuals identified in this study who had attended technical colleges in chemistry-related fields entered works via laboratories. As has been seen the chemical industry provided few locations in manufacturing operations proper for the type of manual skill combined with technical-scientific knowledge associated with mechanical engineering. A study by the Association of Technical Institutions in 1905 indicated an absence of co-operation between employers and technical colleges, compared with the 'mechanical' industries, in the training of chemical workers. Such co-operation was identified in the chemical sector at only one institution (St. Helen's), and there it existed for the purpose of training analytical chemists.[303] This was despite the fact that almost all technical colleges offered chemically-orientated courses, and that the

Association's general survey of courses found them to be second in popularity only to those in engineering.[304] In practice firms like Brunner, Mond and the United Alkali Co. did compel their apprentices to attend technical colleges. It can be surmised that this involved technical training in such fields as engineering joinery and plumbing, and that their chemical apprentices joined the mainstream chemical courses. In most of the firms referred to in this study the clearest differentiation to emerge was not functional but that between Alfred Mond's "evening class student" and the "university man".

It was seen above that Hurter in the late 1890s presented routine analytical work as suitable only for men who had taken DSA examinations, while WH Perkin junior classified it as suitable for men trained by apprenticeship.[305] In 1901 a more complex account of the possibilities was given by AG Green, then acting as works manager and research chemist to the Clayton Aniline Co.:[306]

> The general public, owners of works, members of Technical Instruction Committees are apt to...believe that it is possible to produce an "alkali chemist" and "iron works chemist" or a "dyer's chemist" of a man who has not been trained in pure chemistry, but has studied solely the application of the science to his particular industry. Men of such training may be useful as superior foremen or "testers", but ought in no way to be considered as "chemists".

"The application of the science to his particular industry" is ambiguous, but the reference to "testers" suggests that Green was referring to a training in the relevant analytical field, perhaps combined with descriptions of the relevant industrial processes. Men with a technical education background were to be trained for specific sectors and for highly directed activity "the backbone, if not the head, of industrial chemistry" as one commentator put it.[307]

Around the turn of the century recruitment from British higher-level institutions by the firms studied here increased. This coincided with the departure of German chemists and a sharpening of the university/technical college distinction, as the early civic universities received their charters and London was reorganized as a teaching university. A parallel distinction in the works can be perceived, and would eventually become very sharp, but it was not clear-cut for some years. At Levinstein's Bagnall's work was sometimes undertaken by a foreman. Men were employed in the same laboratory, undertaking essentially similar work and the routes they followed are difficult to separate. The Institute of Chemistry lists of the early 1920s indicate that individuals who had come through the technical colleges (at least the higher level institutions such as that at Manchester) did achieve the move into process management. This may have been aided by an increased fluidity during the War.[308] By the close of the First World War the institutional conflicts among 'chemists' themselves which were manifested in the relations between the Institute of Chemistry, the British Association of Chemists and the National Association of Industrial Chemists reflect an increasing recognition of the force of these educational and works divisions. It will be argued later that they also influenced the Institution of Chemical Engineers.

So far as a cognitively-based industrial relevance was concerned the claims offered for university men were rhetorical rather than instrumental. The question of what could be added to JB Cohen's "one year of qualitative and one year of quantitative and volumetric analysis" remained a largely open question. The difficulties encountered with chemical technology have already been described. Moreover this field represented a threat to the mainstream discipline, and was associated with technical education. The apologists for higher level training during the late ninteenth century confined themselves mainly to emphasizing the need for experience in "research". However, in practice, few men from the universities could claim such experience. By the early twentieth century Donnan and others were making a bid from within mainstream academic chemistry for the industrial relevance of physical chemistry, which had been attracting young Britons to the laboratories of Van 't Hoff, Ostwald and Nernst.[309]

Overall, then, firms drew on and assimilated men from the education system in ways which continued to be influenced by their specific technical, historical and institutional circumstances. Though increasingly sharp divisions between educational institutions were reflected in firms, they were by no means clearly separate in terms of the occupational trajectories to which they led. It remained possible though increasingly rare for a Joseph Turner to reach a senior position even in a technically-advanced industry.

Within this complex of changes, one which will be taken up here is the tension increasingly observed between chemists and another industrial and potentially academic grouping: the engineers. In the 1870s the analyst was contrasted with the manager or even the owner of the firm.[310] By the 1890s this tension was often replaced by that with the engineer. In 1896 JT Dunn imposed it retrospectively on Tyneside ("The manager of a works was as a rule not a chemist at all, but an engineer."[311]) At the turn of the century Lunge was expressing the needs of the chemist aspiring to process management in terms of engineering knowledge, and FG Donnan in 1917 represented the chemist as "a humble 'tester' (so-called analyst) and general hanger-on to the coat-tails of the engineer-manager".[312] What had previously been formulated as a tension explicitly based on the authority structure of the works could now be expressed in terms of competing cognitive and technical competence. The engineer was not generally accused of being an ignorant empiricist and deployer of the "rule of thumb", at least not in public. He was merely a practitioner in an alternative field who constituted a competitor. Moreover he too was an employee, and one whose field was gaining independent recognition at the highest academic level.[313]

On the terrain of the chemical industry the major forms of competence available were those of the chemist and the civil and mechanical engineer. Each of these had _prima facie_ legitimate locations within the works: the chemist in his analytical laboratory and the engineers in the construction of novel and temporary structures and the operation of machinery for the transmission of power respectively.[314] Eventually it would be argued that the central novel technical domain which needed to be addressed within the works, chemical process engineering, bore only a limited relationship to any of these independent domains. During the latter part of the period under consideration here one of the key arguments in the technical and educational arena involved precisely the identification and appropriation of the region known as "chemical engineering". This argument, and the institutional shifts underpinning it, is the subject of the following chapter.

Notes to Chapter 6

1 Russell et al. have given some attention to the limitations of earlier Census Returns in this respect. Russell et al., op. cit. (1977), pp.29-30.

2 Weldon, "On the Present Condition of the Soda Industry" JSCI (1883) ii, pp.2-12. Haber, op.cit. (1958), p.59. Hardie, op.cit. (1950), p.160.

3 Gillispie, op.cit. (1957). The crucial step in the process was that of furnacing limestone, coal and "saltcake", to produce the black ash "balls", which were subsequently extracted with water. No general technical or economic history of the industry will be attempted here, though some of the implications of the physical techniques involved will be discussed. For modern general accounts see K. Warren, Chemical Foundations: The Alkali Industry in Britain to 1926 (1980), Haber, op. cit. (1958), Reader, op. cit. (1970). For detailed contemporary (late nineteenth century) accounts of the manipulations involved see J. Lomas, A Manual of the Alkali Trade Including the Manufacture of Sulphuric Acid, Sulphate of Soda and Bleaching Powder (2nd. edn 1886) and Georg Lunge, A Theoretical and Practical Treatise on the Manufacture of Sulphuric Acid and Alkali, with Collateral Branches 3 vol. (1879-80). See also C. Kingzett, The History, Products, and Processes of the Alkali Trade, Including the Most Recent Improvements (1877). How little this had altered over the mid-century can be judged by comparison with Penny Magazine, op.cit. (1844).

4 Warren, op. cit. (1980), chapter 11.

5 First Report of the Commissioners Appointed in 1868 to Inquire into the Best Means of Preventing Pollution of Rivers (Ribble and Mersey Basins) PP 1870, xl, pp.131-40.

6 On Gaskell (1813-1909) see CTJ xl (1909), p.264. On Deacon (1822-76) see Allen, op. cit. (1906), pp.153-98. It is not clear whether the firm for which Deacon worked was the same as that of Charles J Galloway which had connections with Brunner, Mond and the Bessemer process. If so then Deacon's connection with the chemical industry becomes clearer. CCRO BM7/7. C. Erickson, British Industrialists, Steel and Hosiery 1850-1950 (1959), p.143.

7 Allen op. cit. (1906), p.175. On Robinson (1814-1901) see CTJ xxviii (1901), p.536.

8 For an account of this process see Lunge, op. cit. (1880), vol.ii, chapter 7.

9 H. Deacon, 'On a New Method of Obtaining Chlorine (without Manganese)', CN xii (1870), pp.157-60. Idem., 'On Deacon's Method of Obtaining Chlorine; as Illustrating some Principles of Chemical Dynamics', JCS x (1872), pp.725-67; Lunge (1880) ii, 250-1. Deacon's process had greater initial technical difficulty than its main competitor, that of Weldon, due to catalyst poisoning, but was modified to the Deacon-Hasenclever process later in the century. JSCI xvi (1897), pp.869-70. R. Dickinson, 'Early Documents Relating to the Deacon Chlorine Process' (Internal ICI mimeo, 1965), CCRO, DIC/X7. On R. Hasenclever (1842-1902) see JSCI xxi (1902), pp.1124-5.

10 On Carey (1835-1915) see JSCI xxxiv (1915), p.261. He had been employed from 1857. On Hurter (1844-98) see JSCI xvi (1898), pp.406-11 and Hardie op. cit. (1950), chapter 10. On Jekyll (d.1872) see ibid., pp.99 and 227, and CN xxi (1870), p.221. After Jekyll's death he was

replaced by a "Mr. Rocholl" of whom no more is known. Deacon, op. cit. (1872), p.759. On Driffield see Royal Photographic Society, A Memorial Volume Containing an Account of the Photographic Researches of Ferdinand Hurter and Vero Charles Driffield (1920).

11 CCRO, DCI.

12 CCRO, DCI/BM7/15/3. Hurter to Mond, 20 November 1877. Ridd had not been given a fair opportunity at Gaskell, Deacon because he was not a "pet of Carey's".

13 On Henry Wade Deacon (1853-1932) see Who Was Who. 1929-1940.

14 On Holbrook Gaskell II (1846-1919) see Hardie, op. cit. (1950), p.42 and CA i (1919), p.96.

15 DIC/UA9/1/1-4. They begin on 8 May 1871, but Hurter had been employed from 1867.

16 G. Lunge, 'Hurter Memorial Lecture: Impending Changes in the General Development of Industry, and Particularly in the Alkali Industry', JSCI xviii (1899), pp.892-901 (893). See for example F. Hurter, 'Dynamic Theory of the Manufacture of Sulphuric Acid', JSCI i (1882), pp.8-12, 49-53, 83-5.

17 AW Tangye, quoted in a letter from DWF Hardie to AS Irvine, CCRO/DIC/X7, Tangye file.

18 Hardie, op. cit. (1890), pp.181-4, 189-90. Reader, op. cit. (1970), p.119. CF Cross and EJ Bevan, 'On the Electrolytic Production of Chlorine and Soda', JSCI xi (1892), pp.963-4. F. Hurter, 'Notes on the Efficiency of Electrolytic Apparatus' JSCI xiv (1895), pp.428-33. Earlier Hurter had used arguments based on chemical affinities to 'prove' the viability of the Leblanc industry because of its role in the production in chlorine: "As far as reasoning from scientific principles will permit us to judge, there appears to be no great probability that any enormous revolution will endanger the present plant." Idem., 'Prospects of the Manufacture of Chlorine', JSCI ii (1883), pp.103-8 (107).

19 On James Muspratt (1793-1885) see Allen, op. cit. (1906), pp.70-100 and JSCI v (1886), pp.314-6.

20 Richard Muspratt (1822-1885) managed the Flint works (DCI), Frederick (1825-72) managed that at Widnes for a time (JCS xxvi (1872), p.780), Edmund (1840-1923) was active in the Widnes works (EK Muspratt, op. cit. (1917)). According to Edmund, James Sheridan "proved himself incompetent to carry on business" and found employment as a teacher and author. JCS xxiv (1871), pp.314-6.

21 Danson also worked with JS Muspratt. J.S. Muspratt, 'On Carmufellic Acid', Philosophical Magazine ii (1851), pp.293-7.

22 On Young see chapter 4. On Hart (d.1866) see the obituary of P. Hart JSCI xvi (1897), p.521.

23 On Murphy (1829-77) see JCS xxxiii (1878), p.232. See also JS Muspratt, op. cit. (1860), i. preface and ii. p.925.

24 E.K. Muspratt, op. cit. (1917), p.90.

25 Three grandsons of James (James Liebig, James Knowles and Max) received a scientific education and were active in the works. James Liebig Muspratt (1844-1907) and Sydney K. Muspratt (d.1923), both sons of Richard, were educated at the Royal College of Chemistry, and the former also at University College, London. CTJ xl (1907), p.469; RCSI q.5683; CA ix (1923), p.632; SCSI Appendix 18. Max Muspratt (1872-1934), the son of Edmund was educated at Zurich Polytechnic and joined the Central Laboratory of the United Alkali Co. in 1895. CA vi (1922), pp.684-5; Chemistry and Industry xii (1934), pp.368-9. A great-

grandson, Rudolph, graduated in chemistry at Oxford University and worked for ICI in Widnes during the period 1927-9. On Rudolph Muspratt (1905-29) see JSDC (1929), p.82; ICI iii (1929), p.330.

26 Lunge, op. cit. (1880), ii p.430; Muspratt op. cit. (1860), pp.924-5; CN vi (1862), p.173. J.W. Kynaston, 'On the Composition of Black Ash or Ball Soda', JCS xi (1859), pp.155-65. Kynaston was a Fellow of the Institute of Chemistry but received no obituary. He went on to follow the usual trajectory, via the Runcorn Soap & Alkali Co., to a managership with the St. Helen's Chemical Co. in 1882. He still appeared in the last published membership list of the Society of Chemical Industry in 1917, described as a "chemical engineer".

27 K.W.B. Jurisch, 'Beiträge zur Kenntnis des Deacon'schen Process der Chlordastellung', Dinglers Polytechnische Journal ccxxi (1876), and ccxxii (1876), pp.366-70. It is of interest that he referred to Hurter's purpose-built laboratory and apparatus, and staff of assistants at the Gaskell Deacon works (368).

28 RCSI, q.5683.

29 F. Vorster, 'Ueber die Chemischen Functionen des Glover-Thurmes der Schwefelsäurefabriken', Dinglers Polytechnischen Journal ccxiii (1874), pp.411-23. EK Muspratt, op. cit. (1917), p.149. Lunge, op. cit. (1880) iii, pp.266-8. G. Eschelmann, 'The Loss of Nitre in the Manufacture of Vitriol' JSCI iii (1884), pp.134-7. In the discussion following this paper EK Muspratt remarked that Vorster "based his calculations too much upon experiments in the laboratory rather than in the Chambers themselves".

30 Eschelmann, op. cit. (There is some doubt over the spelling of Eschelmann's name.) C.L. Higgins, 'On the Manufacture of Potassium Chlorate by Means of Magnesia', JSCI vi (1887), pp.248-51. Higgins (1859-1940) moved into management activity. R. Dickinson, 'A History of Central Laboratory Widnes 1891-1926', (internal mimeo, ICI, 1965) p.27. CCRO DIC/X7.

31 On Bostock see CN lvi (1888), p.249-50. On Davies (1865-1941) see Chemistry and Industry xix (1941), p.107.

32 Charles E Dyson (1840-1918) began as a "lad" at the Flint works (JSCI xxxvii (1918), p.352R). John Hedley (d.1927) began as a letter carrier in 1878 (CA xvi (1927), p.576; CTJ lvi (1915), p.103). WH Swim (d.1904) began as an apprentice chemist in the laboratory (CTJ xxxv (1904), p.254). All of these men reached positions as manager or assistant manager with the United Alkali Co.

33 CTJ i (1887), p.85.

34 Ibid., p.24. T. Skinner (ed.), The Stock Exchange Yearbook for 1890 (1890). On limited liability generally see H.A. Shannon, 'The Coming of General Limited Liability', Economic History ii (1930), pp.267-91.

35 R. Dickinson, 'The Mathiesons. The British Origins of an American Chemical Company', Chemistry and Industry (1955), pp.180-3. On Edward Davies (1833-1916) see JCS cxi (1917), p.323. Crace Calvert (1819-73) was educated in France and followed Playfair at the Manchester Royal Institution. DNB.

36 For example none joined the South Lancashire Chemical Society or the Society of Chemical Industry. Wigg's patent was No.1725 of 1873.

37 On Kynaston see n.26. On Wright (1844-1894) who was subsequently active in the establishment of the Institute of Chemistry see JSCI 13 (1894), p.785. C.R.A. Wright, 'On the Practical Loss of Soda in the Alkali Manufacture', JCS xx (1867), pp.407-15. Later Wright gave a somewhat embittered account of the activity at the plant in a letter to

Chemical News xxxii (1875), p.302.
38 On EW Parnell (1848-91) see JSCI x (1891), p.527.
39 Patents 7 November 1877 and 1 June 1878. Lomas, op. cit. (1886), pp.253-5.
40 On Bevan (1856-1921) see PIC (1921), p.295.
41 Tyne Chemical Society, Secretary's Report for the Year Ending March 1879. RCTI, Appendix 37. Subsequent membership lists of the Society of Chemical Industry suggest that Campbell stayed only briefly with the firm.
42 JSA xxvi (1877-8), p.867. DCI. CTJ xxx (1902), p.529.
43 On Raschen (1863-1935) see Dickinson, op. cit. (1965), pp.25-6. On Haydock (Haddock) (d.1916) see PIC (April, 1917), p.39. Haddock was later rejected by Hurter for employment at the Central Laboratory of the United Alkali Co. DIC/UA9/3/1. Membership lists of the Society of Chemical Industry. Class registers, Owens College, 1880-1.
44 CR xvi (1887), p.83.
45 CN xxx (1876), p.138. On Pauli (1836-1920) see JSCI xxxix (1920), p.325R.
46 P. Pauli, 'On the Preparation of Pure Caustic Soda on the Large Scale', CN v (1862), p.351. Lomas, op. cit. (1886), pp.251-2.
47 Hurter has already been referred to in note 10. On Lunge see E. Berl, 'Georg Lunge (1839-1929)', Journal of Chemical Education xvi (1939), pp.453-60. On Brunner and Mond see below under Brunner, Mond. On Schad see Cohen op. cit. (1956), pp.58, 61, 112.
48 On Grossmann (1845-1920) see PIC (1920), p.247. On Steffenhagen see the membership lists of the Tyne Chemical Society. On Schack-Sommer (1853-1936) see JPIC (December, 1936). On Finkelstein see CN (5 June, 1868), advertisement; ibid., xxi (1870), p.311; Roscoe letters, John Rylands Library, MS CH R107, Roscoe to Finkelstein, 26 October 1868.
49 The following can be noted from the 1880s: Auer and Eschelmann at Muspratts, Hamburger at Gambles, Hawliczek at Mathiesons, Raschen at the Runcorn Soap & Alkali and Jarmay, Markel, Quincke, Schellhaas and Staub at Brunner, Mond. The declining Newcastle industry attracted few of these individuals. The largest number detectable at any given firm is at Brunner, Mond: the above list is not exhaustive. The situation there, and at the United Alkali Co. will be discussed separately.
50 On the German connection with Britain see Haines, op. cit. (1957) and (1966), and B.N. Clark, 'The Influence of the Continent upon the Development of Higher Education and Research in Chemistry in Great Britain during the Latter Half of the Nineteenth Century', unpublished Ph.D. thesis, University of Manchester, 1979.
51 G Lunge, 'On Analytical Methods for Alkali Works'. Paper read to the Tyne Chemical Society 10 December 1875, p.25.
52 The Inspectorate's comments suggest that works with a chemist constituted a significant proportion, perhaps a majority, of the total. Seventh Report, PP 1871, xiv, p.74. By 1876 the report was positively enthusiastic about the changes which had occurred, though it implied that there had been a certain amount of chemical work carried on before inspection began: "When the Alkali Act was introduced, few of the alkali makers had good laboratories, still fewer had chemists sufficiently free to test the gases themselves, and I might almost say that few had chemists fit to do so. Now things are entirely changed..." Intermediate Report of the Chief Inspector under the Alkali Acts, 1863 and 1874, of his Proceedings since the Passing of the latter Act, PP 1876, xvi, p.2. In 1866 101 works came under the Act's

authority. Third Report, PP (1867), xvi, pp.18-19.

53 SCSI, qq.7000-26. Clapham's evidence is, however, confusing, as the following exchange indicates:

> [Samuelson] I suppose they are apprenticed to the chemical departments of the works?-Yes, only to the chemical departments.
> That is to say, to the scientific and practical departments, but they do not learn the business of the office?-Just so.
> But they learn the entire course of the practice in the works?-Generally they do; not always, but they are confined to the laboratory.
> Is each one confined to a special department?-No.
> He has the run of the entire laboratory practice of the works?-Yes, he goes into the works if he wishes.
> So that he would receive a knowledge of the operations carried on in the works?-Yes

54 'Experiences of a Works Chemist', Chemical Review vii (1878), pp.308-9, 328-9.

55 "The master and the manager when going about the works always carried canes and used them not infrequently...A one-armed man who had been thus assailed by the master, seized him, pushed him to the edge of a lock on the canal, and was on the point of plunging him in, when two foremen, who happened to be passing, and who could not pretend not to see, were obliged to rescue him." "During the night shift especially the works exhibited the aspect of a perfect pandemonium. Fights were going on as a matter of course: beer and spirits were brought in upon the most lavish scale, and the place swarmed with abandoned women. Had the head of the firm ever ventured down at night...he would assuredly have been murdered." The series of articles was never completed, perhaps not surprisingly.

56 Cohen op. cit. (1935), p.33. Cohen (1859-1935) eventually became Professor of Organic Chemistry at Leeds University. JCS (1935), p.1332.

57 CN lxxiv (1896), p.225.

58 For example, Cresswell (1854-1918) became the first salaried Secretary of the Society of Chemical Industry (PIC (November, 1918), p.25). Davis (1850-1907) of whom more will be said in the following chapter, became a consultant chemical engineer (JSCI xxvi (1907), p.598). JK Hill (d.1941) became a partner in the Clyde Soap Co. (Chemistry and Industry xix (1941), p.772) RC Woodcock (1852-1918) became a partner in the firm of Sanitas (PIC (April, 1918), p.51-2).

59 See for example Bevan above note 40. F Mousley attended the Royal School of Mines after a period as assistant chemist with Chance Bros. Chambers, op. cit. (1896). Gilbert Morgan (1870-1940) followed a similar route (JPIC (1940), p.67), as did Ridd at Gaskell, Deacon.

60 RCTI, Appendix 37. Russell et al. have offered a sixfold classification of groups associated with the chemical industry during the nineteenth century (technically involved and uninvolved entrepreneurs, trained and untrained managers, analytical chemists and "consultants"). The classification is useful, though it presents the categories in a somewhat static way, whereas the shifting significance and meaning is perhaps more important. Russell et al., op. cit. (1977), pp.38 et seq.

61 On the early years of the process see Haber op. cit. (1958), pp.87-90; Lunge, op. cit. (1880), iii pp.87-90; L. Mond, 'On the Origin of the Ammonia-Soda Process', JSCI iv (1885), pp.527-9.

62 Information on Dyar and Hemming is limited. Harrison Gray Dyar (1805-

75) appears to have been a US citizen, later active in electrical telegraphy, who spent some time in Europe. (National Cyclopaedia of American Biography entry for the son of the same name, xiv p.97). John Hemming appears to have been the same who was President of the Mary-le-bone Literary and Scientific Institute, a scientific lecturer to London institutions and early member of the BAAS. J. Hemming, An Address to the Philosophical Class of the Mary-le-Bone Literary and Scientific Institution, Delivered at the First Meeting of Members (1835); CN xxvii (1873), p.164. J.N. Hays, 'The London Lecturing Empire, 1800-50', in Metropolis and Province. Science in British Culture 1780-1850, eds. Inkster and Morrell (1983), pp.91-119.

63 Lunge op. cit. (1880) iii, p.48.

64 On Mond see Cohen, op. cit. (1956); JR Lischka, 'Ludwig Mond and the British Alkali Industry', unpublished Ph.D. dissertation, Duke University (1970).

65 See chapter 3 note 100.

66 Cohen, op. cit. (1956), p.73.

67 On Henry Brunner (1838-1916) see ibid., pp.76, 111; Hardie, op. cit. (1950), Appendix 29. His death was recorded at the shareholders meeting of Brunner, Mond, BM3/12, but it has not been possible to find an obituary. Hutchinson himself (1825-1865) had received some chemical training in Paris before being employed at the St. Helen's alkali works of Andreas Kurtz. The Hutchinson works had the usual mixture of "chemists". As well as Brunner and Mond the firm employed Walter Angus Watts (a graduate of the Queen's University of Ireland, who subsequently became a schoolmaster) and an apprentice chemist, who had received some training at Owens College, JW Towers (1855-1941). Hardie, op. cit. (1950), pp.100-1. (JI Watts), The First Fifty Years of Brunner, Mond & Co., 1873-1923 (private, no date, 1924?), pp.20-4; Chemistry and Industry xix (1941), pp.235-6. C.R. Lewis, History of Farnworth Grammar School (Widnes, Lancashire), (1905), pp.199-205.

68 Watts, op. cit. (1924); CCRO BM7/18/2, Mond to Solvay, 24 June 1874.

69 BM7/18/1 27 January 1874; BM7/19/4 16 March 1873.

70 BM7/18/ Mond to Schott, 11 August 1875.

71 BM7/19/5 5 October 1875; 11 October 1875. Mond wrote "the Ammonia Process for the manufacture of soda requires more practical knowledge and extensive experience in the carrying out of delicate chemical operations than any other manufacturing process which I have come across. It has taken me over 6 months of night and day work to get it into operation, though I had the assistance of some foremen of 20 years experience in chemical works...I consider it impossible to find a man to erect the works and conduct the process." Mond to Hambledon 21 November 1874.

72 BM7/18/2 Mond to Solvay, 14 May 1875. "I have discovered that my foremen have been neglecting the kiln gas test".

73 BM7/18/1 Translation of a letter from Mond to Valentin, 9 April 1877. WG Valentin (1829-1879) was then a demonstrator at the Royal School of Mines. JCS xxxvii (1880), p.260.

74 On Jarmay (1856-1944) JPIC (1944), p.186; ICI i (1928), pp.508-9.

75 J Bajon (an ex-Solvay employee) and Siegfried Pick (a German Ph.D.) are recorded as managing this works, which was taken over by Brunner, Mond in 1878. DCI. BM7/15/3, Bajon to Mond March, 1878.

76 Watts, op. cit. (1924), p.31. BM7/15, 6 July 1883.

77 Hewitt (d.1920) was an Irish doctor of medicine turned chemical works manager. Report of the Royal Commission on Noxious Vapours, PP 1878,

xliv, qq.7045-190. CTJ ii (1888), p.308, evidence of DB Hewitt in the case of Spence vs. Kurtz. It has not been possible to find an obituary for Hewitt, though his death was noted in the Proceedings of the Institute of Chemistry.
78 BM7/3 Gossmann to Mond, 24 February 1879. Gossmann had been a student at Bonn University. On Milner (1838-1902) see CTJ xxxi (1902), p.171.
79 On Watts (1859-1939) see JCS (1939); ICI i (1928), p.509.
80 Erhardt had been educated in France. BM15/4/1, Erhardt to Brunner, Mond, 11 June 1880.
81 BM7/8 Beckett to Mond 31 October 1884. On Beckett (1855-1924) see JCS cxxv (1924).
82 Cohen, op. cit. (1956), pp.157-8.
83 All were of course academically educated. Miall, op. cit. (1931), p.18. HE Armstrong, 'The Monds and Chemical Industry-a Study in Hereditary', Nature cxxvii (1921), pp.238-40. On Langer (d.1935) see Chemistry and Industry xiii (1935), 273-4. On Mohr (1853-1920) (later More) see CA ii (1920), p.341. On Gall (1881-1924) see PIC (June 1924), p.203. On Shields (1869-1921) see JPIC (1921), p.64. See also L. Mond, C. Langer and F. Quincke, 'The Action of Carbon Monoxide on Nickel', JCS lvii (1890), pp.749-53; L. Mond, W. Ramsay and J. Shields, 'On the Occlusion of Oxygen and Hydrogen by Platinum Black', Philosophical Transactions of the Royal Society clxxxvi (1896), pp.657-93. Shields, Quincke and Langer also spent some time at the Winnington works.
84 BM7/8 PF Frankland to Mond, 7 October 1884. Reeks (1860-1938) subsequently became an assistant to the consultant agricultural chemist Augustus Voelcker. JPIC (1938), p.415.
85 BM7/3 Mond to Jarmay, 7 February 1894.
86 On Glendinning (1863-1932) see ICI i (1928), pp.508-9. BM7/15/6, 8 December 1883.
87 On Ellis (1857-1932) see JPIC (1932), p.390. On Markel (d.1932) see AE Musson, Enterprise in Soap and Chemicals. Joseph Crosfield & Sons Ltd., 1815-1965 (Manchester, 1965), p.144. BM3/2/1 (Managing Directors' Minute Book (hereinafter MDMB) 5 March 1884 amd 3 July 1889). Tangye (d.1955) came to Brunner, Mond on the recommendation of Alexander Chance after a course at Owens College, during which he took the City and Guilds examination in Alkali Manufacture. (BM15/31 AW Tangye to AS Irvine 20 April 1950). Roscoe, op. cit. (1887). On Staub see JSCI viii (1889), pp.505-10. Robert Mond (1867-1938) was educated at Cambridge and Edinburgh Universities and Zurich Polytechnic. He worked both at Winnington and at Mond's London laboratory. DNB. Cohen, op. cit. (1956), pp.187-8 JFL Brunner (1865-1929) was also educated at Cambridge University and Zurich. Venn and The Times 17 January 1929.
88 MDMB BM3/2 30 December 1891.
89 BM7/12, Johnson to Mond, 30 January 1888.
90 In 1893, when new offices were being built John Brunner referred to the need to maintain co-operation between the commercial and technical departments: "our success as manufacturers was largely due to the intimate relation between every department." MDMB BM3/2 5 April 1893. The departments were supported by separate administrative arrangements within the offices. Ibid., 11 January 1893.
91 In April 1886 the Managing Directors Minutes noted that "in future, whenever experimental plant is erected, all parts of the plant that can be used over again are to be put to Experimental Plant Construction account, and only special castings, stores and wages are to be charged

to Experiment and Improvement." Ibid., 28 April 1886.

92 Lischka, op. cit., p.136. Experimental work on the ammonia soda process proper appears to have taken place at the Sandbach works. BM7/8, Watts/Richards to Mond, 28 October 1884. In February John Watts was asked to investigate ammonia loss at this plant. Ibid., 13 February 1885.

93 Many letters between Winnington and London and Rome exist on these subjects from the mid-1880s onwards. See for example BM7/12, Johnson to Mond 30 January 1888, BM7/3, Mond to Jarmay, 7 February 1894. Some idea of the detailed process records kept throughout the works can be gained from those preserved in BM10/23-/31. On Mond's other life in London and Rome as patron of the arts see L.M. Richter, Recollections of Dr. Ludwig Mond (1910?), which contrives not to mention the chemical industry, and suggests that Winnington Hall was Mond's "country seat".

94 Some of the large scale experiments are recorded in BM3/9 "Managers' Press Copy Reports to Directors", 1889-94.

95 MDMB, BM3/2, 13 January 1886, 17 February 1886, 5 May 1886, 13 October 1886, 1 June 1887, 28 August 1889.

96 P.F. Frankland, 'The Utilization of Atmospheric Nitrogen for Industrial Purposes', JSCI xxvi (1907), pp.175-80.

97 MDMB, BM3/2 26 October 1887. This refers to the return of CC Moore from the plant to laboratory work.

98 BM7/3 Mond to Jarmay 7 February 1894, 27 February 1894.

99 MDMB, 7 January 1886, 6 October 1886.

100 Ibid., 24 May 1896, 30 May 1896.

101 Ibid., 5 April 1893, 8 February 1899.

102 MDMB, 15 February 1893.

103 BM8/1/10 Wages books: entries for July 1881.

104 On Moore (1862-1920) see JPIC (1920), p.294. MDMB BM3/2, 28 December 1899.

105 These figures are based on the keyed staff photographs reproduced in Watts (1924), and various lists of foremen.

106 BM7/3, Mond to Jarmay, 7 February 1894. ICI iv (1929), p.636.

107 Hoepfner (1857-1901) worked on chlorine recovery. Zeitschrift Naturwissenschaft lxxiii (1900), pp.367-8. A.S. Irvine, technical appendices to Cohen, op. cit. (1956).

108 BM15/28, letter from FA Freeth to AS Irvine. They were, of Continental or mixed UK/Continental background, Jarmay, Schad, Recklinghausen, Lucas, Ewing; from Owens, AW Tangye and JI Watts (Henry Glendinning was not present, indicating that the list is not exhaustive of even senior staff); from the Andersonian, Archibald Kling (Ewing had also spent some time at the Andersonian); from Cambridge University HB Brunner (son of Henry); from the City and Guilds Central Technical College, HA Humphrey.

109 City and Guilds of London Institute for the Advancement of Technical Education, Annual report (1893), pp.5-6. Humphrey had studied Civil and Mechanical Engineering.

110 Owens sent RT Maudsley, AH Sturges, JW Crabtree, GP Pollitt and TC Lamb (the last via Heidelberg to the new Silvertown caustic works, where he moved on quite quickly to become manager). Oxford sent W Akers, DR Eduardes-Ker, HE Cocksedge, WF Lutyens, EM Fraser, AE Hodgkin, JG Gillbert and LA Munro. Cambridge sent WHH Norris. The City and Guilds College sent AE Hill and FD Napier-Clavering. Liverpool sent FA Freeth.

111 On Cunnington (1876-1908) see Venn and [AS Irvine], 'The History of the

Alkali Division, formerly Brunner, Mond & Co. Ltd.' (internal ICI mimeo), typescript in DIC/X7, pp.20-1.

112 For example BM7/3 Mond to Jarmay, 27 February 1894, 3 March 1894. In the second letter Mond refused permission to expand operations at the Caustic Soda plant until he had returned and discussed it. Mond was in Rome at the time.

113 MDMB, BM3/2, 8 February 1899. Imperial College London Archives B HUM C Mond to Humphrey 28 February 1899.

114 Reader, op. cit. (1970), pp.219-20.

115 On Alfred Mond (1868-1930) see H. Bolitho, Alfred Mond, First Lord Melchett (1933). On Roscoe Brunner (1871-1926) see The Times 5 November 1926. Both men had read for the Natural Science Tripos at Cambridge and subsequently been called to the Bar.

116 BM/3/6 (loose typescript minutes of Managers' Meetings) entry for 11 January 1898. The minutes begin at about the same time as the formal acknowledgement referred to in note 113. The meetings included senior commercial staff.

117 Ibid., 31 March 1919. Among those of known education 5 had attended Owens College. Unfortunately the background of a considerable number of those attending at this time is unknown, though it seems unlikely that they were without some formal higher education.

118 MDMB, BM3/2/10, 4 December 1918; 24 October 1919.

119 V.E. Parke, Billingham-the First Ten Years (ICI, Billingham), pp.57-8.

120 On Freeth (1884-1970) see Biographical Memoirs of Fellows of the Royal Society (1976), p.105 et seq. On being told that Brunner, Mond were appointing men Freeth is reported to have said "They'll never take me, I haven't a German degree...". In fact he found WHH Norris and DR Eduardes-Ker already in the laboratories, and HE Cocksedge arrived at about the same time. BM15/38 Freeth to Irvine.

121 On Akers (1888-1954) see Chemistry and Industry (1954), p.1449 and W. Akers, 'The Research Laboratories at ICI Ltd.', Proces Journées Internationals de Chimie Industrielle (1948) pp.345-58.

122 Reader, op. cit. (1970), p.218.

123 F.A. Freeth, 'Explosives for the First World War', New Scientist xxiii (1964), p.274, and ibid., xviii (1962), p.157. Irvine, op. cit. (1958), pp.80-1. Irvine suggests that Cunnington was Head of Research, but he seems rather to have been in charge of the analytical laboratories.

124 Biographical Memoirs of Fellows of the Royal Society 22 (1976), pp.105-18.

125 PP Bedson commenting on N.H. Martin, 'Germany and Chemical Industry', JSCI xxxiii (1914), pp.1130-5. There is some contradiction between these remarks and those of Reader that, pre-War, Brunner, Mond "recruited bright young scientists, but for plant management rather than research. Such research as the young men did carry out was combined with their duties in the factory..." (p.231). Reader implies elsewhere that some independently-constituted research did occur (p.285). In any case the process of assimilating 'bright young scientists' (a mid-twentieth century notion) to plant management is an altogether more problematic question than he implies. Reader's view clearly contains a large element of truth, but the way in which research was located in the firm, and the way in which men came to undertake it, is a more complex problem than he allows. He glances briefly at this subject before moving on to the (for him) more interesting question of Brunner, Mond's commercial relationship with Lever.

126 _Royal Commission on University Education in Wales_, PP 1917-18, xii, qq5207-8.
127 Reader, op. cit. (1970), pp.282-99.
128 The first formal recognition of the role of fundamental research did not occur until after the War: the new laboratory being built at Winnington was planned with the intention that it should undertake: "(a) Pure Research, (b) Works Research, and (c) Works problems which arise from day to day". MDMB BM3/2/10, 13 October 1920.
129 F.A. Freeth, 'New Research Laboratory: Request for a Low Temperature Installation and Additional Personnel', BM9/2. Partington, op. cit. (1964), iv pp.638-9.
130 Warren, op. cit. (1980), pp.111-20.
131 This was "the best laid out and best built of all the ammonia soda works in the UK". BM3/12 Minute Book of the Shareholders' Meetings, 25 May 1897. Murgatroyd committed suicide in 1894, allowing Brunner, Mond to take over. _CTJ_ xv (1894), p.371.
132 _CTJ_ ii (1888), p.347. Watts op. cit. (1924), p.33. DCI.
133 MDMB, BM3/2/1, 5 March 1884, 25 February 1885.
134 Ibid., 15 May 1889, 21 August 1889, 18 November 1891. It may be recalled that Hawliczek himself (an Austrian Ph.D.) had had some connection with Mond, working on nitrogen fixation. It is not clear whether he ever worked on the ammonia soda process. Frankland, op. cit. (1907), p.175.
135 MDMB, 28 December 1899. In 1902 3 technical staff at Lostock, were discharged, and reference was made to the "agreement referring to taking work with our competitors". Ibid., 25 February 1902.
136 BM7/12, Hewitt to Mond, 29 January 1888.
137 N. Swindin, _Engineering without Wheels. A Personal History_ (1962), p.37.
138 Imperial College London Archives B HUMC Humphrey to Jarmay 2 January 1897.
139 BM3/2/1 MDMB, 16 December 1903, 27 December 1904.
140 Watts, op.cit.(1923). On Brunner's wider political activity see S.E. Koss, _Sir John Brunner-Radical Plutocrat_ (Cambridge, 1970). A large proportion of the Managing Directors' minutes is concerned with 'welfare' activity.
141 "...they make chemical analyses of a limited character, and we can train them to a high degree of accuracy in that work, and, perhaps, even they do that mechanical kind of work better than a university man, but they never do more, because they have not the scientific foundation. Your evening education class boy you will be able to train up to that pitch, but the probability is that he would get to a point where he would never get any further." _Royal Commission on University Education in Wales_, PP 1917-18, xii, q.5224. Winnington was of course some distance from large technical institutions, and to that extent something of a special case.
142 Warren, op. cit. (1980), chapter 13. Reader, op. cit. (1970), pp.105 et seq.
143 On TW Stuart (1846-1933) see _JPIC_ (1933), p.329. United Alkali Co., Minute Book of the Directors, UAC3/2/1, 23 January 1891.
144 Wylde (1856-98) had taken the technological examinations of the Society of Arts in 1877 during his progression through the firm. Hardie, op. cit. (1950), p.73. _CTJ_ xxiii (1898), p.358, xxiv (1899), p.67.
145 Ibid., xxvi (1900), pp.204-5.
146 The new company had retained the management staff at each works,

supposedly as part of the effort to maintain technical continuity and 'level up' operating standards. United Alkali Co., Ltd., The Struggle for Supremacy: Being a Series of Chapters in the History of the Leblanc Industry in Great Britain (Liverpool, 1907).

147 W Windus, Bristol (Chemistry and Industry vi (1928), p.559; T Minton, Sullivan (Chemical Trade Journal lvii (1915), p.525); JR Wylde (Widnes Alkali), J Hedley, Muspratt; VC Driffield, Gaskell, Deacon; T Glover, Mort, Liddell (DCI); RH Davidson, Gaskell, Deacon (DIC/X9/3); FJ Norman (Chemistry and Industry liv (1936), p.240); F Wright; J McCulloch (DCI). [JT Conroy], 'The History of the United Alkali Company Limited, 1890-1926' (corrected proofs of an unpublished book, 1939), pp.33-5. CCRO, DIC/X9/3.

148 AR Garrick (DCI and membership lists of the Chemical Society); TT Best (JPIC (February, 1928)); J Kynaston, CL Higgins, TW Stuart, WL Rennoldson. Ibid.

149 UA3/2/1 Minute Books of the Directors, 19 December 1890. Hardie op. cit. (1950), pp.174 et seq. Dickinson, op. cit. (1965).

150 UAC9/3/1 'Central Laboratory for the United Alkali Co.' 19 February 1891 (Press copies of reports to Directors). "I conceive of the duties of this laboratory to be:

1) Original research in general, to promote the interests of the company.
2) Investigations of processes offered to the company for sale.
3) Investigations of all patents referring to the Alkali and allied trades, whether offered to the company or not.
4) Investigations into all inventions made by servants of the company.
5) Analytical Work, in connection with short methods for routine testing in the works, in connection with complaints made by customers, to check the results of the works chemists, and to investigate differences between them and public analysts."

151 UA3/2/1 Minute Book of the Directors, 20 February 1891. By December 1891 £3,000 had been spent on the laboratory, ibid., 18 December 1891.

152 Hurter, Auer, Raschen, Zahorski and AE Hetherington (the last from University College, Liverpool and Heidelberg). Conroy, op. cit. (1939), p.40. R. Dickinson, "A History of Central Laboratory Widnes, 1891-1926", (internal ICI mimeo, 1965).

153 These were: Arthur Wareing (a graduate who eventually moved to a managerial position), CA Dawson (originally a works chemist, but otherwise of unknown background) and William Thomason (an ex-student at University College, Liverpool (not a graduate) and apprentice to Edward Davies). DCI.

154 Liverpool: AJ Allmand, JT Barker, GC Clayton, JT Conroy, ML Davies, JH Shores, HJ Feeny, FN Kitchen, A Lamble. Owens: AL Allen, HA Auden, HM Broadhurst, A Carey. A number of these men held German Ph.D.s. Some had already been works chemists before joining the Central Laboratory.

155 UAC9/6 'General Index to Accounts of Researches and Processes', 1895. Raschen was involved in numerous patents for the manufacture of cyanides, and the laboratory also focused on other electrolytic techniques. J.T. Conroy, 'Some Experiments Relating to the Manufacture of Cyanides' JSCI xv (1896), pp.8-13, and 'The Raschen Process for the Manufacture of Cyanide', JSCI xviii (1899), pp.432-6. Dickinson, op. cit. (1965), pp.25-6. The Company's somewhat lumbering approach to the whole question of innovation and technical development is suggested by the sequence of papers produced by its "Committee of Experts" which

surveyed the entire chemical industry. UA3/9/1, 'Report for 1905 to the Directors of the Company, by the "Committee of Experts", with a Memorandum by the Chairman and an Introduction and Summary by Mr. Max Muspratt'. (Marked "Private and Confidential".)

156 See Hardie, op. cit. (1950), chapter 11 and Reader, op. cit. (1970), pp.116-19.

157 London County Council, op. cit. (1896), pp.23-4.

158 Some of these men have already been referred to. SJ Willcox (d.1919) DIC/X9/3; A Carey (1867-1923) DCI and CA viii (1923), p.179; TJ Norman (1889-1918), PIC (April, 1919), p.58; Max Muspratt (1872-1934) was trained at Zurich Polytechnic CA vi (1922), pp.684-5, Chemistry and Industry xii (1934), pp.368-9.

159 "The large scale operations cannot be learnt and practised other than in the works, and the only method of procedure is for a chemist to be employed in the laboratory at the commencement of his career with any firm. In a short time he is naturally, as soon as opportunity offers, placed in charge of some practical part of the business." JSCI xxvii (1909), pp.174.

160 W.L. Rennoldson, Chairman's Address to the Newcastle Section, JSCI xxi (1902), pp.1379-80. Rennoldson (d. c.1903) had originally worked in the laboratory at Tennant's St. Rollox works. RCTI Appendix 37. UA3/2/1 'Report on Changes in Managers etc.' 24 October 1907.

161 For example J Huyton at Gerard's Bridge and JA Hill at Hazlehurst. DCI. There is no information on the background of these men.

162 W.W. Gleave, 'Reminiscences of the Chemical Industry in Fleetwood and Widnes, 1901-28' (internal ICI mimeo, 1965), DIC/X9.

163 On Davidson (1863-1948) see Dickinson, op. cit. (1965), p.32.

164 On Gaskell (1878-1951) see Hardie op. cit. (1951) and Venn.

165 Conroy, op. cit. (1939), p.41. AE Malpas. AW Harrold and WI Thatcher were recruited from the College. CTJ (10 October, 1930). Walker, op. cit. (1936). Works engineers were more likely to have been works-trained, as for example Thomas Minton, engineer at the Muspratt works, who began as an apprentice fitter at the Sullivan works, where his father was manager. DCI.

166 Hardie, op. cit. (1950), p.211.

167 M. Muspratt, 'The Individual and the Corporation in the Chemical Industry', JSCI xxvii (1908), pp.1185-7.

168 By contrast, for manual labour, wherever "skilled labour was in the past highly paid, owing to its very special nature and demand exceeding supply...(t)he modern tendency is towards simplification, with a consequent lowering of individual wages." Ibid.

169 United Alkali Co., op. cit. (1907), p.62.

170 From 1905 the "Widnes Municipal Technical School" (a set of evening classes held in the local secondary school) offered a course relevant to "Chemical Industries", which consisted essentially of analytical and descriptive chemistry. To this was added from 1906 a course leading to the City and Guilds examination, which apparently attracted a somewhat similar clientele. Borough of Widnes. Council Minutes. Municipal Technical School Session 1905-6. Scheme. The City and Guilds classes attracted, for a time, about 20 students for examination, suggesting a considerable demand for training as analytical chemists in the town. City and Guilds of London Institute for the Advancement of Technical Education, Annual Report, 1907 and later reports.

171 On Bowman (1888-1934) see JPIC (1934), p.160. Bowman left the Company in 1916, but JM Taylor (1871-1945) who had followed a similar route at

an earlier date, went on to become Chief Analyst at the Central Laboratory. Taylor obtained the Fellowship of the Institute of Chemistry in 1918 at the age of 47, apparently under the temporarily relaxed regulations of the Institute. Russell et al., op. cit. (1977), p.180.

172 UA9/3/13 Report Book. Central Laboratory. 27 July 1923, p.27. The report noted that "Each works has its own laboratory (and in some cases departmental laboratories), with its Head Chemist and a number of subordinate chemists." The Committee did not appear to use the information in its report. First Report of the Dyestuff Development Committee, PP 1931, xl, p.29.

173 The National Certificate Scheme began in 1921 with the aim of rationalizing the large number of "technical" qualifications then available in chemistry. In chemistry it was largely devoted to a limited amount of general chemistry combined with a training in analytical work. R.T. Briggs, 'The Development of the ONC and HNC with Particular Reference to the Development of Chemistry Syllabuses', M.Sc. thesis, University of Sheffield, 1966, pp.116-20.

174 The National Association of Industrial Chemists was formally established in Sheffield in September 1917 see CTJ lxi (1917), p.186. and JSCI xxxvii (1918), p.69R. It was often represented as a body for "glorified lab. boys" (CTJ lxii (1918), p.417) On the general terms of the conflict see the correspondence in CTJ lxiii (1918) p.308 and passim. This was part of wider changes in the professional organization of chemists, centred around the negotiations between the (Provisional) British Association of Chemists and the Institute of Chemistry. On the wider development of the organization of scientific workers at this time see E.K. MacLeod, "Politics, Professionalism and the Organisation of Scientists: the Association of Scientific Workers", unpublished Ph.D. thesis, University of Sussex, 1975 and R. Macleod and E.K. Macleod, 'The Contradictions of Professionalism: Scientists, Trade Unionism and the First World War", Social Studies of Science ix (1979), pp.1-32.

175 See W.V. Farrar, 'Synthetic Dyestuffs before 1860', Endeavour xxxiii (1974), pp.149-55; R. Brightman, 'Manchester and the Origins of the Dyestuffs Industry', Chemistry and Industry (1957), pp.86-91; W.H. Perkin, 'On the Colouring Matters Derived from Coal-Tar', CN i (1861), pp.346-55. Runge (1794-1867) (whose blue obtained from aniline was sometimes represented as the inspiration of Perkin's work) received a medal at the 1862 Exhibition, "For the influence which his researches has exercised on the development on the development of the industry of coal tar". Industrial Exhibition, 1862, Medals and Honourable Mentions Awarded by the International Juries, with a List of Jurors and the Report of the Council of Chairmen (1862), p.34. On Runge see B. Anft, 'Friedlieb Ferdinand Runge: a Forgotten Chemist of the Nineteenth Century', Journal of Chemical Education xxxii (1955), pp.566-74. See also R.D. Welham, 'The Early History of the Synthetic Dye Industry', JSDC lxxix (1963), pp.98-105, 146-52, 181-5.

176 See chapter 3.

177 CN ii (1860), pp.244-5.

178 F.A. Mason gave the following table of dyestuff patents granted to Britons and Germans during the previous 50 years:

Period	Germany	UK
1856-60	8	20
1861-5	21	54
1866-70	17	23
1871-75	8	11
1876-80	47	13
1881-85	113	15
1886-90	201	39

'The Influence of Research on the Development of the Coal-Tar Dye Industry', Science Progress x (1915), pp.237-55, 412-22 (422)

179 W.H. Perkin, 'The Aniline or Coal-Tar Colours', JSA xxii (1868), pp.99-105.

180 The death of TD Perkin (1831-91) was noted in the Journal of the Society of Chemical Industry but there was no obituary. See W.H. Perkin, Hofmann Memorial Lecture, JCS lxix (1896), pp.575-95; R. Brightman, 'Perkin and the Dyestuff', Nature clxxvi (1956), pp.815-21.

181 W.H. Cliffe, 'The Dyemaking Works of Perkin & Sons. Some Hitherto Unrecorded Details', JSDC lxxiii (1957), pp.312-8; 'Pacta coventa--the Last Days of Perkin & Sons', ibid., pp.318-22; 'Litera Scripta Manet--the Alizarin Debacle', ibid., pp.323-8. On JT Brown, (c1844-1894) see JCS lxv (1894), pp.382-3. On BF Duppa, FRS (1828-73), see JCS xxvii (1873), p.1199. On Alexander Pedler FRS (1849-1918) see JSCI xxxvii (1918), p.235R. On Frederic Stocks see RCSI q.5683 and Cliffe, op. cit. (1957). On CH Greville Williams FRS (1829-1910) see JSCI xxix (1910), p.803. On R Williamson (1853-1914) see JCS cvii (1915), p.590.

182 F.M. Perkin, 'The Artificial Colour Industry and Its Position in this Country' JSDC xxx (1914), p.339. W.H. Perkin (jun.), 'The Position of the Organic Chemical Industry', JCS, cvii (1915), pp.557-78.

183 W.H. Perkin, Presidential Address to the Society of Chemical Industry, JSCI iv (1885), pp.427-38

184 J.J. Beer, The Emergence of the German Dye Industry (Illinois, 1959), pp.32, 74-93; 'Coal Tar Dye Manufacture and the Origins of the Modern Industrial Research Laboratory', Isis xlix (1958), pp.123-31. G. Meyer-Thurow, 'The Industrialization of Invention: a Case Study from the German Chemical Industry' Isis lxxiii (1982), pp.363-81. Homburg has emphasized the importance of an earlier tradition of innovatory work in calico-printing undertaken by colourists. E. Homburg, 'The Influence of Demand on the Emergence of the Dye Industry. The Roles of Chemists and Colourists', JSDC xcix (1983), pp.325-33, and 'De Inschakeling van Chemici in De Kleurstofindustrie' in H. van den Belt, B. Gremmen, E. Homburg and W. Hornix. 'De Ontwikkeling van de Kleurstofindustrie. Onderzoeksproject van het Wetenschap en Samenleving-Programma van de K.U. Nijmegen' (Nijmegen, 1984), pp.107-63. On the importance of constantly changing designs and fashion see, for example, EM Sigsworth, Black Dyke Mills. A History (Liverpool, 1958).

185 John Dale (1815-89) had served an apprenticeship with a druggist and received tuition from Dalton. He had had various employments including one in a calico-printing works. JSCI vii (1889), pp.529-30. Thomas Roberts (d.1896) had previously manufactured dyewood extracts as Mottershead & Roberts. CTJ xix (1896), p.400. The partnership had works in Warrington and Manchester.

186 CA Martius (1837-1920) later founded Agfa. JSDC xxxvi (1920), p.220. Caro (1834-1910) became a partner, but returned to Germany in 1867. He eventually joined BASF. JSCI xxix (1910), pp.1143. Griess (1829-88)

had spent some time at the Royal College of Chemistry. Despite the fact that he is associated with the azo dyestuffs his main employment was in the brewing industry, and he acted merely as a consultant to Roberts, Dale. *JSCI* vii (1888), pp.612-3; W.H. Cliffe, 'The Life and Times of Peter Griess', *JSDC* lxx (1959) pp.278-85. Leonhardt returned to Germany to become a partner in Cassella. I Levinstein, Chairman's Address to the Manchester Section, *JSCI* xxi (1902), pp.1377-9.

187 On J Dale (1840-71) see *JCS* (1872), pp.344-5. On RS Dale (d.1899) see Victoria University of Manchester, op. cit. (1908); R.S. Dale and C. Schorlemmer, 'The Phenates of Amido-bases', *JCS* xli (1883), pp.185-7. See also I. Levinstein, 'The Development and Present State of the Alizarin Industry', *JSCI* ii (1883), pp.213-27 (214). On Dancer (1841-1928) see Lingard op. cit. (1970), pp.107-8, and *CA* xviii (1928), p.344.

188 *CTJ* i (1887), p.66.

189 On EC Nicholson (1827-1890) see *JSCI* ix (1890), p.1023. On George Maule (c1827-c1892) see *RCSI* q5683, Frankland op. cit. (1902), pp.23-4, 29 and C.A. Russell, *Lancastrian Chemist: the Early Years of Sir Edward Frankland* (Milton Keynes, 1986), p.111. On George Simpson see *RCSI* q.5683 and *JSDC* xlii (1926), p.377.

190 Brightman, op. cit. (1956), pp.817-8.

191 On D. Price (d.1889) see *JCS* lv (1885), p.294; Perkin, op. cit. (1896), p.610. On AP Price see Perkin op. cit. (1885). It seems unlikely that Perkin was confusing the two men, though both lived in London, both were FIC, FCS and members of the Society of Chemical Industry, and they joined the Chemical Society within months of each other: perhaps they were related.

192 On Spiller (1836-1926) see *JPIC* (1926), p.230. On Field (1826-85) see DNB and *JCS* xlix, pp.349-52. On Lowe see *RCSI* q5683 and Chambers, op. cit. (1896). On Alison (1844-1924) see *JPIC* (February, 1925), p.60.

193 On the litigation surrounding the Medlock patent see *CN* (1863) and (1864), passim.

194 *CN* xix (1868), p.i, 142. Levinstein, op. cit. (1884), p71.

195 Levinstein, op. cit. (1884), p.71. *RCSI* q5683. *JSDC* xlii (1926), p.377.

196 On John Spiller (1833-1921) see *PIC* (1921), p.357. On Nickels (1830-1889), see *JCS* lvii (1890), pp.452-3.

197 Brooke, Simpson & Spiller proved incapable of operating Perkin's alizarin patent, and in 1876 the works was purchased by Burt, Boulton & Heywood, which in turn sold it to the British Alizarin Co. This firm was mainly orientated towards serving dyeing interests, and resisting attempts by the Germans to monopolize alizarin production after the expiry of the relevant patents. See below p.273. Cliffe, op. cit. (1957).

198 RJ Friswell (1849-1908) *PIC* (April, 1908), p.29. R.J. Friswell, 'The Newer Artificial Colouring Matters Derived from Benzene', *JSA* xxviii (1879-80), pp.444-80 *Report of the Departmental Committee on Alcohol*, PP 1905, lxiv, qq.1-4. James Dewar, later Professor of Chemistry at Cambridge University and the Royal Institution, commented on this in *JSCI* vii (1888), p.478.

199 R Meldola, 'On Nitroso-β-Naphthosulphonic Acid', *JCS* xxxix (1881), p.48.

200 On Royle (1837-1906) see *JSCI* xxv (1906), p.682.

201 A.G. Green, 'Some Notes on the Discovery and Introduction of Primuline', *JSDC*, xxxiii (1917), pp.137-46. R. Meldola, 'The Scientific

Development of the Coal-Tar Colour Industry', *JSA* xxxiv (1885-6), pp.759-71.

202 *The Dyer and Textile Printer* lxxi (1934), pp.605-6.

203 JC Cain (Owens), T Cooksey (UCL), F Evershed, ME Fylemann (UC Nottingham), TA Lawson (UCL), C Mills (City and Guilds Central Technical College), WS Simpson (Royal College of Chemistry), WF Stainton (Leeds University), H Wilkinson (Leeds University) were among those employed there at various times. See also H. Wilkinson, 'Brooke, Simpson & Spiller', *JSDC* lxxvii (1957), pp.508-11.

204 On CG Williams (1829-1910) see *JSCI* xxix (1910), p.803; DNB.

205 On Typke (1856-1931) see *JPIC* (1931), p.64. On Witt (1853-1915) see *JSCI* xxxv (1915), p.49. On Alison see note 192.

206 *Chemistry and Industry* xi (1933), p.895. *Chemical Review* x (1880), p.42. The firm traded briefly as William Bros. & Ekin in partnership with Charles Ekin (1841-1909), who had served an apprenticeship as a pharmacist, one of the later chemical manufacturers to have begun in this way. *PIC* (June, 1909), p.22.

207 On Read Holliday (1808-89) see *Huddersfield Examiner* 4 March 1889 (scarcely more than a death notice). Little has been found on his early years or on the man himself.

208 No early material has survived from the works, and this account is compiled, except where otherwise indicated, from the following sources: Read Holliday & Sons Ltd., Huddersfield, England, *History of the Rise and Development of the Company* (Huddersfield, 1914); 'A Pioneer Color (sic) Making Firm', *The Dyer and Calico Printer* (1915), pp.18-20; summary of the history of the firm, of unknown provenance (but relatively recent), held at ICI Organics Division Archives, RSF06 DH2604. On Mansfield (1819-1855) see *JCS* viii (1855), p.110. On Read Holliday's work on oil lamps see J. Butt, 'Technical Change and the Growth of the British Shale-Oil Industry, 1680-1870', *Business History Review* xvii (1964-5), pp.511-21.

209 On Thomas Holliday (1840-1898) see *Huddersfield Examiner* 5 March 1898. On Charles Holliday (1842-93) see ibid., 30 December 1893. On Robert Holliday (1855-1901) see *JSDC* xvii (1901), p.111 and *Huddersfield Examiner* 6 April 1901. Two of the sons died in the USA and received no UK obituary.

210 Medlock (c1840-1875) had been a student at the Royal College of Chemistry. *JCS* xxviii (1875), p.1317. The Medlock patent had passed to Richard Hands, yet another onetime Royal College of Chemistry student, later a Coventry dyer, from whom it had been transferred to Simpson, Maule & Nicholson. *CN* vii (1863), p.20.

211 J Holliday, No. 341, 1866; R. Holliday, 'A communication from H Minhorst and FW Chultes, Crefeld', No. 1340, 1866. *CN* xiii (1866), p.274.

212 W. Haynes, *American Chemical Industry* (New York, 1954) vol. i, pp.303, 307.

213 On Wolf (1847-1915) see *PIC* (April, 1914), p. 41; *CN* xlv (1882), p.129.

214 On Paul (1856-1934) see *JPIC* (1934), p.85. G.T. Morgan, 'Personal Reminiscences of Chemical Research', *Chemistry and Industry* (1939), pp.665-9. On Morgan (1870-1940) see *JPIC* (1940), p.67. On Streatfield (1858-1918) see *PIC* (November, 1918), p.29. Read Holliday was also involved with the French inventor WJS Grawitz and took out patents for his work, which later proved to be worthless, in the late 1870s. He also bought the rights to Schutzenberger and Lalande's indigo vat. E. Noelting, *Scientific and Industrial History of Aniline Black* (New York,

1889). Read Holliday also undertook contract dyeing, reflecting the firm's generally opportunistic approach, and the chemists were involved with the dyehouse.

215 On Joseph Turner (1868-1939) see Huddersfield Examiner 27 October 1939 and The Dyer and Calico Printer xxvi (1929), p.73.

216 Read Holliday & Sons Ltd., Minute Book, 1890-1901, preserved in ICI Organics Division, Blackley, DH0045. This contains little of relevance to technical matters or personnel.

217 C.M. Whittaker, 'Some Early Stages in the Renaissance of the British Dyemaking Industry', JSDC lxxii (1956), pp.557-63. On CM Whittaker (1878-1960) see JSDC lxxvi (1960), pp.592-3.

218 The patents awarded to Read Holliday & Co. and the firm's arch-competitor Levinstein during this period were:

Period	Read Holliday	Levinstein
-1895	19	9
1896-1905	19	32
1906-1914	17	40

The figures conceal a trough for Read Holliday just after the turn of the century. Both sets of figures are of course very small compared with those of the firms' German competitors. Source: indexes to JSCI.

219 On LB Holliday (1880-1965) see The Dyer and Calico Printer lxix (1929), p.115 and The Times 20 December 1965, the latter referring mainly to his later activities as a racehorse owner.

220 Report of the Departmental Committee on Alcohol, PP 1905, lxiv, q.4557.

221 For example TPK Crosland (JPIC (February, 1920), p.67), FGC Stephens (JPIC (1932), p.273) and HG Frank, CCRO DIC/X10/28 'The History of the British Dyestuffs Corporation' (proofs of an unpublished book, c1938), p.37. Chemists named Thevanaz and Badier were also employed.

222 M.E. Sadler, Report on Secondary and Technical Education in Huddersfield (1904), p.89.

223 In his 'Memorandum on the Coal Tar Industry of Great Britain' (22 August 1917) Herbert Levinstein claimed that Levinstein manufactured 80% of the country's dyestuffs. ICI Organics Division Archives, DH1083. As will be seen, Levinstein had a more extensive recruitment policy.

224 Cardwell, op. cit. (1972), p.175.

225 Leeds University, CFO F84 Memo. dated 6 August 1915.

226 M. Wyler, Ivan Levinstein. What I Know of Him. The First Ivan Levinstein Memorial Lecture (Manchester, 1937). Manchester Guardian, 16 March 1916. JSCI xxxv (1916), p.458. AG Green, Manchester Chemistry and Chemists in the Nineties (Manchester, 1938). Autobiographical letter, recipient unknown, dated 13 April 1886, in ICI Organics Division Archives, DH3091. EA Littlewood, 'Levinstein Limited. Some Reflections', (typescript in ICI Organics Division Archives, c1938). The only significant document relating directly to the firm which has survived from this period is the Directors' Minute Book for the limited liability company (1890-), but this contains little of interest in terms of personnel or their employment.

227 Wyler, op. cit. (1937).

228 H Rosicki, A Liebmann, A Studer and H Kupferberg all appear in the Society of Chemical Industry membership lists around 1885, and at least one other German, A Klepl, was also with the firm around this time.

229 Reports of Patent Cases (1885), pp.73-118.

230 Studer and Liebmann formed a consultancy in Manchester. On Liebmann (1852-1927) who was employed at Levinsteins from 1881 to 1884 see

Chemistry and Industry v (1927), pp.241-2.
231 Reader, op. cit. (1970), pp.262-3.
232 For example Weber, von Hohenhausen, Pfeifer, Sartorius, Busch, Herz, all with German Ph.D.s.
233 JSCI xvi (1897), pp.599-601.
234 EH Bagnall (see below), WH Bentley, JC Cain, GB Stones and JL Rose all fall into this category.
235 On Feilman see JPIC (1944), pp.288-9 and Eighth Report of the Commissioners for the Great Exhibition of 1851, PP (1911), xxi.
236 On Herbert Levinstein (1878-1956) see JSDC lvi (1956), pp.582-3.
237 Report of the Departmental Committee on Alcohol, PP 1905, lxiv, q.140.
238 Littlewood, op. cit. (1938).
239 CTJ xxxix (1906), pp.549-50. Bagnall vs Levinstein, Law Times Reports xcvi (1906), pp.184-9.
240 Wyler, op. cit. (1937), p.2.
241 Men recruited from Leeds from 1905 onwards include J Baddiley, EA Bearder, RS Horsfall, E Marx, HH Stocks. 'Addresses of Students and posts obtained on leaving the University', MS notebook held by Leeds University Department of Colour Chemistry and Dyeing.
242 JSDC xix (1903), p.22. The Department appears to have passed through a crisis in the later stages of Hummel's tenure. 'Preliminary Statement of Professor Hummel in reply to the Clothworkers' letter on the present condition of the Dyeing Department', 11 November 1901. The substance of the criticisms appears to have been that Hummel's teaching was old-fashioned and orientated towards dyeing practice rather than a chemical understanding of textile colour. Letter from EJ Wilkinson to the Department, 5 November 1901. Leeds University Archives.
243 Manchester Municipal Technical School Student Registers 1893-1904 (bound volumes held at UMIST, Registrar's Department). Manchester Municipal Technical School, 'List of successes obtained at the examinations of the Science and Art Department etc', 1893- (printed lists held at UMIST Registrar's Department). Entries for C Milnes, N Evans, CW Moore, D Brownlie, JH Wilson.
244 Littlewood, op. cit.. See also Manchester Municipal School of Technology (University of Manchester), Register of Graduates, Associates and Other Former Students (Manchester, 1913); CCRO DIC/X10/28 'The History of the British Dyestuffs Corporation' (proofs of an unpublished book, c1938).
245 CW Moore, gained an MSc in 1907 and a German Ph.D., eventually becoming works manager at Joseph Crosfield & Co. JH Wilson, the father of the future Prime Minister, appears to have followed a similar course. After beginning as a laboratory chemist undertaking part-time study, he returned to full-time study, and eventually moved into process management at LB Holliday & Co. Personal communication from Lord Wilson of Rievaulx.
246 Harry Hampson was trained at the Salford Institute taking City and Guilds examinations, and spent his entire career in the laboratories. ICI Organics Division Archives, DH1577, Hirschberger to Hampson, 1 July 1904 and Dixon(?) to Hampson, 4 September 1901; Hexagon Courier (August, 1948), p.8.
247 Directors' Minute Book, Levinstein Ltd, FP2/D04 DH0041, 1914.
248 The only record of the original department is a keyed photograph held in ICI Organics Division: J Payman, F Henderson, EH Rodd, Connolly, DB Stanhill, JH Baddiley, WJS Naunton, R Horsfall, HP Brown, SM Cross and three unknown.

249 British Dyes Ltd., 'Report of the Proceedings at the Statutory Meeting Held at the Memorial Hall, Manchester' (13 July 1915), and ensuing reports. When British Dyes and Levinstein were amalgamated into the British Dyestuffs Corporation, Levinstein had a larger research organization. 'The Research Organisation of the British Dyestuffs Corporation', 1919, held at ICI Organics Division, Blackley, BDC F08.
250 Green, op. cit. (1938).
251 The staff at the British Alizarine Co. were distributed as follows:

Year	Process managers	Other technical staff	Laboratory assistants	Research
1883	2	3	5	0
1893	3	3	6	2
1903	3	4	8	2
1913	3	3	8	2

Manuscript document in ICI Organics Division Archives, BA/F02/DH1687.
252 F.D. Miles, A History of Research in the Nobel Division of I.C.I. (ICI, 1955). Other material is contained in ICI, Imperial Chemical Industries Ltd., and its Founding Companies. I. The History of Nobel's Explosive Company and Nobel Industries Limited 1871-1926 (1938), and Reader, op. cit. (1970), i. chapter 2.
253 On Liedbeck see ICI, op. cit. (1938). On McRoberts (1840-1896) see JCS lxi (1896), p734. Others recruited at this time were William Donald (ICI, op. cit. (1938), pp.33-4 and RCTI Appendix 37) and RM Kater (1852-1937) see ICI, op. cit. (1938), p.35.
254 Men known to have been recruited about this time are J Sayers (1860-1935; JPIC (1935), p.329), JM Thompson (1858-1924; JPIC (1924), p.271); J Lawrence (d.1924; Chemistry and Industry iii (1925), p.484), TM Wilkie (d.1899) and HRM Murdoch (ICI, op. cit. (1938), p.57-8).
255 On Lundholm (1850-1934) see JPIC (1934), p.239.
256 Miles op. cit. (1955), p.28
257 University of Strathclyde Archives, F/2/2.
258 E.A.B. Hodgetts, The Rise and Progress of the British Explosives Industry (1909), p.398.
259 Miles op. cit. (1955), pp55-71. Rintoul (1870-1936) had been apprenticed to RR Tatlock and attended the Andersonian. JPIC (1937), pp.396-7. On Beckett see note 81 above.
260 Miles, op. cit., p.49.
261 Davis noted one Lancashire firm (not necessarily in the chemical sector) which began by "knocking down a wall between a stable and a wash-house, converting them into one room, and dignifying this with the title of 'The Laboratory'. Selecting a greenhorn fresh from school, paying him about one-third the wages of an ordinary engine-tenter, keeping a tight hand on what he spent on chemicals and apparatus, talking largely about 'our chemist'." CTJ ii (1887), pp.69-70.
262 F Abel, 'The History of the Royal College of Chemistry and Reminiscences of Hofmann's Professorship', JCS lxix (i) (1896), pp.580-96 (593), and Hofmann's own remarks cited in note 108 to chapter 2.
263 See for example RCSI q.9158.
264 R.M. MacLeod, 'The Alkali Acts Administration 1863-1884: the Emergence of the the Civil Scientist', Victorian Studies ix (1965), pp.85-112.
265 They were not confined to the immediately apparent materials involved in the Leblanc process. The potential by-product metals in waste

materials, recovery of sulphur, manganese and chlorine also involved analytical work. George Davis told the Society for the Promotion of Scientific Industry in Manchester, in relation to causticization that "...instead of leaving the operation entirely to the workman, a sample of the batch should be obtained when the operation is near completion, and the steam should not be turned off until the chemist in charge of the process has declared at least 95% of the alkali to be causticized'. CN xxxii (1875), p.188. Kingzett remarked that 'the chemist's duty in an alkali works consists in the examination and analysis of materials consumed and products manufactured'. Kingzett, op. cit. (1877), p.9. Compare also the advertisements in CN xxxv (1877), 20 April. Lunge's account of the operation of lead chamber for sulphuric acid production gives some indication of the sheer number of analyses which could be required. Lunge, op. cit. (1880) vol.ii, pp.342-63.

266 Lunge noted in the 1880s that in some works 'the payment is regulated directly by the alkalimetrical assay of the black ash'. Lunge, op. cit. (1880) vol. ii, p.399-40.

267 The required codification of diverse practices provided a useful rhetorical tool for the proponents of the Institute of Chemistry. CN vii (1877), pp.263-4; xxii (1871), p.178; xxix (1874), p.8. R. Dickinson, 'Early Documents Relating to the Deacon Chlorine Process', (internal ICI mimeo, 1966), DIC/X9, p.41.

268 See, for example, A.M. Chance, 'The Recovery of Sulphur from Alkali Waste by Means of Lime-Kiln Gases', JSCI vii (1888), pp.162-79. G. Davis, 'A New Process for the Production of Carbonate and Caustic Soda, without the Formation of Any Noxious Waste, and the Recovery of the Sulphur', Journal of the Society of Arts, xxv (1877), p.633-42. C.L. Higgins, 'On the Manufacture of Potassium Chlorate by Means of Magnesia', JSCI vi (1887), pp.248-91. Compare Jacob Grossmann's account of 'semi-tech' work at Gambles around 1880. J. Grossmann, 'Recent Developments in the Manufacture of Chlorates', JSCI xv (1896), pp.158-61. See also Morrison op. cit. (1890).

269 J. Morrison, 'On the Manufacture of Caustic Soda', Transaction of the Newcastle-upon-Tyne Chemical Society iii (1874), pp.27-55.

270 "I have hitherto had only those in mind who aspire to filling the higher positions in chemical works, and ultimately hope to become themselves managers or owners of factories. Of course, only a few can ever reach that goal, and the great majority must content themselves with obtaining intermediate positions, but if they have honestly worked during their college time, they may trust not to be left always in the condition of 'testing slaves', but to be promoted to manage some part or other of the real manufacture". Lunge, op. cit. (1897).

271 The Times Engineering Supplement, 9 February 1910.

272 CN viii (1866), 11 May; ibid., p.249.

273 Comments of Mr. Evans on N.H. Martin, 'Germany and Chemical Industry', JSCI xxxiii (1914), pp.1130-4.

274 J.H. Davidson, 'Chemical Shams', Chemical Review x (1881), pp.172-4. CTJ vii (1890), p.349.

275 His distinction is more complex, and more informative, in full: "We may divide chemical work roughly into two kinds: routine work--analysis, teaching, examining, and so on-- and what is often, though not very appropriately, called 'research'". JCS lxi (1892), pp.475-82. A letter to Chemical News in 1892 classified chemists into "the analytical chemist in the works, the analyst pure and simple, and the professor who is open for consultation." CN lxv (1892), p.119.

276 JSCI xix (1900), pp.589-620 (595).
277 Nature lxxxiv (1910), p.347.
278 On the general point see K. Quinton, Science and the Manufacturer (1906), p.21. I. Levinstein, op. cit. (1892), pp.877-8. The only concrete examples which have been discovered during this study are in the dyeing industry SCSI, q.4048, and that referred to in note 275 to chapter 4.
279 R.B. Pilcher, The Profession of Chemistry (1927 ed.), p.65. In 1931 a typical individual working in the oil industry was said to 'start as an analyst and ...afterwards become an assistant to a man engaged in developing a new process'. Transactions of the Institution of Chemical Engineers ix (1931), p.18.
280 J. Swinburne, 'Applied Electrochemistry', JSA xliv (1896), pp.839-45 (839). J.A. Fleming, 'Official Obstruction of Electrical Progress', The Nineteenth Century xlix (1901), pp.348-63. Comments by JT Dunn on N.H. Martin, 'Germany and Chemical Industry', JSCI xxxiii (1914), pp.1130-4. Comments of Louis in Congress of the Universities of the Empire, 1912, Report of the Proceedings (1912), p.98. The comments of the Department of Scientific and Industrial Research in 1916 illustrate contemporary ambivalence. The Department noted "(w)e have been told by other manufacturers that the rapid conversion of the businesses in their trade into limited liability companies has thrown the control into the hands of salaried works managers whose training and experience has been confined to their own industries, and who are therefore apt to resist proposals for improvement." It suggested however that large limited companies would be better able to undertake long-term research. The report went on to argue for a division between laboratories for routine, development ("improving") and fundamental work, and the need to "make the most of mediocre ability". A general formulation in terms of personal competencies, rather than any emphasis on the changes in the structures by which authority was transmitted and new knowledges utilized was characteristic of contemporary commentaries. Department of Scientific and Industrial Research, op. cit. (1916), pp.26-40.
281 F.M. Perkin, 'The Artifical Colour Industry and Its Position in this Country', JSDC xxx (1914), p.339.
282 Tyne Social Chemical Society, Inaugural Address for the Second Session, 1871-2.
283 CN xvi (1872), p.57. WV Farrar, 'The Society for the Promotion of Scientific Industry, 1872-6', Annals of Science xxix (1972), p.81-6. Tyne Chemical Society, 'Secretary's Report for the Year Ending March 1876'. The "Social" was dropped from the Society's name in 1873-4. It resisted proposals for an amalgamation with the owner-dominated Newcastle Chemical Society "so antagonistic was it to the aims of the other local society". J. Morrison, Inaugural Address, 1878-9. An amalgamation did eventually occur in 1879, Transactions of the Newcastle Chemical Society iv (1877-80), pp.325-6. See Russell, op. cit. (1983), pp.209-12, A. Chaston Chapman, 'Two Tyneside Chemical Societies', JSCI li (1932), pp.718-19; W.A. Campbell, 'The Newcastle Chemical Society and Its Illustrious Child', Chemistry and Industry (1968), pp.1463-6.
284 JSCI xxiv (1915), p.749. St. Helen's Standard, 2 October 1875, 9 October 1875, letters from 'Analyst' and 'Leo'. See also D.W. Broad, Centennial History of the Liverpool Section, Society of Chemical Industry, (1981).

285 JSCI xxiv (1915), p.749.
286 Society of Chemical Industry, Minute Book of the Preliminary Meetings, held at the Society's headquarters. Compare the initial committee, published in CN xli (1880), pp.260-1 with the first Council in JSCI i (1882), p.1. The first Council contained 18 manufacturers, 1 works chemist, 3 consultants, 4 academics, 2 others and 1 of doubtful occupation. The long and unexplained delay in the establishment of the Society was the subject of some complaint. CN xliii (1881), p.59.
287 JSCI xl (1921), p.87R.
288 "Caustic Alkali" wrote in 1881 that "(t)he rules of admission to the Institute tended to exclude "the very class which ought to be the backbone of such an association, namely, the technical chemists themselves." CN xliii (1881), p.194. The Institute of Chemistry and Society of Chemical Industry can be seen as alternative approaches to the control of chemical activity in an industrial environment, though many other elements were involved. The Society of Chemical Industry demonstrates characteristics of localism and heterogeneity which are seen by Johnson as reflecting a 'corporate patronage' approach to such control. T.J. Johnson, Professions and Power (1972), pp.72-4.
289 G. Lunge, 'Remarks on the Teaching of Chemistry', in Society of Arts, International Congress on Technical Education, Report of the Proceedings of the Fourth Meeting, (1897), pp.15-18.
290 W.H. Nichols, 'The Management of a Chemical Industrial Organisation', JSCI xxiv (1905), pp.707-12. Nichols was associated with the foundation of the General Chemical Co.
291 See for example Hobson, op. cit. (1906).
292 Report of the Committee of the Privy Council for Scientific and Industrial Research for the Year 1915-16, PP 1916, viii, p.40.
293 See, for example, the evidence of Rudolf Messel, David Howard, and Hurter to the LCC inquiry , LCC, op. cit. (1896), pp.22-4. AG Green told the LCC in 1902 "In respect of the technical training of the workmen it is absolutely unrequired...Whilst chemical processes must always be devised by the chemist and controlled from the laboratory, the successful carrying out of routine operations is in no way assisted, but rather impeded by a partial knowledge of the chemical reactions involved...Even in the production of the finest chemical products, where more than usual skill is required, the workman is usually selected from his fellow-workmen for superior intelligence, or has been brought up in the factory as a laboratory lad." LCC, op. cit. (1902).
294 Lomas, op. cit. (1886), p.87. Warren, op. cit. (1980), pp.97-8. Chemical Works Committee of Inquiry, The Conditions of Labour in Chemical Works, PP 1893-4, xvii. A.P. Laurie, 'The Chemical Trades' in Dangerous Trades. The Historical, Social and Legal Aspects of Industrial Occupations as Affecting Health, by a Number of Experts (1902), pp.568-98. Even the supposedly less objectionable ammonia soda process was by no means universally so. It was said that at the "Filter Stage", around the turn of the century, it was necessary to remove ammonia from inhaled air by "breathing only through the mouth and scrubbing the gaseous mixture in the saliva before it went into the lungs". CCRO DIC/X9 (Gleave, p.3). Gleave went on to state that "some of the men ate the fat from the wagon axles boxes".
295 On the more general role of foremen, within which the situation in chemistry might be considered an extreme case, see J. Melling, 'Non-commissioned Officers: British Employers and their Supervisory Workers,

1880-1920', Social History v (1980), pp.183-221, and K. Burgess, 'Clydeside and the Division of Labour', ibid., xi (1986), pp.211-33.

296 On this, and the whole issue of "deskilling", see H. Braverman, Labor and Monopoly Capital. The Degradation of Work in the Twentieth Century (1974). R.C. Edwards, Contested Terrain. The Transformation of the Workplace in the Twentieth Century (New York, 1979). D. Clawson, Bureaucracy and the Labor Process. The Transformation of U.S. Industry 1860-1920 (New York, 1980).

297 Royal Commission on the Depression of Trade and Industry, Reports and Minutes of Evidence, PP 1886, xxi, xxii, xxiii, pp.306-8. Evidence of Christian Allhusen. Lomas (op. cit. (1886), p.182) remarked that the revolving furnaces developed over a number of years by Elliot and Russell, Stevenson and Williamson and by Mactear were less effective in terms of quality, but "(t)he dispensing with skilled labour...is a great advantage...upon a pinch, and with responsible supervision, ordinary labourers can be put to the task." (182) (Lunge, op. cit. (1880) vol.ii, pp.404-5) The introduction of the "salt decomposing furnaces" was similarly motivated. Speaking of the "Jones and Walsh" furnace William Jones told the Newcastle Chemical Society that "...it became at last a serious question whether they could not dispense with (the decomposing men) altogether; he made up his mind that they would endeavour to do so, even if it cost them more to do the work by mechanical means." Transactions of the Newcastle Chemical Society (1874-7) iii, pp.198-9. Most of the technical innovations in the mainstream Leblanc process (as opposed to novel ancillary processes) were orientated to removing their operation from the control of workmen and the apparatus required was not complicated.

298 Transactions of the Newcastle-upon-Tyne Chemical Society, iii (1874-7), pp.137-8.

299 The process developed by Hargreaves and Robinson (c1870) was described by John Morrison in 1881 as "a process which -- excepting in management-- rejoices in the entire abandonment of the obligations of skilled labour." He elaborated this argument by reference to the fact that the process was open to "scientific" exploration by methods "quite within and compatible with the resources of any ordinary Works' laboratory, and any ordinary Works' chemist and manager..." J. Morrison, 'The "Hargreaves" Process', Transactions of the Newcastle-upon-Tyne Chemical Society v (1881), pp.60-96. See also Lunge, op. cit. (1880) vol.ii, pp.128-60 and J. Morrison, 'On the Manufacture of Salt-Cake', JSA xxiv (1876), pp.639-45.

300 C. Duisberg, 'The Education of Chemists', JSCI xv (1896), pp.427-32.

301 Haber, op. cit. (1971), chapter 6.

302 L.O. Ward, 'Technical Education and the Politicians', British Journal of Educational Studies (1873), pp.34-40. See for example the comments of James MacTear. JSCI viii (1889), pp.329-30. The National Association for the Promotion of Technical and Secondary Education produced a pamphlet entitled 'Is Technical Education a Device of the Employers?', which it has not proved possible to trace.

303 Association of Technical Institutions, Report of an Enquiry as to the Co-operation of Employers and Technical Institutions. Issued by the Association, December, 1905 (1905).

304 Association of Technical Institutions, op. cit. (1901), p.9.

305 W.H. Perkin (jun.), 'The Training of Technical Chemists', JSDC xi (1895), pp.202-9 (207)

306 LCC, op. cit. (1902).

307 E.B.R. Prideaux, 'The Education of the Industrial Chemist', JSCI xxxiv (1915), pp.535-6.

308 On the fluidity which prevailed in the Institute of Chemistry during the latter stages of the War see Russell et al., op. cit. (1977), pp.178-81. The following account indicates the movement between industry and academe. "It was necessary to fall back upon the young and usually inexperienced chemists of the country, who were mostly without either works experience or administrative knowledge. These were selected and trained as works chemists on existing plant...Towards the end of 1915 it also became necessary to organise a system of training for chemist foremen...The new class of chemical foremen was created from intelligent young chemists who were drawn first from Great Britain...and were trained in the actual working of the process before they were put in charge of a shift." History of the Ministry of Munitions viii (part 1), p.49.

309 F.G. Donnan, 'The University Training of Technical Chemists', JSCI xxviii (1908), pp.275-80; 'The Relations of Physical Chemistry to Modern Chemical Industry', ibid., xxxii (1913), p.115. This claim was continued with the publication of HE Potts' translation of a German text on the area: R. Kremann, The Application of Physico-Chemical Theory to Technical Processes and Manufacturing Methods (1913), and the post-War Cantor lectures by J.C. Philip, 'Physical Chemistry and Its Bearing on the Chemical and Allied Industries', Journal of the Royal Society of Arts lxvii (1919), pp.94-102, 108-18, 122-31. On the development of physical chemistry see R.G.A. Dolby, 'The Case of Physical Chemistry' in Lemaine et al op. cit. (1976), pp.63-73. JC Philip (1873-1941) was Professor of Physical Chemistry at Imperial College.

310 Thus Lunge remarked in 1873 that "(abroad) the chemist is considered equally important with the practical manager". Lunge, Transactions of the Newcastle-upon-Tyne Chemical Society ii (1871-4), p.170. Galloway noted in 1880 that "(t)here is frequently a manager as well as a chemist in chemical works; the manager is frequently unacquainted with Chemistry...The chemist is usually confined to analysing the raw and manufactured substances...". R. Galloway, Education, Scientific and Technical; or How the Inductive Sciences Are Taught and How They Ought to Be Taught (1881), p.379.

311 Commenting on Lunge, op. cit. (1897), p.20.

312 F.G. Donnan, 'The Training of the Chemical Student for Work in the Factory', Transactions of the Faraday Society xiii (1917-18), pp.72-8. G. Lunge, 'Problems of Applied Chemistry', Notices of the Proceedings of the Meetings of the Members of the Royal Institution of Great Britain... xviii (1905-07), pp.556-76 See also Chandler, op. cit. (1900) and the comments of PP Bedson in Martin, op. cit. (1914), p.1132.

313 D.F. Channell, 'The Harmony of Theory and Practice: the Engineering Science of WJM Rankine', Technology and Culture xxiii (1982), pp.39-52. On the growth of engineering training in general see P.L. Robertson, 'Employers and Engineering Education in Britain and the United States, 1890-1914', Business History xxiii (1981), pp.42-58.

314 Though civil engineering appeared in chemical works in a somewhat primitive form. John Morrison once commented that a vertical chimney in Widnes was a novelty. 'On Chimneys and Smoke', a paper given to the Tyne Chemical Society, 8 February 1878.

Chapter 7. The Origins of Chemical Engineering in England

A. Introduction

In 1915 the consultant chemical engineer AD Little, who was also a Visitor to the Department of Chemical Engineering at MIT, suggested that the course at the Institute should be reformulated around the notion of "unit actions" or "unit operations" (generalized types of plant and activity), and that it should be located at a number of "research stations" associated with industrial firms.[1] The report in which these ideas were expressed made almost no reference to mechanical engineering. While the terminology Little used was novel, and was to have a role in constituting chemical engineering as an independent field, it formalized a common approach to chemical engineering in the USA and elsewhere at that time. This situation appears to fit well with David Noble's interpretation of the origins of chemical engineering in the USA, in which he claims that the "chemical-engineering profession" and its attendant educational activity was conceived by "independent consultants and company officials", by whom it was "made to order".[2] However, Noble treats as unproblematic the creation by these groups of chemical engineering as a 'unitary' discipline (rather than an amalgam of chemistry and mechanical engineering) and the emergence of industrial positions where its graduates were able "to organize and manage the activities of corporate employees". In the USA the situation may have been influenced by the many emergent large scale corporations and the intimate relations between business and educational institutions, and by the dominance of the heavy chemical industry. Even so, Noble's view of MIT has been attacked by Servos.[3] In this chapter the origins of chemical engineering in the UK, as academic discipline and as occupation, will be traced from about 1880 to 1920. It will be argued that it is difficult to see these events in terms of the 'one-directional' set of influences described by Noble.[4]

The general use of the term chemical engineering in Britain grew out of the increasing mechanization of the chemical industry during the third quarter of the nineteenth century. The use of the steam engine, of rotary furnaces, and of compressors and other pumps required the presence of someone with a mechanical engineering competence.[5] The title chemical engineer was not very common however. In 1882, among the original membership of the Society of Chemical Industry only 15 individuals (5% of the membership) listed themselves as chemical engineers.[6] One such was John Morrison who had regularly so described himself in the 1870s.[7] Despite his chemical background, which was referred to in the previous chapter, Morrison was at pains to stress the engineering aspects of his work on the Hargreaves process, and his enthusiastic use of the term may have been intended to signify the shift from laboratory status referred to above (p.277). He was involved in the mechanization of works for the production of artificial fertilizer, one of which he established himself.[8]

Another early enthusiast for the title was George Davis. Davis took over as Secretary during the preliminary meetings of the Society of Chemical Industry around 1880, and he canvassed the title "Society of Chemical Engineers" for the embryonic organization. Early letters to the press had this heading, and the matter was argued at a number of meetings.[9] The name was twice agreed upon, but eventually rejected in favour of the present title.[10] According to Davis the opposition to his suggestion was led by "the professional element", which in context seems to have meant academic and consultant analytical chemists and their supporters.[11] The tension within the early meetings between employees and employers (noted in chapter 6) can also be recalled. Davis's proposed title certainly focused on technical practitioners rather than employers. At one of these meetings Davis's former colleague at Bealey's chemical works, DB Hewitt, by then a manager with Brunner, Mond, explained the proposed title as follows:[12]

> (T)he object of starting the Society was the fact that while good analysts and good manufacturing chemists were to be had abundantly, there was not a sufficient supply of men of engineering skill also versed in the arts of manufacturing chemistry. They could obtain plenty of men capable of carrying through processes in the laboratory, but not competent to apply these on a large scale.

Strains are evident here between academic and industrial practice, and between engineering and chemistry. There is also an emphasis on the intention to create a supply of employees for specific purposes, though it is not clear whether applying processes on a large scale meant designing them or operating them. These themes will run through this chapter.

The Society of Chemical Industry in fact devoted little attention to defining or promoting chemical engineering, focusing rather on surveying technical innovations and patents. Developments occurred instead in the sphere most appropriate for the production of manpower -- that of education. It was in the educational institution most clearly under the control of industrial and financial capitalists, the City and Guilds Institute in London, that chemical engineering was first given serious curricular attention.

B. Chemical Engineering at the City and Guilds Central Institution

The early history of the City and Guilds from its establishment in 1877 has already been discussed with particular reference to its Technological Examinations in chemical fields. However the main aim of the Institute was often said to be the establishment of a Central Technical Institution. This was increasingly presented as training an upper stratum of the industrial workforce, but had to wait upon complex negotiations over siting with the Department of Science and Art and the Commissioners for the Great Exhibition. During this preliminary activity the Chairman of the Institute's Executive Committee (FJ Bramwell) stressed the need for the City-dominated Institute to retain its independence and avoid being swallowed by "South Kensington", a remark which communicated approximately equal hostility to Government and academic interference.[13] In chapter 3 the public resistance of the Institute's Governors to the influence of academics and others was discussed. They claimed that its activities were subservient to educational needs as formulated by industrial entrepreneurs. The situation will be repeated in the actual development of the Central

Institution.

By 1884 the planning of the Central Institution was well advanced, under the control of a Sub-Committee (Sub-Committee A) of the Executive Committee. A Scheme of Organization was drawn up in February 1884, emphasizing the authority of this Sub-Committee over the main academic forum, the Board of Studies.[14] The Sub-Committee moved to appoint Professors in the major fields of chemistry and civil, mechanical and electrical engineering. Many prominent contemporary chemists were considered for the chemical chair, and eventually a shortlist of three was drawn up: Henry Armstrong, Georg Lunge and TE Thorpe.[15] Lunge had not in fact applied, but was approached by the Sub-Committee.[16]

Armstrong was already employed at the Institute's "model" technical college at Finsbury, and his efforts to obtain the new appointment included canvassing Owen Roberts, a Governor of the Institute. Roberts agreed to see Armstrong, but made it clear that his preference was for Lunge. He added that he "regretted the decision of the Committee not to appoint specialists all round".[17] The exact meaning of this is not clear, but since Armstrong was a well-qualified academic chemist it appears that Roberts was referring to men with industrial experience. He may even have meant that specialists from each industrial sector should have been appointed. In the event nothing was heard from Lunge. Thorpe withdrew, to be replaced by William Tilden. Eventually Armstrong was appointed, but it is not clear with how much enthusiasm on the part of the Sub-Committee.[18]

The conflicts which were to mark the academics' relations with the men from the City began quickly. Frederick Abel and William Perkin were consulted on the question of staffing, and Armstrong wrote to them suggesting a split into sub-departments within chemistry, one operating a basic course and the second orientated towards individuals "chiefly devoting themselves to original work".[19] However Armstrong's apparent inclination to establish a department of academic chemistry was to be frustrated. The Institute issued a Preliminary Programme in August 1884 which emphasized that the students who studied chemistry would also obtain "a knowledge of the parts of engineering likely to be most useful to them". The course and diploma were entitled "Chemical Engineering".[20] There is no formal record of how this title was chosen. Armstrong was certainly unhappy with the emphasis on engineering. He wrote to EC Robins in January 1885 explaining the changes he would have to make to his own preferred course "to make it agree with the programme", and suggested to Sub-Committee A that a four year course was necessary. When this was rejected he had a comment inserted in the minutes of the Board of Studies, noting of the proposed course, that "it would be impossible for students following such a course to acquire such a knowledge of chemistry as should entitle them to the Diploma of the Institute".[21] In addition to having his curricular advice rejected Armstrong was denied permission to set up a small research "class" by Sub-Committee A until 1889.[22]

The Institution's full programme, published in 1885, reinforced the engineering emphasis of the chemistry course: "(t)he course is arranged to suit the special requirements of those who will enter works where a knowledge of the principles, and the use, of machinery, the strength of materials, building construction, &c., is of the greatest importance."[23] This formulation of the curricular aims makes clear that no qualitative shift from the types of curricula available elsewhere, in the separate fields, was envisaged. The course consisted rather of a combination of mechanical and other forms of engineering and mainstream academic chemistry. This continued throughout its existence, though the title Chemical Engineering was dropped in 1887, in an effort to revitalize the flagging course.

Armstrong's view of the course which he was required to offer was ambivalent. While employed at the Central Institution his public comments made no reference to his efforts to reduce its engineering emphasis.[24] He was sometimes dismissive of the need for special technical instruction for industries related to chemistry. He told the Cowper Commission in 1893 that "you cannot draw any distinction between technical chemistry and what we call chemistry...practically no machinery is necessary. All we do, as a rule, is to mix our materials and apply heat, sometimes, perhaps, under pressure,...". Similarly, dyeing was "bye-play" for a trained chemist.[25] However this view contrasts with that offered to Sub-Committee A, where he stressed the need for students to carry out "chemical manufacturing operations" in the laboratory on a reduced scale. The future chemical engineers "should have the opportunity afforded to them of becoming acquainted with all the more important technical operations which the chemical engineer is called on to perform".[26] In 1899 he represented the activity to the LCC as a simple mixture of academic chemistry and engineering, and was dismissive of the notion that any approach to manufacturing operations in chemistry other than that found in existing courses was needed. Once he had left the Institute he became dismissive of the wisdom of teaching engineering to chemical technologists. In 1921 he remarked:[27]

> Chemical engineers are much in demand. We may raise a few by striving to teach engineers to be chemists; a larger proportion perhaps by teaching chemists engineering...but in neither case will the hybrid be really competent in both subjects; if we are wise we shall follow the German example and manacle chemist with engineer...

These remarks suggest that Armstrong was far from conceptualizing chemical engineering as an independent 'unitary' field. They undermine his sympathy for a broad curriculum at this level, which appears in any case a somewhat retrospective one.

All in all it is not easy to establish exactly what view Armstrong took. His own work on organic materials had an orientation towards materials of industrial interest, and some of it was undertaken in conjunction with German dyestuff firms. However, given the resources invested in research by the German firms and the character of the field, it is likely that most organic research was of industrial relevance. Armstrong gave some indication of his underlying motives when he remarked that the information available in the German firms' patents was "at least a year in advance of the public scientific literature".[28] By contrast he appears to have undertaken little or no work in relation to the industrial production of the materials he studied. Teaching in connection with industrial activity proper seems to have been undertaken by assistants such as AK Miller, who left in 1888 to become a manager with Bayer in Glasgow.[29] Armstrong himself was not even a member of the Society of Chemical Industry until after his retirement. In private he expressed disillusionment with the work he was asked to undertake, and was anxious to find a post where he could set up an authentic research school in chemistry. However he found no suitable position. His only reason for not applying for TE Thorpe's Chair at the Royal College of Science in 1894 was fear of "public rejection".[30]

Armstrong's unhappiness at the Central Institution was increased by a wider hostility which developed between the academic staff, on the one hand, and the governing body and its main executive officer, Philip Magnus, on the other. The former were treated, in Armstrong's words, as "office staff". Armstrong's protests about the chemical engineering course were accompanied by attempts by the Board of Studies to gain representation on Sub-Committee A. The Sub-Committee refused to allow any permanent representative, and resisted a "customary" attendance by the Dean. Magnus, on the other hand, had a permanent ex officio place in Board of Studies meetings as Organising Secretary.[31] Sub-Committee A retained a firm hand on all aspects of the organization of the Central Institution. It had some acrimonious disputes with Armstrong over his employment of research assistants and other issues. However the Board of Studies did successfully resist the imposition of external examiners to monitor teaching standards.[32]

The Department was not a success. Armstrong was worried about its lack of popularity, and already thinking of leaving, in 1886, but no post was available.[33] In 1889 Sub-Committee A called for a report on the Institution's equipment. Armstrong's response to this has already been referred to. In fact the apparatus he requested was orientated more towards servicing his research interests in organic aspects of crystallography and optical activity than expanding the provision of 'industrial' equipment. In 1899 the College still lacked facilities for carrying out industrial type operations.[34] The Central Institution was criticized in The Times in 1886. Armstrong was well aware that the basic problem was lack of students, and this in turn was said to be due to the large non-chemical component of the course.[35] It was the chemistry department which was the particular failure, as the figures in Appendix 2, Table 3, show. The recruitment of chemistry students did not improve throughout the college's independent life, and the chemistry department declined steadily in relative importance. In 1896 the Central Technical College (the name had been changed in 1893) was subject to an attack in a pamphlet entitled "Is the Central College a Failure?", and the Chemistry Department was singled out for criticism.[36] A special committee was set up by the Governors, and this vindicated the College and the Department.[37] However the statistics which it cited failed to point out that most of the "chemical" students were first and second year mechanical and electrical engineers. Armstrong's position remained invidious, and in 1903 he was again called to account by the Governors for his department's lack of success.[38]

The unhappy life of the department came to an end in the aftermath of the formation of Imperial College in 1907. In planning the new College's curriculum it was decided that engineering students needed to study less chemistry and that this could be supplied by the Royal College of Science Department.[39] This destroyed the basis for Armstrong's department, and he was told summarily that his services were no longer required.[40] He later remarked that his students were left to the "tender mercies" of the Royal College of Science, where they "received the treatment meted out to students of professional chemistry".[41] In view of his own earlier desire for an appointment at the College, Armstrong's view of the course he himself had been constrained to offer at the Central Institution is again seen to be ambivalent and perhaps only retrospectively affectionate.

The most reasonable judgement on the available evidence is that the structure of Armstrong's course was a consequence of an attempt to impose a directly industrial character on the chemical department of the Central Institution. The idea of inserting mechanical engineering into the curriculum avoided the well-canvassed difficulties of constructing courses which directly addressed industrial chemistry itself (against which the Institute had been warned by the 'experts' it had consulted) while reflecting the increasing mechanization of the industry. It was regularly indicated that the engineering element was utilitarian in intention, rather than reflecting an attempt to obtain a balanced curriculum. It may also have been a consequence of the fact that the Institution had been unable to recruit a distinguished teacher who yet had industrial experience, in the form of Lunge. Armstrong was directly under the control of men with a City and industrial background, and in an institution where academics were given little authority to act independently. In private, to Norman Lockyer, he referred to "the depraved condition of public feeling in this country with regard to chemistry".[42] It is not clear whether he considered the City and Guilds Governors to be part of that public.

Most of the forces in play are not revealed by minute book entries and the bare statistics of student numbers. Nevertheless, the attempt to synthesize chemical and engineering training clearly failed to attract students, and Armstrong's later remarks suggest that he found it an academic failure also. He does not seem to have taken seriously the attempt to introduce the techniques of industrial operations or focus on industrially relevant work. In later years he reserved some of his strongest criticism for the German universities which developed close links with industrial activity.[43] The Central Technical College had little attraction for chemistry students, who could acquire chemical knowledge elsewhere without studying engineering subjects of doubtful perceived relevance to their likely future employment. The composite of chemical and mechanical engineering knowledge seems to have had little attraction for firms, whose knowledge demands were more focused: Brunner, Mond's only known recruit from the college was a mechanical engineer, as were those of the United Alkali Co.

Perhaps not surprisingly, Armstrong's activities at the Central Institution received comparatively little attention from those who were later active in establishing chemical engineering as an independent field. They in turn received only criticism from him. Attempts were occasionally made by Armstrong himself and later acolytes to reinstate him as a founder of chemical engineering, with some audacity but little success.[44] Nevertheless, some of the pressures which he had experienced had parallels in later years, though within a different complex of forces. They appear at intervals in the next section, which explores the place of chemical engineering in public discussion during the years before the First World War.

C. Chemical Engineering in the Public Sphere 1887-1917

It was seen in chapter 4 that a similar industrial influence to that at the Central Institution was to be found at the Andersonian. It eventually had a similar effect, and a course entitled chemical engineering was inaugurated there in the late 1880s, though its character was not really documented at that time.[45] Of greater interest, partly because it is better documented, is the well-known course given by George Davis at the Manchester Technical School in 1887, and reprinted in his Chemical Trade Journal in 1888.[46] Davis was mentioned earlier in this chapter, attempting to establish a Society of Chemical Engineers in 1880. Aspects of his career are relevant to this discussion.

He had been trained at the Royal School of Mines, and then worked at various chemical firms, following the usual trajectory from analysis to process control and development work.[47] In 1881, after a period of as a consultant, he was appointed as an assistant Alkali Inspector, working in the Midland Region. He resigned from this position in 1883, setting up again as a consultant in Manchester. During the following year he placed an advertisement in the Journal of the Society of Chemical Industry which referred to the experience gained from his former public appointment. This precipitated a minor crisis in the Society when Alexander Chance, of the Midland chemical firm, objected to the advertisement, pointing to Davis's previous right of access to works.[48] Davis refused to withdraw the advertisement, but the Council of the Society did not terminate it, through fear of litigation. The Council contented itself with a public statement of disapproval in the Journal.[49]

There are echoes of this situation at the time of Davis's lecture course. In an editorial preface to his reprints of the lectures in the Chemical Trade Journal he noted that a certain manufacturer had remarked of them:[50]

> It is all very fine for Davis after having the entree of all the chemical works in the country to now go and lecture about them.

Davis was scathing in his response.

> This little speech...shows the absolute ignorance of the speaker on the subject of chemical engineering. The science of chemical engineering does not consist in hawking about trade secrets...Chemical engineering has higher aims, it endeavours to work out the application of machinery and plant to the utilisation of chemical action on the large scale...

These comments reflect some of the tensions which marked chemical technology in educational institutions and which were discussed in chapter 4. They were compounded by Davis's earlier public employment. Davis did not resolve the tension by advocating instruction in academic science, but by developing a conceptualization founded on the plant used in such industrial operations as filtration, distillation and so on. He made clear that he was not focusing on the construction of machinery or works (a point of view which was to sustain the notion of chemical engineering as a form of mechanical or civil engineering) but rather to the selection, design and operation of plant in its chemical aspect--"the utilisation of chemical action on a large scale". Davis also commented on the relationship of the field to manual labour.[51]

> (I)t is a question for discussion whether the technical information should be given to the labourer or to those in charge so to speak of the process; I think the latter. The labourer is the equivalent of the engine. You instruct your engine as much as you can by means of automatic appliances...

So far as methodology was concerned Davis's chief focus was on the issue of scaling up, and he emphasized the difficulty of replacing small-scale with large-scale operation. However, instead of making references merely to the need for individual experience he developed the idea of the "technical experiment", in which some of the constraints of large-scale operation were deliberately reproduced in an intermediate-scale laboratory. Davis also attempted to systematize and generalize the plant and operations involved at the larger scale, and their investigation, in ways which ran across the production of specific commercial products. He converted chemical manufactures into a set of phenomena which could be studied independently of such specific and potentially-secret chemical processes.

This 'deconstructing' of industrial processes can perhaps be connected with Davis's chosen occupation, industrial consultancy. Consultants had to transmit their experience from plant to plant and from process to process, yet in a way which did not compromise the private or specific knowledge which contributed to a given plant's profitability.[52] As he himself remarked

> if a chemical engineer were discovered taking the processes and the details from one works to another, his professional reputation would soon come to an end...

This almost paradoxical problem had strong parallels to those of public curricula of chemical technology.

There is also an implication here that the chemical engineer is someone acting in a "professional" consultant's role. The elements which go to make up Davis's approach (scaling up through the technical experiment, breaking down of chemical manufacturing operations (both phenomenologically and into regions of public and private significance), the systematization of plant and the conscious replacement of manual technique within the machine) constitute an important shift from the notion of a derivative 'applied science' on the one hand, and holistic descriptions of particular manufactures on the other.

The course in Manchester ran only briefly: there is no record of the number or type of students which it attracted, and it was not acknowledged in the Technical School's official programme. Like the Central Institution and the Andersonian, the Manchester Technical School was strongly influenced by manufacturers. The course may even have been instigated by Ivan Levinstein, who was one of Davis's clients and, as has been discussed, active in the Technical School. In 1886 he had referred to the need for chemical engineers and for courses of the type Davis gave.[53] However it seems unlikely that the course linked with routes directly into works, whatever the sympathies of manufacturers in their public roles. Ostensibly it was grounded in the design of chemical process operations, but a brief lecture course was unlikely to have been adequate to develop instrumental competence in its auditors. There is no evidence that manufacturers employed individuals (other than consultants) specifically for this purpose. Those who undertook such activity (either within works or as consultants) were experienced men unlikely to attend such a course. The course was closer to a programme or set of headings which gave the rubric of Davis's consultancy practice rather than its substance: in parts it resembled a plant manufacturer's catalogue. Overall his notion of the chemical engineer did not possess a developed pedagogy or engagement with the industrial employment structure.[54]

Davis's ideas were taken up at intervals in the Society of Chemical Industry. In 1890 Norman Tate, the Chairman of the Liverpool Section, called for "good practical expositions of general operations...instead of some of the courses on special processes".[55] There is here a pre-echo of the terminology of Little's 'unit operations'. The Institute of Chemistry briefly offered an examination in General Chemical Engineering in 1893.[56] But the novel field was not without opponents. In 1894 Arthur Smithells made an attack on the domain. Smithell's early view that training for the chemical industry must be that of "a chemist pure and simple" has already been noted.[57] He argued that "at the bottom of all these schemes for producing chemical engineers" was the demand by manufacturers for immediate usefulness in the graduate. In this they were mistaken, he claimed, as "there is no royal road to chemical engineering". By this he appears to have meant that the field could not exist in an academic form as compared with industrial or consultancy practice. George Beilby, then President of the Society of Chemical Industry, took up the idea more sympathetically in 1899.[58] He suggested that the notion of the chemical engineer had developed as a complex of activities which were undertaken in works, but which did not form the subject matter of any existing curriculum, and were distinct from the fields of the "general engineer or architect". This complex was focused on the techniques for scaling from the laboratory to "new methods, new forms and new materials...works operations are not simply laboratory operations writ large". Beilby was aware of the difficulty of exposing chemical processes in the public sphere, and attempted to resolve it by distinguishing between apparatus and processes.[59]

> Apparatus is generally the property of the whole trade, or it is patented...Processes on the other hand are much more difficult to protect by patents and are often worked secretly.

These comments indicate some of the forces in play which led to the emphasis on chemical engineering as a medium of education in chemical technology, as well as the resistance to it. Beilby offered his remarks as a direct response to the difficulties in deciding what was the appropriate training of the technical chemist other than teaching him "how to analyse things". His account was derivative of that of Davis, to whom he referred.[60] Raphael Meldola, in the subsequent discussion, took up the theme that chemical engineering must constitute "a distinct branch of applied science".

The late nineteenth exploration of the notion of chemical engineering reached a kind of conclusion with the publication in 1901 of George Davis's famous textbook A Handbook of Chemical Engineering, based on the 1887 lecture series. Here Davis distinguished applied chemistry, chemical technology and chemical engineering, setting up the last as a generalized large-scale complement of applied chemistry.

This was a shift from the usage which represented industrial activity in the chemical field as "applied chemistry". Davis painted the chemical engineer as a specialist who had developed from the need to handle the growing body of publicly-available information in the chemical sector, the implication again being that he was referring to the consultant.[61] Davis argued that the new field stemmed from the reconstruction of this body of material into a specialism which was potentially an academic field. The impetus for the new "branch of applied science" came from this body of commercial-technical specialist knowledge and not from any separately-constructed "pure" science. For Davis, then, chemical engineering was a "branch of applied science" but not "applied chemistry". The publication of Davis's book and the attention devoted to the field by the Society of Chemical Industry were the first indications of the presentation of chemical engineering as a potential resolution of conflicts over what was an appropriate curriculum in chemical technology.

In part the issue was subsumed within the general question of teaching "technology", discussed in chapters 3 and 4. The idea that mainstream academic disciplines underpinned industrial practice was well-entrenched by the turn of the century, and they themselves were well institutionalized. This was reinforced by claims to be setting up curricula defining a class of day students appropriate for relatively senior positions within industrial firms. Such men would follow courses embodying a high level of generality, remote from the detail of plant operations. Evening class students were in a different position, and it was here that new courses involving a version of chemical engineering were first deployed around the turn of the century. A list of early courses in chemical engineering which has been published excludes those available at this time in a number of technical institutions, such as Bradford Technical School and Battersea Polytechnic.[62] These seem often to have been opportunistic combinations of chemistry and mechanical engineering. The title may have been an attempt by lower level educational institutions, anxious to signal their dedication to direct industrial relevance, to exploit the aura of practicality associated with "engineering". Mechanical engineering offered opportunities for intervention in the reproduction of the artisan workforce for which there was no chemical equivalent, and these courses perhaps represented attempts to reproduce this in a chemical context.[63]

In 1909 something of a breakthrough occurred, with the establishment of JW Hinchley's integrated course at Battersea Polytechnic. The Chemical Trade Journal commented as follows:[64]

> It is gratifying to see that our educational institutions are at last recognizing that chemical engineering cannot be taught successfully by digressions in cognate subjects. It is now a complete and separate subject,...and its elements can no more be taught by studying those parts of chemistry, chemical technology, and engineering which entrench on each other...It has taken long for the special character of chemical operations in the gross to be recognised.

This formulation anticipated a sharpening of the argument, both publicly and within institutions, which developed during the the second decade of the twentieth century. The establishment of the Battersea course was significant, but it was the course at Imperial College, to be discussed in detail shortly, which was the clearest location for the field in high level institutions. Chemical engineering would be offered there as an appropriate preparation for higher level works employment which went beyond "chemistry pure and simple".

It was from these initiatives that chemical engineering emerged as profession and discipline during the first decades of the twentieth century. Yet, in contrast to the situation in the USA as interpreted by Noble, in the UK a complex body of personnel contributed to the process. It ranges from industrial 'leaders' through their employees to the consultants already discussed. In addition academics from the main science disciplines were active, as were specialists in a range of other emergent technological fields. In the following pages the views taken by these groups will be surveyed, beginning with consultants, the group within which chemical engineering was most sharply conceived at the turn of the century.

In 1906 a second textbook on the subject was published by a Manchester consultant chemical engineer, Jacob Grossmann.[65] Grossmann rejected the teaching of chemical operations "just as they occur in connection with certain industries", suggesting that chemical engineering constituted the "essential principles" underpinning such specific manufactures. The key dimension which plant-scale operations involved was that of cost, and this should be fundamental to an understanding of processes.[66] Costing was an element which was present in most accounts of chemical engineering curricula. However, because it was rarely explored in detail, and did not precipitate any radical reconceptualization of the field, it will be given little attention in this account. Another consultant, Oscar Guttmann, while describing himself as a chemical engineer, was more ambivalent about the term chemical engineering ("because all branches of engineering come into use").[67] He was himself a Member of the Institution of Civil Engineers, which may indicate the source of his doubts. Consultant plant designers such as Davis and Grossmann had an important role in formulating the idea of an independent profession through to the 1920s, operating in a symbiosis with educational activity. In the USA the consultants Walker and Little were similarly placed.[68]

Some of the reasons for consultants' special position in the selection of public and generalized elements of manufacturing chemistry have been indicated earlier. A number of points can be added about the emphasis on chemical plant rather than specific chemical processes. Beilby's comments on the public character of the former have already been noted. In mechanical terms the machinery used in chemical works was relatively unsophisticated: physical precision was not crucial, could indeed be a disadvantage when corrosive chemical materials were being handled. It was sometimes claimed during this period that the main speciality of the chemical engineer was in deploying corrosion-resistant materials. One of the reasons for the importance of security in chemical works was the possibility of keeping secret the chemical process used. The reproduction and alteration of simple machinery was easier, and the proof of novelty correspondingly difficult. Relatively few of the patents appearing in the Journal of the Society of Chemical Industry dealt with specialist chemical manufacturing apparatus rather than materials.[69] Moreover consultant chemical engineers frequently did not "design" machinery so much as select and combine that of specialist plant manufacturers, as well as ensuring its operation in novel circumstances. The 'catalogue' character of Davis's lectures was referred to earlier. Indeed in 1915, when there was a surge in the use of the term, the Chemical Trade Journal complained that "agents for the sale of chemical plant" were describing themselves as chemical engineers.[70] Chemical machinery was treated in a relatively open and relaxed way. It can be argued that it was for this reason that machinery became an important medium for the public conceptualization of industrial chemical activity in ways which engaged directly with plant activity. It is less easy to explain why men like Grossmann, Davis and, later, JW Hinchley should have been attracted to develop their ideas in educational terms.

As consultants began to formulate the field in this way, it is among academics that the strongest response can be found. As has already been noted, the field attracted hostility from some men in established fields. Other academics took a different stance. That of Raphael Meldola was among the most positive, and in 1909 (though not referring directly to the Battersea course) he gave the field an enthusiastic endorsement:[71]

> We are, I think, in a position to face that bugbear with a certain class of chemical teachers--chemical technology in educational institutions. What does it mean?...it means generalised chemical engineering...

He also attempted to map the issue against the potential divisions of labour among the workforce, and took up the notion of "general operations" which had been suggested by Norman Tate nearly twenty years before. He added, however, that many teachers poured contempt on "the much despised hybrid chemist and engineer". Another academic supportive of the area was FG Donnan, who suggested "a sort of laboratory of general applied chemistry, with some of the general apparatus of chemical engineering".[72]

The identification of the claims of a specific domain of chemical engineering was also given an impetus by the First World War. As the Ministry of Munitions expanded its demands and the armed forces recruited men from industrial plants the term became identified with an area in which shortage of personnel was experienced--the capacity to control the operations of chemical plant.[73] In 1915 the Chemical Trade Journal commented on the increased popularity of the title and its usurpation by "opportunists" of various kinds.[74] Also at about this time the first attempt was made (excepting the efforts of Davis in the 1880s) to set up a 'professional' institution in the field. This will be discussed later. Referring to the class of men able to set up and run chemical plant FG Donnan remarked

> let us call them 'chemical engineers'. The name does not matter very much. I greatly dislike the name 'works chemist'...(it) recalls to my mind the ill-paid 'maid-of-all-work'...[75]

Donnan was referring to the association of the term "chemist" with routine analytical work which was referred to in the previous chapter. By contrast "engineer" communicated an association with competence on the large scale, as one of the advocates of professional organization argued just after the War.[76] It was occasionally suggested that the basic classes of personnel required in the chemical industry were research chemists and chemical engineers.[77]

As chemical engineering spread outside the technical colleges the new enthusiasm precipitated a number of public exchanges about its appropriate academic position.[78] It was brought to the consciousness of a more hostile audience. Arthur Smithells argued in 1916 that[79]

> they must have the engineer trained with chemical sympathies, and the chemist trained with engineering sympathies...and they must not talk too much about that doubtful and indescribable person , the chemical engineer, being trained for that particular vocation in life.

This hostility is particularly significant when compared with Smithells' general support by this time for training in industrial chemistry. FG Donnan (whose attitude to technical studies in universities was generally much more ambivalent) offered an argument formulated both to support the novel discipline and his own physical chemistry specialism:[80]

> They certainly wanted constructional engineers, and engineers of every sort, and they absolutely wanted chemical engineers...there was a very large class of young man who was required to go into the mill and turn the wheels and carry out experiments in order to get the data required for engineering design of a chemical plant which might very well be included under the name of applied physical chemistry...

Men of this type he estimated to be required in the ratio of ten to one over research chemists. They needed to study "reaction velocity, equilibrium, etc...". Donnan had argued earlier that his own specialism of physical chemistry ought to be the foundation of the relevance of academic chemistry to industry (see pp.289-90). His approach to chemical engineering may have been a tactical move in this respect. However, during this period a small group of men began to make an explicit claim to greater curricular independence for chemical engineering. JW Hinchley received a mixed reception, in the relatively sympathetic forum of the 1917 Conference of the Faraday Society on chemical engineering, when he remarked that

> ...he wished to put in a plea for the chemical engineer. It was absurd to talk about the chemist appealing to the engineer unless they defined what sort of an engineer they meant. The ordinary mechanical engineer was quite untrained in the particular points which the chemical manufacturer had to handle.

Critics attacked this view, one calling it an "ad hoc" notion of the chemical engineer. Frequently these attacks on the independent idea of chemical engineering came from manufacturers and their senior managers. Donnan, in 1915, claimed to have experienced hostility from the industrial sector to the notion of chemical engineering.[81] This returns the discussion to Noble's view of chemical engineering as "made to order".

The influence of industrial capitalists on educational activity in Britain was always ambivalent. The efforts of Ivan Levinstein to influence the curriculum in the Manchester institutions, discusssed in chapter 4, can be counterbalanced by examples of industrialists who emphasized only the benefits of curricula in the 'pure' sciences. This is not to say that industrial capitalists did not wish to exert a direct influence on educational institutions. The Report of the Departmental Commission on the Royal College of Science in 1906 was criticized in academic circles for the extent of industrial representation in its recommendations for the membership of the governing body of the new college at South Kensington.[82] The Society of Chemical Industry was represented on the Governing Body, rather than the Chemical Society or the Institute of Chemistry. John Brunner told the Liverpool University Club in 1901 that universities would need to give power to those "who hold the purse", which, he explained, meant "men of business".[83] But Brunner's attitude was not utilitarian, at least not narrowly so, as he indicated two years later:[84]

> If we as a nation were now to borrow ten millions of money in order to help science by putting up buildings and endowing professors we should get the money back in the course of a generation a hundredfold. There was no better investment for a business man than the encouragement of science...

Collective attempts to influence curricula in very specific ways, such as that of the American Institute of Chemical Engineers from 1908, were uncommon.[85] In 1899 Raphael Meldola told the Society of Chemical Industry that he supported "preliminary training in the use of chemical plant for large-scale operations" despite the fact that when giving evidence to the recent LCC Sub-Committee "the whole weight of the evidence given by the expert manufacturers...was against me".[86] The attitude of manufacturers becomes particularly difficult to define as aspects of chemical engineering which gave it a novel conceptual and curricular basis come into focus.

When the idea of chemical engineering did receive support the formulations stemming from industry usually presented the chemical engineer as a composite of the two fields. George Beilby had tended to fall back on this position.[87] Among the larger number which was hostile there was resistance to the erosion of what were seen as fundamental specialisms in chemistry and mechanical engineering, however conceptualized.[88] It will be seen in the later discussion of the situation at Imperial College that there was hostility to the weakening of divisions between technical colleges/polytechnics and universities. Overall, with the possible exception of the last element, the influence of industrialists cannot be seen as fitting any uniform model.

The views from industry were underpinned by industrial personnel structures, where industrialists could have an immediate influence and direct knowledge. The clearest potential role for the academically trained chemical engineer was not in process control but in plant design and development, where quasi-academic investigatory procedures could be invoked. This area had developed quite a complex structure by this time: a paper to the 8th International Congress of Applied Chemistry in 1912 delineated five stages in the development process.[89] During the Faraday Society conference referred to earlier HL Heathcote, a Midlands chemist, argued that the power of a firm to assimilate classes of trained men depended largely upon the extent of its organization.[90] It seems reasonable to look for the recognition of a new specialist role, and its projection into academic form, in the more technically advanced UK firms.

However it does not seem that the complexity of the procedures which may have developed in some cases was reflected in a formal differentiation between personnel, or at least not in one which included the chemical engineer. When Leeds University was considering the establishment of a chemical engineering department in 1916 JC Cain of British Dyes Ltd. was invited to a small conference on the subject. Cain was then establishing a 1/100 scale laboratory at the firm's Huddersfield works. Nevertheless he expressed hostility even to the idea of training chemists in engineering, and argued that co-operation of specialists was what was required.[91] He certainly did not envisage the chemical engineer as a new specialist available for deployment. Though the firm had a direct involvement with the University this was not converted into attempts to shift curricula in radical ways.[92] The proposed department was not formed.

Similarly, in the immediate post-War years, when Brunner, Mond was working to develop ammonia synthesis using a process studied initially by the Ministry of Munitions at University College, London, it possessed no body of chemical engineers available for research and development work. Many of the staff for work at Billingham were recruited in 1919 from the Ministry of Munitions team.[93] The laboratories at the Billingham works were modelled on those at University College. As new staff were recruited there is no evidence of any emphasis on or recognition of specialist chemical engineers.[94]

Firms of this kind, at the limit of technical organization in the UK, were only slowly and not particularly surely constructing models for the separation (and organizational integration) of novel classes of employee, while working on problems at the limit of what was technically feasible. It does not seem possible to argue, at least for the UK, that they, still less technically undeveloped firms, influenced educational practice by offering novel curricular 'blueprints' to educational institutions. Most of the process of development of such curricula was an internal academic negotiation.[95]

This section has mainly surveyed the situation in the sphere of public argument and representation. The following section looks more closely at the early development of chemical engineering at a key British institution--Imperial College of Science and Technology. This will allow discussion of the forces in play in a specific academic environment. Some have already been referred to, but others will be apparent. Though the discussion will mainly refer to Imperial College, some reference will also be made to University College.

D. Chemical Engineering at Imperial College London

It is not intended to give a detailed history here of the situation at Imperial College, but rather to rehearse those events which reflected the problematic nature of chemical engineering in an academic environment. This aspect of the college curiculum involved especially a tension between technical specialisms in the chemical field, on the one hand, and chemical engineering as a force for unification, on the other.

Imperial College was formed partly as a result of the Departmental Committee on the Royal College of Science in 1905-6, with the aim of combining and rationalizing the facilities offered by the City and Guilds College, the Royal School of Mines and the Royal College of Science into a large scientific and technological centre comparable with those of Germany.[96] In the years after the formation of the Royal College of Science the Chemical Department at South Kensington had been devoted entirely to courses in "pure" chemistry, with no provision for chemical technology. The first Professor of Chemistry at Imperial College was William Tilden, and Tilden's views reflected this situation. He told the Departmental Committee that in educational institutions "there is (no) practical difference between pure chemistry and applied chemistry...I myself do not incline at all to this idea of establishing a sort of mimic manufacturing operation in a college".[97] During the first years of the College's existence the subject continued to receive no public attention, and was not mentioned in its first Annual Report. The Central Technical College, an obvious location for such activity, was described as devoted to "Applied Science, especially in relation to Mechanical, Civil and Electrical Engineering".[98] As the courses within the constituent colleges were integrated, Armstrong's department was run down and closed in favour of the more popular Royal College Department.

The first steps towards curricular reconstruction occurred with the establishment in 1907 of an Organisation Committee of the Governing Body, with four subject-orientated Sub-Committees.[99] The emphasis on industrial representation on the Governing Body has already been noted. The "Pure and Applied Sciences" Sub-Committee, under which chemical technology was classed, co-opted five others of whom at least three and probably four were industrialists.[100] The issue of chemical technology was raised by the Governors. A report was produced in 1908 by two of the co-opted men, George Beilby and Richard Threlfall. It recommended a department with a four year course, but plant to support it came fourth in the Committee's order of priorities. A number of ad hoc specialist courses was suggested in the meantime.[101] Chemical technology was already exhibiting the tendency to disintegration observed in chapter 4. Only one of the suggested courses, on Gas Manufacture, was implemented. At the suggestion of Tilden another, on Gaseous Combustion, was given by William Bone in 1909-10, under the auspices of the Chemistry Department.[102] Whether because of lack of resources or Tilden's lukewarm attitude the recommendation for a full department was not acted upon, and the report suggesting it had been forgotten when the subject was seriously reconsidered in 1911.

In 1909 Tilden retired and was replaced by TE Thorpe. Thorpe's attitude to industrial chemistry was more positive than that of Tilden.[103] In 1910 he recommended to the Organization Committee that a lectureship in Chemical Engineering be established, though to offer only fourth year courses. At about the same time the Governors again raised the question of a Department of Chemical Technology with the Organisation Committee. Financial constraints were still operating, but the proposal also faced difficulties because of its vagueness. Requests for information passed between the Finance Committee and the Organisation Committee during 1910, but the former was unwilling to set a figure for the money which might be available, while the latter was unable to identify and thus cost the key plant and resources which such a department would require.[104] The Annual Report remarked that "financial considerations" prevented the "full and immediate realisation" of the Department of Chemical Technology, though what such a "realisation" might be was not stated. Eventually the Organization Committee agreed to the establishment in the meantime of a course on "Design of Plant Required for Chemical Manufacturing".[105]

It was not until November 1910 that JW Hinchley was appointed to teach this 20 week course of two afternoons per week.[106] Hinchley had begun the course in chemical engineering at Battersea Polytechnic in 1899 which had so pleased the Chemical Trade Journal. He was to be extremely active in the institutionalization of chemical engineering in the UK, and it is not surprising to find that, like Davis and Grossmann, he was mainly occupied as a consultant in the design of chemical plant.[107] The course was announced with a comment that was dismissive of existing chemistry or engineering courses as a sufficient preparation for the design of chemical plant, and which prefigured Hinchley's commitment to chemical engineering as an independent activity.[108] A clearer impression of Hinchley's view of the activity can be gained from his private comments at about this time. In a letter to the chemical manufacturer William Pearce he suggested that the course was intended to replace, so far as possible, "years of experience and many failures...Commercial efficiency will be the test of pupils' designing...".[109] Later in the year, writing to Thorpe, he supplemented this in a statement of the apparatus which he would require.[110] This would be

> apparatus for the determination of construction, or factors relating to design, which cannot be deduced from physical or chemical knowledge...This apparatus does not attempt to eliminate causes of disturbance which are present in factories, but makes it possible for the student to appreciate their value.

Here Hinchley seems to be avoiding the idea that his field was merely derivative of the "pure" sciences, as well as anticipating in principle the existence of techniques by which technical phenomena might be conceptualized in an independent way.

Hinchley was also very conscious of organizational implications in the employment of men with specialist competencies. In a paper to the Association of Chemical Technologists delivered in 1912 he was anxious to press the division of labour as far as possible.[111] He explicitly contrasted detailed control and monitoring of processes by trained men, with secret working and individualistic knowledge: the authority and communication structure of the works, he implied, would embody a framework of knowledge beyond that accessible to individuals. He also argued that this required a well-ordered hierarchy, with strict discipline over the lines of reporting and command. Hinchley's view of the technologist ("able to direct and improve methods of manufacture, and to control and organise factories") fits well within the paradigm offered by Noble for the USA. However, Hinchley himself demonstrates the differences which the British situation displays, since he was not a representative of that industrial elite to which Noble gives a key role. He was active in Labour politics in his youth and in the organization of scientific workers during and after the War. It is not surprising to find that Hinchley was a Fabian.[112]

The existence of Hinchley's and Bone's courses, under the auspices of the Chemistry Department, was seen by the representative of the Society of Chemical Industry, Edward Divers, as undermining a more integrated approach and late in 1910 Thorpe agreed to produce a memorandum on the subject.[113] Divers was asked to canvass the views of the Society's Council, to establish their preference between a single department and ad hoc courses.[114] What the full Council thought is not recorded, but Divers remarked privately that Hinchley's course "was certainly received coldly at a Committee of the Society of Chemical Industry,...comparison being made with 'polytechnics'...".[115] The ambivalence of the response of industrialists to proposals for high-level technological work can be seen here. The main pressure for a new department came from within the Governors of the College, but there was also a resistance to novel curricular ideas, expressed, significantly, in terms of their resemblance to institutions which catered for a lower class of student.

Thorpe's Memorandum was completed in January 1911. Neither he nor the College's Rector, Alfred Keogh, was aware of the existence of the Beilby/Threlfall report from three years earlier.[116] In the report Thorpe saw the new department as a composite of many specialists teaching particular industrial fields, and independent of the Chemistry Department. He alternated between calling it "Applied Chemistry" and "Chemical Technology". The course was to be full-time and preceded by the usual 3-year course in science. While Thorpe was producing the document Keogh undertook many consultations with industrialists and others about the best type of activity to initiate. The issues of specialization, secrecy and the type of apparatus which could be used, referred to in chapter 4, continued to dominate the replies which he received. Among this correspondence is an enquiry from a potential evening student about the possibility of part-time or evening studies, which was dismissed summarily.[117] Raphael Meldola argued in his reply to Keogh's enquiry that the function of the College was to train men to enter industry "at a high level". Men for "subordinate posts" could be trained mainly in the works. He added however that for teaching purposes on such courses "(t)he purely academic chemist is of no use...".[118]

In fact Hinchley believed that a study of chemical engineering was a sufficient qualification in itself. He tried to pre-empt the work of the Committee during 1911 by suggesting a separate Certificate in Chemical Engineering. Consideration of this was deferred by the Governors, and overtaken by events, but Hinchley continued to advocate an independent qualification.[119] Eventually a sub-committee under Arthur Rucker was appointed to consider Thorpe's report.[120] This sub-committee agreed that the department be established, in as inexpensive a form as possible, under a suitable director. It then became involved in a rather embarrassing attempt to find a director: numerous men were approached (eg. Otto Witt, William Bone, George Beilby, Gilbert Morgan and Meldola). The details of this activity were of course often simply personal, but one of the underpinning difficulties was still the doubtful unity and independent status of the "Department": William Bone, for example, was said to be "deficient on the organic side" while Otto Witt was perhaps "too magnificent" for such an enterprise.[121] One of the methods suggested for ensuring that the department covered the field was the affiliation of other institutions (the Leathersellers' College was mentioned as an example). This proposed connection with lower level institutions provoked hostility in some quarters, despite the provision for it in the College's Charter.[122]

The Sub-Committee's eventual recommendation was that the "Department" should be formed, but merely by the addition of electrochemistry to the existing lecture courses given by Bone and Hinchley.[123] It considered recommending that they should be placed under Thorpe, as "sub-departments" of chemistry. In fact Thorpe had been in informal contact with William Bone as a potential Director throughout the year, and Bone had produced a detailed commentary on the various proposals.[124] In June he was hoping that the still-vague proposals would become more definite, and not clear whether his own interest was to be limited to Fuel.[125] Eventually he was offered a Chair involving general responsibility for the field, but this was still to be under the formal supervision of Thorpe. According to the Executive Committee minutes there were to be three "Departments", within Chemical Technology. Informally Bone was told that Thorpe's effective control would be minimal.[126] At the suggestion of the Society of Chemical Industry's representative, now Rudolph Messel, an Industrial Advisory Board was to be established. According to an information booklet published at the time this was to ensure that the Department's development was "in accordance with industrial demands."[127]

The surviving documents do not make clear the positions being adopted, but it is apparent that the difficulties in defining and institutionalizing chemical technology in an academic environment, which figured so largely in the nineteenth century, had carried over into the twentieth. The department established under the pressure of the Governors was a composite of _ad hoc_ initiatives. Ambiguities in the positions both of Bone and Hinchley, and what the Department was attempting, were to precipitate numerous conflicts. The most important of these concerned the unity or otherwise of the proposed 'Department'. The question of its orientation to works personnel was effectively resolved by its post-graduate character, and by the resistance to affiliation with other institutions. The first of these also resolved, formally, the curricular relations of the field to 'pure' science. Some soundings were made about possible duplication of effort within London University. From Ramsay at University College came the relaxed message that while University College had considered setting up such a course it was now felt that "we have enough to do with our pure science here".[128] Evidently practitioners in the maturely established "pure" discipline felt confident about its position. University College also had experience of the difficulties of chemical technology. This lack of interest might have been repeated at Imperial College but for the Governors' repeated intervention.

Bone's position quickly became the focus of conflict. He objected to a press release in _The Times_ which described him as subordinate to the Professor of Chemistry. He particularly argued that anything which appeared merely as a component of the Chemistry Department would receive little support from industry.[129] This fear, combined with resistance to _ad hoc_ initiatives, reflects the tensions within a field which was derivative of other disciplines. In terms of Bone's appointment, as recorded, _The Times_' description appears accurate. Nevertheless he was apparently granted a _de facto_ independence, since in the following year the Chemical Technology Department appears separately in the College's _Calendar_.[130] The independence had few curricular implications. The four-year course leading to the College's Diploma, suggested by Bone to the Board of Studies in 1913, followed Thorpe's recommedation and was based on the ARCS course in its first three years. The fourth year involved a large proportion of chemical engineering (2 days per week) with the remaining time being used for a variety of more specialist work, such as that of Bone himself on Fuel.[131]

Hinchley continued to be responsible for the chemical engineering activity. This was based on the approach referred to above, though with a substantial emphasis on students generating a body of data which systematically covered a wide range of situations. They undertook concrete chemical engineering projects based on "units of plant": the course was thus built around 'unit operations'. The Department possessed a range of industrially-related plant, including an experimental gas producer plant donated by Robert Mond. Hinchley was doubtful about the value of lecturing. Reliance on individual working caused him to be requested at one point to give his students greater supervision, but he was by all accounts an effective and conscientious teacher.[132] His description of the work to the Conference of the Faraday Society on Chemical Engineering in 1917 indicated his approach, and recalled the comments previously referred to. The student was to "make himself familiar with methods of handling problems which are too involved for exact treatment...".[133] Though "the wisdom obtained by experience" could not be taught, the "seed" of such wisdom might be planted. He was to gain a limited insight into that body of knowledge previously only attainable by the practitioner. That this activity was seen as underpinning the rest of the Diploma course is made clear by the structure of the latter, and this underpinned much of the tension between Hinchley and Bone.

The early facilities for chemical technology were in a basement of the Chemistry Department. When new buildings were constructed in Prince Consort Road in 1914 Bone prevented Hinchley from moving into what was commonly called the "Fuel Building", arguing that the space was needed for other work. Despite his protests Hinchley was located in an annexe of temporary buildings.[134] During this period Hinchley was still operating a consultancy practice, while Bone was a full-time Head of Department (though still allowed to undertake consultancy) and there was little explicit conflict between the two men. The original proposal for a department had envisaged a range of specialisms, but these were not implemented, apparently on financial grounds. Thus in June 1914 Keogh resisted a suggestion from Henry Roscoe that the Department be expanded to include explosives.[135]

During the First World War the activities of the College were curtailed.[136] Reference has already been made to the increased prominence given to chemical engineering during the War. This was merely a minor component of the radical changes which occurred at that time in the environment for educational activity. The position of science in relation to industry and public support was also strengthened.[137] Many educational institutions and fields made bids for involvement in anticipated post-War expansion from an early stage. So far as chemical engineering was concerned the 1917 Conference of the Faraday Society, at which Hinchley spoke, addressed the new situation.[138] Within a few days of the Conference Bone prepared a Memorandum on the future organization of the Chemical Technology Department at Imperial College.[139] He made little reference to chemical engineering, arguing rather for a diversification of the department into a "broader basis of work and study". External events were however to influence his view.

At University College, following the death of William Ramsay in 1916, the Professorial Board set up a Committee to consider a suitable memorial. In addition the college, now less relaxed about the prospects for chemical technology in universities than in 1911, began to make provision for courses in applied science and the design of chemical plant. Promises of an eventual more systematic approach appeared in the <u>Calendar</u>.[140] In May 1917 it became clear from reports in <u>Nature</u> that the University College proposals for a Ramsay Memorial were to be orientated mainly towards chemical engineering, acting also as a resolution of the issue of applied chemistry within the college.[141] At Imperial College this stimulated Bone to correspondence in which he questioned the legitimacy of the University College move, but it also caused him to alter his view of the needs of Imperial itself. Referring specifically to the potential University College course he told Alexander Gow, Secretary of Imperial College, that it was desirable that Hinchley should be promoted to assistant professor and his teaching time increased.[142] When the Ramsay appeal was formally launched, in June, Bone persuaded Gow to write to Nature on the suitability of the proposed memorial, but the letter was not published.[143] In June 1918 the Executive Committee at Imperial College appointed a special committee to look at the future development of the Chemical Technology Department. Bone produced a second memorandum on the subject, in which the argument for diversification was diluted, and which looked to the appointment of a full Professor of Chemical Engineering.[144]

Bone also attempted to prevent the establishment of an independent department of chemical engineering at University College. He persuaded the authorities at Imperial to object to the initiative, using the procedure which had been established to control relations between institutions associated with London University.[145] In March 1919 after a Joint Committee had failed to resolve the matter a "delegate conference" was called, under the auspices of London University Senate.[146] Bone's were the main objections stated. He claimed that there would be "wasteful overlapping" between the two institutions, but suggested also that "Chemical Engineering cannot be properly developed as a subject of post-graduate study except in close association with other branches of Chemical Technology". For his part EG Coker, Professor of Mechanical Engineering at University College, suggested that the approaches of the two institutions were radically different, and that Imperial College department was in fact "a series of Research Schools in various branches of Chemical Technology". Eventually deadlock was reached, and the Conference resolved merely to make no objection to the University College proposal.

Bone was of course speaking only for himself in relation to chemical engineering. Hinchley certainly disagreed. When, after a long delay, the University College Chair was eventually advertised he, and another member of the Imperial College Department, applied unsuccessfully for it.[147] Bone's fears on the subject were made more explicit some years later, when he told the Board of Studies at Imperial College that, partly as result of the University College department, "in some quarters, the term 'Chemical Engineering' is being used as synonymous with 'Chemical Technology'".[148] Hinchley was now close to a full-time member of staff, with the courtesy title "Professor". His interest in the independence of chemical engineering became more explicit both internally and, as will be seen, externally. The situation at Imperial had reached a stability (or deadlock) which changed only slowly. The process of change can only be sketched here.

In the period from 1920 to 1926 Bone and Hinchley were involved in a sequence of disputes over such matters as salaries, Hinchley's representation of the financial position of Chemical Engineering, his independent requests for funds, the signing of requisitions, the use within Imperial of the title "Professor", and eventually Hinchley's proposed editorship, without consultation, of a book on fuel. The last occurred after Hinchley had obtained a full Chair, and is indicative of his view that chemical engineering underpinned Bone's specialism.[149] The College authorities generally appear more sympathetic to Hinchley. In 1921 they took legal advice on Bone's contract and the possibility of placing chemical engineering on an independent footing, but nothing came of this.[150] By 1926 the hostility between the two men was sufficiently strong to cause the Executive Committee again to propose granting chemical engineering a formally separate status, at the same time as giving Hinchley a full Chair.[151] Bone objected to the former by means of a memorandum claiming that the activities of the department could not be encompassed within the title chemical engineering, and that its name was "wisely chosen". Hinchley needed to be in explicit subordination to Bone. Bone gave a breakdown of the students, indicating that only 35% went on to become chemical engineers, chemical works managers or control chemists, though in a subsequent letter he acknowledged that roughly half of the students since the department's foundation had specialized in chemical engineering.[152] Possibly as a result of Bone's intervention Hinchley was not given full independence, though after the establishment of his full chair he was allowed to offer an MSc in Chemical Engineering from 1928. First degrees in chemical engineering were not granted until 1937, some years after his death.

At University College the establishment of a Chemical Engineering Chair took a number of years. There is no record of the origin of the delay, which was probably financial rather than due to conflicts within the institution. It was 1923 before the Ramsay Memorial Chair was inaugurated.[153] The new department followed the route towards the 'primary' claims for chemical engineering which had been prevented at Imperial college. The course was based around what were called "unit actions" and a claim to be appropriate for a wide range of industries. It was not to attempt to[154]

> train men in the special knowledge and requirements of any particular chemical industry...there are many fundamental operations common to a large number of chemical industries, which can be studied and investigated from the point of view of physics, physical chemistry and engineering.

The majority of the applicants for the Chair were involved in works management rather than being specialists in plant design, a point of wider significance. A small number of full-time consultants also applied, and a similar number of academics. The person eventually appointed, EC Williams, was a chemist who had been in charge of the manufacture of intermediate products in the British Dyestuffs Corporation.[155]

The basis of Williams approach can be identified from his inaugural lecture. He reinforced the field's claims to be the appropriate general training for men intending to enter the chemical industry. As well as emphasizing the characteristics noted in the previous paragraph he stressed its potential for imitating plant-based "experience", and that the "principles" of chemical engineering could be studied without compromising the need for secrecy in works.[156] In relation to this he argued, in terms which echoed Hinchley, that "knowledge of the theory of plant design and operation are of very little use unless accompanied by the knowledge of where theories break down". He resisted, though with caution, the idea of chemical engineering as a derivative field. While suggesting that early specialization would tend to reduce the chemical engineer to a "technician" (the term is a significantly novel one, used in this sense), he nevertheless questioned the field's status as a purely postgraduate study and raised the possibility of a special undergraduate course.

By the early 1920s chemical engineering was established within high-level institutions at a postgraduate level and thus as an ancillary to mainstream chemistry courses. There had been little conflict over this institutional position as a derivative of chemistry, and to a lesser extent mechanical engineering. In practice the subject-matter incorporated in courses, as indicated by published material, drew heavily on a phenomenology of industrial chemistry, rationalized around the unit operations approach. The first bachelor's degree in chemical engineering was inaugurated at Glasgow University in 1923, though it had little success in attracting students. It received severe criticism from Hinchley in 1928 because of the absence of the unit operations approach.[157] As the field began to press more independent claims, the conflicts with mainstream chemists became sharper. In 1925 chemical engineering figured largely in a conference on applied chemistry organized by the Institute of Chemistry. A few chemists such as JF Thorpe affected to be shocked at the claims being made for applied disciplines. EF Armstrong objected to "chemical engineering courses in which the turning on of taps takes up a certain amount of the student's time...".[158] The tone of interacademic hostility at this meeting is surprisingly bitter, full of veiled threats and accusations about undermining the foundations of science education.

This thesis does not explore the academic position of chemical engineering beyond the early 1920s. While the field had developed some claims to be the fundamental disciplinary form of manufacturing chemical technology, resolving some of the conflicts in chapter 4, its boundaries both with technical specialisms and "pure" chemistry were not well-defined. In 1925 Smithells argued that Leeds University had deliberately preferred the route of separate industrial specialisms, echoing Bone's position at Imperial College.[159] By 1931, when the Institution of Chemical Engineers addressed the question of curricula, the battle between postgraduate and undergraduate studies dominated the argument.[160] A number of accounts have been given of the field's conceptual development, stressing its development of semi-independent theories of industrial phenomena (i.e. not deriving directly from physico-chemical theory).[161] This may have been a concomitant of its development towards independent academic institutionalization, but occurs later than the period treated here. The idea of "unit operations", despite their importance during the period of this thesis, were too naturalistic to bear the weight of disciplinary independence.

Earlier in the chapter reference was made to David Noble's view of academic chemical engineering as "made to order". The evidence from this study is that such a view does not hold for the UK. Chemical engineering, while it benefited from industrial pressure, was not a result of the implementation of curricular prescriptions from this direction. Hinchley claimed that the demand for chemical engineers was "manufactured by the production of good students".[162] Indeed where it involved curricular innovation chemical engineering generally received a hostile response from industrialists. Their pressure was unfocused, even contradictory, and the primary curricular initiatives were developed and negotiated in academic arenas. Moreover, the particular complex of activity and knowledge upon which such curricula were based did not lead directly to any well-defined location within industry. This was reinforced by its orientation to plant design rather than plant control. These points can be developed further by considering the institutionalization of chemical engineering as an occupation, and it is therefore appropriate at this point to move to a discussion of the Institution of Chemical Engineers.

E. The Origins of the Institution of Chemical Engineers

The first evidence of the collective organization of scientifically-trained men employed in the chemical industry during the twentieth century appeared in March 1911, with the establishment of the Association of Chemical Technologists.[163] There was certainly an emphasis on chemical engineering here: the intended journal of the Association was to be called Chemical Engineering.[164] However, in general these men classified themselves as technical chemists or chemical technologists, and were resistant to any attempt to assimilate their activity to an academic category.[165] As a self-description, "chemical engineer" remained uncommon. The Society of Chemical Industry membership lists for 1900 and 1915 each include only about 2% of individuals describing themselves in this way.[166]

In 1915 a proposal was floated in the Chemical Trade Journal for an Institution of Chemical Engineers. This received some support from works chemists. However, it was undermined by the intervention of the President of the Society of Chemical Industry, the mechanical engineer Charles Carpenter, who claimed that "all engineering is fundamentally mechanical engineering", and argued that such men ought to join the Society of Chemical Industry.[167] Carpenter was a Director of the South Metropolitan Gas Company. Whether JW Hinchley was involved in this attempt is not known, but he had been active in the Association of Chemical Technologists, and is reported as being involved in some activity of the kind. In 1918 Hinchley developed the stratagem of obtaining a public forum for chemical engineering by proposing the establishment of a Chemical Engineering Group within the Society of Chemical Industry. He canvassed support for the idea at the Chemical Industry Club in February, and in July a meeting was held in London, at which a Committee, of which Hinchley was Chairman, was elected.[168] At this point consultants rather than employees had a central role. The Committee was dominated by men with this background. At least six of the ten members, not counting Hinchley, were consultants, and there may have been more.[169] In 1924 the proposal was said to have been "oratorically and polemically crucified" when originally voiced, though it has not been possible to find contemporary evidence of this.[170] It was made clear in the literature which was distributed that a separate organization might be needed: a fairly unsubtle threat to the Council of the Society of Chemical Industry. Fears were expressed in some quarters that the Group might come to absorb the entire Society.[171] Shortly after its establishment the Group was put in charge of the serious component of the Society's Annual Meeting.[172]

The Chemical Engineering Group attracted about 400 members, which was very much greater than the number of individuals describing themselves as chemical engineers in the Society's membership list. Thus EF Armstrong, who had inherited his father's distaste for the idea of the chemical engineer, was actively involved, apparently distinguishing between the field and the occupation or discipline. Hinchley certainly encouraged this approach.[173] Nevertheless the objects of the organization demonstrated an educational orientation and, after the approval of Council had been obtained, Hinchley took a more independent line. He told the Inaugural Meeting in March 1919 that[174]

> (there) were many who were still unable to appreciate the existence of the chemical engineer, and there were many engineers today who would not agree that such a person existed. The Chemical Engineering Group was insisting on a special kind of training for the chemical engineer.

Harold Talbot, who had been active with Hinchley in setting up the group, took the situation a stage further in 1920 when he told the Chemical Industry Club that[175]

> ...chemical engineering was neither a branch of chemistry nor a branch of engineering, but a science to be taught and a profession to be practised...

In addition Talbot placed great emphasis on the shift which chemical engineers needed to have made from "research or routine laboratory" work to activity "directly associated with the works".

The Chemical Engineering Group emphasized that chemical engineering was orientated towards chemical plant rather than chemical processes, and this 'mechanical' emphasis served a useful purpose in undermining claims made for the fundamental status of chemistry. However the new group attracted numbers of mechanical engineers from the chemical industry, and the period around 1920 saw attacks mounted from within the Chemical Engineering Group itself on claims such as that of Talbot. An article in Chemical Age in 1920 criticized a member of the group's committee who adopted the "older line of argument" that "chemical engineering is a branch of (mechanical?) engineering, and that the chemical engineer must be an engineer first, last and for all time" (my addition).[176] The Chemical Age author, who may well have been Hinchley, cited developments in curricula in the USA which reduced the civil and mechanical engineering content of courses, concluding that chemical engineering was a "definite science", with chemistry the "foundation subject". He also referred, perhaps disingenuously, to the "department of chemical engineering" at Imperial College. CS Garland defined the chemical engineer positively as "a chemist who transferred results obtained in the laboratory to operations conducted on an industrial scale...".[177] A tension can be seen here between a focus on plant design and construction (which gave independence from chemistry) and one on scaling up of specifically chemical operations (which gave independence from mechanical engineering).

A joint meeting of the Society of Chemical Industry and the Institute of Chemistry in 1920 found itself focusing yet again on the issue, and the Journal of the Society noted that the nature of chemical engineering was a "vexed question" on which "there was naturally some difference of opinion".[178] Some doubts were expressed about the viability of the chemical engineer as an occupational category, recalling its limited recognition within works. The closing remarks indicate that chemical engineering was perceived as the resolution of the problem of technical education for the chemical industry: after expressing general doubts about such instruction as a whole, the meeting nevertheless concluded that if it existed at all "it should be on quite general lines, e.g., methods of evaporation, distillation, transport, properties of materials used in works."

Later in that year the propagandists for an independent chemical engineering were powerfully reinforced by Lord Moulton. In a speech at University College on the subject he contrived to make no reference to mechanical engineering, yet stressed the need for the student to "have access to laboratory accommodation in which can be carried on, be it only on a comparatively small scale, truly manufacturing processes."[179] Throughout this period, then, Hinchley and his supporters maintained their propaganda effort and at the 1921 AGM of the Chemical Engineering Group Hinchley launched the idea of an independent Institution.[180] About 100 men expressed an interest.[181] Hinchley succeeded in gaining Arthur Duckham as Chairman of a Provisional Committee, and WJU Woolcock as Vice-Chairman, while Hinchley himself became Secretary. Neither of the first two was directly involved in technical activity.[182]

The establishment of the Institution was in the end a comparatively painless affair. The application for incorporation was opposed by the Institutes of Chemistry and of Civil Engineers, but the Institution was eventually inaugurated in May 1922.[183] A number of elements contributed to its creation. The first was Hinchley's forceful individual efforts to construct underpinning institutions for his own educational activity. His interest in constituting the field independently coincided with his increasing educational involvement (though even in 1923 he was still consultant to 10 firms). He saw the Institution as promoting "the special study of the special plant employed in the chemical industry" able to "set up standards of examination and attainment for university and technological centres".[184] Yet Hinchley seems also to have had a genuine interest in the organization of scientific workers: he was very active in the British Association of Chemists and even gave support to the more radical National Association of Industrial Chemists.[185]

The difficulty of placing any single interpretation on the origins of the Institution is shown when Hinchley is compared with the second group of protagonists: men like Duckham and WJU Woolcock (Director of the Association of British Chemical Manufacturers (ABCM)). These men looked towards defining a class of personnel to occupy industrial positions. Duckham was explicit about this: he was involved, he said, "not merely for the purpose of forming an Institution, but for the education and production of men competent to handle our chemical industries".[186] They did not have Hinchley's concrete experience in the precise curricular activity involved, and their aims were often vaguely formulated, as in Duckham's remark that "it was not felt that existing institutions supplied quite the thing which it was believed was wanted".[187]

The connection with the ABCM is of interest. The setting up of the Association had been recommended by a joint committee of the

Chemical Society, the Society of Chemical Industry and the Society of Dyers and Colourists in 1916.[188] Yet each member of the Council of the Association was to be a "director, manager, or other prominent official of a corporation". The reason for this was made quite explict in 1916 by EJ Boake, who remarked that "the control must be confined to the manufacturing interests and not get into the hands of professional chemists...".[189] Its aims included that of influencing universities and technical colleges so that their methods "shall be better adapted to the practical necessities of the chemical industry". Woolcock's presence as Vice-Chairman of the Institution of Chemical Engineers evidently forwarded this aim, as well as signalling the non-radical character of the Institution.

The previous section suggested that even industrialists involved in the Institution of Chemical Engineers had few well-defined employment or training aims. Nevertheless, as Sanderson has argued, the War experience, with its enforced association between academics and industry, seems to have generated an increased awareness of the new roles and competencies which could be established within firms by the employment of academically trained men in systematic ways. The modelling of the laboratories of Synthetic Ammonia and Nitrates on those just built at University College London is a concrete metaphor for this process.[190] Though the language is often difficult to interpret precisely, this group often continued to formulate their aims in terms of a composite course of study, which contrasts with the emphasis of Hinchley and others on the specialist, independent character of the field.[191]

A second important group was the consultants. The new Institution stood in a transitional relationship to the traditional domain of the consultant, who was retained by firms as a designer or troubleshooter. One critic of the chemical engineer as a separate entity envisaged that beyond the design stage the chemical engineer would cease to be involved: "once a chemical process is running smoothly, there is no real chemical work involved in carrying it on".[192] Hinchley took care to ensure in his propaganda effort that chemical engineering was used so as to encompass the operation as well as the design of plant, and to be the specialized academic domain appropriate to this activity. Speaking of plant which failed to perform to specification he observed that[193]

> (g)enerally the manufacturer is not sure of his case, sometimes the design is disproportionate, but often the fault lies in the plant being controlled by a chemist or an engineer with an imaginary knowledge of chemical engineering.

Nevertheless this tension in the orientation of chemical engineering would remain. The President, JA Reavell, suggested in 1931 that the Institution would need to allow its members to focus on "design <u>or</u> operation" of plant (his emphasis).[194] This shifting basis was reflected in the membership of the provisional committee. The original Committee of the Chemical Engineering Group had been dominated by consultants whereas the provisional committee of the Institution, while involving consultants, included roughly equal numbers of academics and works employees.[195]

The final group contributing to the Institution's formation was of course the bulk of the membership itself. The motivation of this group is less obvious than that of the academics and industrialists. The proposed Institute certainly cannot be interpreted as a creation of industrialists and academics. Hinchley claimed, and it seems to have had some foundation, that there was independent pressure for the establishment of an organization in Manchester. A considerable proportion of the early membership came from the Yorkshire and Lancashire area.[196] Most of the members accepted at the first meetings of the Institution were also members of the Society of Chemical Industry. An analysis of their occupations as given in the membership list of the latter is given in Table 12. It shows few describing themselves as chemical engineers.

Table 12. Self-descriptions of founding members of the Institution of Chemical Engineers

chemist	22
works manager	9
chemical engineer	5
engineer	5
academics	5
analyst	2
manufacturer	2
public employee	1
total	51

The origins of a large majority of the earliest members were thus in chemistry rather than engineering. When new members began to be recruited into the Institution records were kept of their occupations. These individuals were generally of the same type as the founding members, with a background in chemistry, but the descriptions of their activities in the minutes are slightly more elaborate. The characteristic which they stressed was their involvement with the operation of plant. Examples of such statements include: "Full control of coke oven and by-product plant", "Works chemist; creation and running of plant", "..supervising the working of all plant...", "Control of all design", "In full charge of plant, technical processes &c".[197] It can be argued, on the basis both of their chemical background and their emphasis on involvement with plant operations proper, that the Institution constituted for this group a certification of the shift from routine analysis. The definition of a chemical engineer provided by Harold Talbot in 1920 had a strong negative element: he was an individual not involved in the works laboratory.[198] Similarly in 1919 Norman Collie had described the proposed chemical engineering course at University College as aimed at chemical students "who are intending to take responsible positions in Industrial Works, requiring a knowledge of matters other than chemical analysis".[199] This bland description nevertheless encompassed the trajectory which has been observed throughout this thesis. It was characteristic of the early members of the Institution of Chemical Engineers, and it can be hypothesized that it was this shift from analysis to process control which was recognized by membership of the Institution.[200]

Finally, the claims which were made within the Institution for the wider relevance of chemical engineering beyond the manufacture of "chemicals" can be noted. Duckham argued that the field underpinned many sectors:[201]

> Something had been said about...manufacturing chemical commodities, but...he wished to emphasise that chemical engineering went much further than this...(it) must not be confined to chemical businesses, as chemical businesses were understood. Steel works, coke oven works, and many other works, were all waiting for the chemical engineer.

These comments recall the main thrust of Hinchley's conflict with Bone. To some extent the establishment of the Institution involved an attempt to constitute chemical engineering as the "primary technology" of chemical operations.[202]

The forces and groups contributing to the establishment of the Institution were then diverse. They show considerable overlap with those contributing to the field's academic development. Certainly for some industrialists the Institution constituted an attempt to influence educational activity vicariously, and this may partly explain its initial unwillingness to establish a route to entry by its own examination. Indeed the Institution's qualifications for membership were extremely relaxed, or at least informal, perhaps indicating the diversity of interests they needed to reflect.[203] The Institution was an instrument by which these often feebly coupled interests were mobilized. With about 100 members it was, however, numerically small in comparison with the Society of Chemical Industry and even the Institute of Chemistry. As with its academic institutionalization chemical engineering had by the early 1920s reached a stable position from which a process of slow negotiation of boundaries and growth would begin. The process by which this position was reached was complex, subject to many forces and fits no simple model of institutional growth.

Notes to Chapter 7

1 The widespread influence of the report in which this view was propounded is indicated by the fact that a copy found its way almost immediately to the University of Leeds when that institution was considering setting up a department. Leeds University Central Filing Office, CF0176F1. 'Report of the Visiting Committee for the Department of Chemical Engineering at Massachusetts Institute of Technology', 8 December 1915.

2 Noble op. cit. (1979), pp.38, 194.

3 J.W. Servos, 'The Industrial Relations of Science: Chemical Engineering at M.I.T., 1900-1939', Isis lxxi (1980), pp.531-49. For a general account of the US situation which shows some parallels with that to be given here see T.S. Reynolds, 75 Years of Progress--A History of the American Institute of Chemical Engineers, 1908-1983 (New York, 1983); idem., 'Defining Professional Boundaries. Chemical Engineering in the Early 20th Century', Technology and Culture xxvii (1986), pp.697-716.

4 Guedon has argued the specificity of national cases, though his account of the situation in the UK cannot be accepted. J.-C. Guedon, 'Conceptual and Institutional Obstacles to the Emergence of Unit Operations in Europe', in Furter, op. cit. (1980), pp.45-75.

5 An extremely early reference to the chemical engineer occurs in Andrew Ure's A Dictionary of Arts, Manufactures and Mines (1839), p.1220 in connection with the manufacture of sulphuric acid, though Ure does not appear to use the term again, and it was not in general use. The most useful works on the history of chemical engineering are both edited by W.F. Furter: History of Chemical Engineering (Washington, DC, 1980), and A Century of Chemical Engineering (New York, 1982). For other accounts see O.A. Hougen, 'Seven Decades of Chemical Engineering Progress', Chemical Engineering Progress (1977), lxxiii (1977), pp.89-106; G. Bohme, W. van den Daele and W. Krohn, 'The Scientification of Technology', in Finalization in Science. The Social Orientation of Scientific Progress, ed. W. Schäfer (Dordrecht, 1983), pp.172-205; K. Buchholz, 'Verfahrenstechnik (Chemical Engineering)--Its Development, Present State and Structure', Science Studies ix (1979), pp.33-62; F.R. Whitt, 'Early Teachers and Teaching of Chemical Engineering', The Chemical Engineer (1969), pp.356-60 and (1971), pp.370-4.

6 JSCI i (1882), p.250.

7 Morrison, op. cit. (1875-6), pp.644-5.

8 Idem., 'A Brief History of the Chemical Manure Industry, with Special Reference to the North-East', JSCI ix (1890), pp.262-5.

9 CN xliii (1881), p.81. A subsequent statement gave the title Society of Chemical Industry, but referred to the organization as a Society of Chemical Engineers, adding "(i)t may indeed prove desirable to found a distinct branch of the Engineering Profession". Ibid, p.154.

10 Society of Chemical Industry, Minute Book of the Preliminary Meetings, entries for 19 April 1880 and 14 December 1880.

11 Chairman's Address to the Manchester Section, JSCI xiv (1895), pp.929-35. However he also indicated that at one of the meetings a chemical manufacture had claimed not to know "of the existence of such a genus" as a chemical engineer. CTJ ii (1888), p.306.

12 The Chemist and Druggist xxiii (1881), pp.182-4. The Society's Bye-Laws meanwhile reflected the tension between generality and specificity which was discussed in chapter 4 and which will be met again here. It

aimed

"A To advance applied chemistry in all its branches

B To promote the acquisition and practice of that species of knowledge which constitutes the profession of a Chemical Engineer."

JSCI i (1882), p.288.

13 City and Guilds of London Institute, Report for the Year Ending March 10th, 1880, Presented by the Council of the City and Guilds of London Institute to the of the Institute, pp.5-13. Guildhall MS 21,834/1, "Notes on the Remarks Made by the Chairman of the Executive Committee (FJ Bramwell FRS) in Introducing the Committee's Draft Report". Sir Frederick Bramwell (1818-1903) was a mechanical engineer turned consultant. DNB. For a general account see A. Whitworth, A Centenary History. A History of the City and Guilds College, 1885 to 1985 (1985), and the relevant sections of Eyre's biography of Henry Armstrong J.V. Eyre., Henry Edward Armstrong 1848-1937 (1958). Whitworth somewhat confuses matters by appearing to suggest that the subsequent Department of Chemical Technology at Imperial College was continuous with the chemical department of the City and Guilds Central Institution which is about to be discussed. It is necessary to state that the account of the Central Institution which follows differs somewhat from Armstrong's own. There he is seen retrospectively as a curricular innovator, with an orientation towards "scientific method", whose position was undermined by circumstances. This view will not be restated here. Whatever may have been the supposed function of the chemical studies undertaken by mechanical and other engineers at the Institution, it seems fairly clear from the sources quoted below that the function of the engineering studied by chemists was thought of as being largely utilitarian. Armstrong's later account of the events is not easy to reconcile with some of his contemporary statements on university curricula. See W.H. Brock, H.E. Armstrong and the Teaching of Science 1880-1930 (Cambridge, 1973), pp.1-54.

14 "Scheme for the Organization of the Central Institution", 4 February 1884, Guildhall MS 21,834/5. Minutes of Sub-Committee A, entry for 8 January 1884, Guildhall MS 21,819.

15 Minutes of Sub-Committee A, 18 February 1884, 3 March 1884.

16 Imperial College Archives, Armstrong MS 205, WN Hartley to HE Armstrong, 12 March 1884.

17 Ibid., MS 373, O Roberts to HE Armstrong, 18 March 1884. Sir Owen Roberts (1835-1915) was a barrister, illustrating the difficulty of allocating the influential figures in the City Guilds to any single category. Who Was Who.

18 Minutes of Sub-Committee A, 19 March 1884. Minutes of the Executive Committee, entries for 17 March 1884, 28 April 1884, Guildhall MS 21,817.

19 'The Central Institution', The Central xxxv (1938), pp.49-69(54) (Armstrong Memorial Issue).

20 City and Guilds of London Institute, Preliminary Programme of the Central Institution (1884), pp.8-9.

21 Armstrong MS, Imperial College Archives, EC Robins to HE Armstrong, 16 January 1884. Board of Studies Minutes, 3 March 1885, 28 March 1885. Minutes of Sub-Committee A, 6 April 1885. In his own account, Armstrong claimed not to have been consulted on the Central Institution's programme, and to have attempted subsequently, and without support, to introduce engineering. This can be compared with

the fact just noted that the earliest Programme of the Institution called the chemical course "Chemical Engineering" and Armstrong's quoted comments. It was in this account that Armstrong claimed to be "the Father of Chemical Engineering". H.E. Armstrong, 'The Beginnings of Finsbury and the Central', The Central xxxi (1934), pp.1-14.

22 Eyre, op. cit. (1958), p.109.

23 City and Guilds of London Institute, Programme of the Central Institution (1885), p.26.

24 He was however less inhibited about the amount of teaching of chemistry to mechanical engineering students which he was required to undertake. Minutes of Evidence Taken by the Royal Commissioners Appointed to Consider the Draft Charter for the Proposed Gresham University, PP 1894, xxxiv, q.24,151 (Cowper Commission). Armstrong correspondence, Imperial College Archives, HE Armstrong to Norman Lockyer, 30 March 1894. This teaching was steadily increased: Board of Studies Minutes, 1 October 1886, 5 October 1888. This activity may have stimulated Armstrong to formalize his view of a science education orientated towards ideas of "scientific method" around the notion of heurism. He told the Cowper Commission "it is no good treating students of that class as though they were going to be chemists". In a talk on the same subject some years earlier he remarked that a major reason for teaching science to engineers was so that they would "learn to observe; to make experiments with a set object in view; and to reason from observation and observation". 'The Relation of Chemistry to Engineering' Address to the Junior Engineering Society, 21 January 1887, p.19. See also the essays reprinted in Brock, op. cit. (1973).

25 Cowper Commission, qq.24,182-5.

26 City and Guilds of London Institute, 'Report of the Board of Studies on the Equipment of the Central Institution with Apparatus and Tools'. Minutes of Sub-Committee A, 20 June 1889.

27 H.E. Armstrong, Pre-Kensington History of the Royal College of Science, (1921), p.20. It is confusing to find Armstrong, in other of his writings, claiming to have advocated what he condemned here. See, for example, JSCI xxxv (1916), pp.1191.

28 Cowper Commission, q.24,173.

29 Board of Studies Minutes, 18 May 1888. On Miller (1855-1945) see JPIC (1945), p.155.

30 Imperial College Archives, Armstrong correspondence, HE Armstrong to F Abel, 30 March 1894.

31 Board of Studies Minutes, 3 March 1885, 28 March 1885. Minutes of Sub-Committee A, 10 March 1885, 28 March 1885. A similar situation had occurred at the Finsbury Technical College. (E.F. Armstrong), 'The City and Guilds of London Institute. Its Origins and Development', The Central xxxv (1938), pp.14-46. The protagonists were often barely on speaking terms. Magnus is reported to have said to Armstrong "Your business is to teach boys, not to do research...". Eyre, op. cit. (1958), p.95.

32 Minutes of Sub-Committee A, 10 July 1886. Board of Studies Minutes, 27 March 1888.

33 Ibid., Armstrong to EC Robins, 3 November 1886. "I am very anxious about the Institute...the Central is not as popular as it should be...". In 1887 he wrote "It is obvious that to catch our students something will have to be done...". Armstrong to EC Robins, 17 February 1887.

34 Typical of the type of apparatus requested by Armstrong were a

polariscope, spectroscope, goniometer and crystallography instruments. In 1898 the Annual Report lamented the absence of "a room ..fitted up somewhat in the style of a factory for chemical operations on a large scale". City and Guilds of London Institute, Annual Report, 1898, p.13.

35 Eyre, op. cit. (1958), pp.97-8, 114. It has not been possible to find these critical comments.

36 Guildhall, MS 21,096. Is the Central College a Failure? (1896).

37 City and Guilds of London Institute, 'Report of the Special Committee Appointed by the Governors of the City and Guilds of London, at Their Extraordinary Meeting on June 2nd, 1896', pp.62-75.

38 Eyre, op. cit. (1958), p.146.

39 Ibid., p.163.

40 City and Guilds, Annual Report (1911), p.xxviii.

41 'The Central Institution', The Central xxxv (1938), pp.44-69(66).

42 Armstrong correspondence, Armstrong to Norman Lockyer, 30 March 1894.

43 Armstrong, op. cit. (1921), p.11.

44 Eyre op. cit. (1958), p.93. Armstrong, op. cit. (1934).

45 Glasgow and West of Scotland Technical College, Calendar 1887-1888, p.25.

46 Chemical Trade Journal ii (1888), pp.306 et seq. G.E. Davis, A Handbook of Chemical Engineering (1901), preface.

47 On Davis (1850-1907) see JSCI xxvi (1907), p.598, N. Swindin, Engineering without Wheels. A Personal History (1962), and The George E. Davis Memorial Lecture, Transactions of the Institution of Chemical Engineers xxxi (1953), pp.187-200, D.C. Freshwater, 'George E. Davis, Norman Swindin, and the Empirical Tradition in Chemical Engineering', in Furter, op. cit. (1980), pp.97-111. On the other partner in Davis Bros., Alfred Davis, see Jubilee Number, JSCI (1931), p.109.

48 Society of Chemical Industry, Council Minutes, 21 November 1884. No copy of the advertisement seems to have survived.

49 JSCI iii (1884), p.539.

50 CTJ ii (1888), p.290.

51 Ibid., p.307.

52 It is not intended to exaggerate the overall novelty of Davis's consultancy practice which, Swindin has indicated, also contained a very large analytical component. Swindin, op. cit. (1962), p.31.

53 Levinstein, op. cit. (1886).

54 The course on chemical engineering established in 1888 at MIT was based firmly on a combination of mechanical engineering, chemistry and various other courses. "The course is so arranged that the student will receive a suitable general training in mechanical engineering, and at the same time will devote a portion of his time to the study of the applications of chemistry to the arts..." CTJ ii (1888), p.408-9. A similar situation occurred at other institutions. J.W. Westwater, 'The Beginnings of Chemical Engineering in the USA' in Furter, op. cit. (1980), pp.140-52. A number of other papers in this volume also discuss this issue.

55 A.N. Tate, 'On Some Aids to the Further Development of the Chemical Industry', JSCI ix (1890), pp.1010-12. On Tate (1837-92) see JCS lxiii (1893), pp.764-5.

56 Pilcher, op. cit. (1914), p.125.

57 Smithells, op. cit. (1894), p.20-1. On Smithell's view see chapter 3, p.81.

58 G.T. Beilby, 'The Relations of the Society to Chemical Engineering and

to Industrial Research', JSCI xviii (1899), pp.333-40. Beilby (1850-1924) was a director of a number of companies, but seems also to have undertaken some freelance consultancy. DNB.

59 Beilby, op. cit. (1899), p.337. Idem., Chairman's Address to the Scottish Section, ibid., xvi (1897), pp.874-6.

60 Elsewhere he offered it as the basis of Glasgow University's relationship with the chemical industry. The University of Glasgow, Its Position and Wants (Glasgow, 1900).

61 Davis, op. cit. (1901), pp.2-4. A precursor was A. Parnicke, Der Maschinellen Hilfsmittel der Chemischen Technik (The Mechanical Auxiliaries of Chemical Technics), (Frankfurt, 1894).

62 F.R. Whitt, 'Early Teachers and Teaching of Chemical Engineering', The Chemical Engineer (1969), pp.356-60 and (1971), pp.370-4. On the Bradford course see CN lxxxii (1900), p.139. On that at Battersea see ibid., lxxxiv (1901), p.148. The Battersea course (not to be confused with that of JW Hinchley, given some years later) was not referred to in the Prospectus, but advertisements referred to the chemistry and engineering departments only. CN lxxxiv (1901), pp.48. On Battersea Polytechnic generally see H. Arrowsmith, Pioneering in Education for the Technologies. The Story of Battersea College of Technology 1891-1962 (University of Surrey, 1966). The activity at Bradford had a similar structure: "The times of the lectures are so arranged that students may take a combined course in Chemistry, Bacteriology, and Engineering...". It did include a short course on chemical plant, though this was given in the Engineering Department by a mechanical engineer. Bradford Municipal Technical College, Calendar for the Year 1900-1901 (Bradford, 1900), p.47.

63 For a view of chemical engineering as essentially mechanical engineering with chemical plant see for example the statement to the Society of Chemical Industry in 1889 that "(fewer) than 50% of the chemists are able to make a scaled drawing from which chemical engineers could make plant." JSCI viii (1889), p.341.

64 CTJ xlv (1909), pp.307-8.

65 J. Grossmann, The Elements of Chemical Engineering (1906). Grossmann (1854-1920) had come to Manchester in 1875-6 as assistant to Henry Roscoe, then worked for various firms and established his own manufacturing firm, before gravitating to consultancy. PIC (1920), p.247. In its review of the book the Chemical Trade Journal emphasized academic dominance of industrial training, rather than any true content barrier, as preventing the teaching of chemical technology (understood as chemical engineering) in the UK. CTJ xxxviii (1906), p.625.

66 Grossmann, op. cit. (1906), pp.123-5.

67 O. Guttmann, 'The Works Chemist as Engineer', JSCI xxvi (1907), pp.564-71. On Guttmann (1855-1910) see JSCI xxix (1910), p.996. In 1909 JBC Kershaw, a Liverpool consultant, described chemical engineering as 'a new profession'. 'The Relations between Applied Chemistry and Engineering' CTJ xlv (1909), pp.356-7. Because consultancy received very little attention among propagandists for science education its role tends to be underestimated. In 1896 William Tilden suggested that it was the main method used to attack industrial problems (LCC, op. cit. (1896), p.21), and a similar point was made in 1902 (LCC, op. cit. (1902), p.43). Keith Quinton's book Science and the Manufacturer (1906) laid heavy emphasis on consultancy.

68 Various papers in Furter, op. cit. (1980) discuss these men.

69 On the special position of chemical innovations in regard to secret

working see H.E. Potts, Patents and Chemical Research (Liverpool, 1921), p.1. It is of interest that Potts also emphasizes the role of theory, by implication not necessarily of an academically validated kind, in extending the validity of a patent and in foreseeing and avoiding claims of invalidity. Ibid., pp.72-3.

70 CTJ lvii (1915), p.578.

71 Meldola, op.cit. (1909). Similarly GG Henderson identified "General Chemical Technology" with "Chemical Engineering in a broad sense". Institute of Chemistry (1913), p.16.

72 F.G. Donnan, 'The University Training of Technical Chemists', JSCI xxviii (1908), pp.275-80(276).

73 History of the Ministry of Munitions, viii, p.49.

74 CTJ lvii (1915), p.517

75 F.G. Donnan, 'The Training of Technical Chemists', CTJ lvii (1915), pp.519-20.

76 Chemical Age ii (1920), p.552.

77 For example see Donnan above, note 75. Compare HL Heathcote: 'The University Training of Industrial Chemists', JSCI xxviii (1909), pp.171-7.

78 Examples of discussions focused wholly or largely on the subject of chemical engineering include: G.T. Beilby, 'Chemical Engineering', ibid. xxxiv (1915), pp.769-74. F.G. Donnan, 'The Training of Technical Chemists', CTJ lvii (1915), p.519-20. E.C.C. Baly, 'The Future Position and Prospects of the British Chemical Trade and the Question of Concerted Action by Manufacturers', JSCI xxxiv (1915), pp.53-5. C. Carpenter, 'Chemistry and Engineering', JSCI xxv (1916), pp.1185-91. Faraday Society, 'The Training and Work of the Chemical Engineer' Transactions of the Faraday Society xiii (1917-18), pp.61-118. H. Louis, Presidential Address, JSCI xxxvii (1918), pp.207T-12T. The Faraday Society originated as the Society of Electrochemists and Metallurgists in 1903. CN lxxxvii (1903), p.287 and lxxxviii (1903), p.34.

79 Comments in Carpenter, op. cit. (1916), p.1189.

80 Comments ibid., p.1190.

81 Comments on Carpenter op. cit. (1916) p.1189 and Donnan, op. cit. (1915).

82 Imperial College of Science and Technology, The Royal Charter of the Imperial College of Science and Technology (1957), p.120.

83 The Need of a University for Liverpool (Liverpool, 1901).

84 Nature lxviii (1903), p.28. Brunner financed activity in archaeology and physical chemistry as well as engineering and metallurgy.

85 'Report of the Committee on Chemical Engineering Education', Transactions of the American Institution of Chemical Engineering iii (1910), pp.122-45. The Association of British Chemical Manufacturers, established in 1916, had some aspirations in this direction but does not seem to have carried them through. See below note 188.

86 JSCI cviii (1899), p.339.

87 See the comments in his Board of Education Report on Applied Chemistry in 1914, where he oscillated between a focus on the aspects of the field specific to chemistry and suggesting that engineering departments are needed to give a training in the methods of the engineer rather than the chemist. PRO 119/27.

88 This was the 'official' response in the editorial column of the Journal of the Society following the 1916 meeting referred to in note 78: "In the discussion which followed this address the claims of the 'chemical

engineer' were put forward by several speakers--but what is a chemical engineer? Is he more than an engineer who knows sufficient chemistry to appreciate the chemist's point of view?" It went on to argue that to attempt any more would result in someone incompetent in both fields. JSCI, 30 December 1912, editorial.

89 J. Whiting, 'The Commercial Development of Chemical Processes', CTJ li (1912), pp.322-3. Whiting was a member of the MIT committee which produced the report dealing with "unit operations" referred to in note 1. Compare also R.F. Bacon, 'Some Principles in the Administration of Industrial Research Laboratories', JSCI xxxv (1916), pp.18-26.

90 Faraday Society, op. cit. (1917-18), p.106.

91 'Report of an Informal Conference on Chemical Engineering', 24 November 1916. Leeds University Central Filing Office, CF0176F1. JC Cain (1871-1921) was a member of the Technical Committee of British Dyes Limited. JSCI xl (1921), pp.58R.

92 British Dyes Ltd., Report of Proceedings at the Statutory Meeting (13 July 1915). The 1919 report on the organization of the British Dyestuffs Corporation also indicates that their was no provision for chemical engineers as such. 'The Research Organization of the British Dyestuff Corporation', ICI Organic Division Archives BDC F08. Even within a less radical domain (an arrangement in which the University undertook research into dyestuffs) the relationship between the University and the firm was fraught. It led to hostility both within the University and in its relations with Levinstein, and eventually to the resignation of AG Green. Leeds University Central Filing Office CF0184F25, notably "Chronological Notes of Certain Events Connected with the Negotiations with British Dyes Limited". CF0185F60 Green to Sadler, 24 February 1916.

93 Parke, op. cit. (1957), pp.63-4. Parke, a chemistry graduate from Edinburgh University, who was involved in the activity, indicates that the work was split between chemists and engineers. AH Cowap stated in 1921 that chemical engineering work was undertaken by men without any familiarity with chemical plant. Reader, op. cit. (1971), p.363. On the recruitment from the Ministry of Munitions see Brunner, Mond, Managing Directors Minute Book, DIC/BM3/2/10 entry for 24 October 1919. See also Nitrogen Products Committee, Final Report PP 1919, xxvi.

94 HA Humphrey recalled that he was requested to recruit "the best young Engineers, Chemists, Physicists and specialists available". Humphrey to RS Hutton, 12 September 1948. At the time he was told by GP Pollitt that his recruits: "should be, must be, highbrows. Nothing else is any use. They shd have a first class knowledge of physics, some considerable physical chemistry as well as the usual Engineering Subjects in their theoretical aspects. We do not want practical engineers for these posts. It is the chance of a lifetime to get men of your own type of training. " Pollitt to Humphrey, 16 May 1923, (his emphases and abbreviation). Humphrey Correspondence, Imperial College London, B HUM F/51 and 18.

95 For general accounts of the growth of academic control in universities see D.R. Jones, 'Governing the Civic Universities', History of Education Quarterly, xxv (1985), pp.281-302. G.C. Moodie and R. Eustace, Power and Authority in British Universities (1974).

96 Imperial College of Science and Technology, The Royal Charter of the Imperial College of Science and Technology (1957), p.120. A.R. Hall, Science for Industry. A Short History of the Imperial College of Science and Technology and Its Antecedents (1982).

97 Departmental Committee on the Royal College of Science, qq.2510, 2513.
98 Imperial College of Science and Technology, First Annual Report (1908), p.1.
99 Imperial College of Science and Technology, Minutes of the Governing Body, 25 October 1907; Second Annual Report (1909). See also M. de Reuch, 'History of the Department of Chemical Engineering and Chemical Technology 1912-1939' (1960), typescript held in the Archive Department at Imperial College. The Sub-Committees had responsibility for, respectively, Mining and Metallurgy, Other Branches of Engineering, Biological Sciences and Other Pure and Applied Sciences.
100 The co-opted men were GT Beilby, Ludwig Mond, Arthur Schuster, Richard Threlfall and HR Annulph. See DNB for all but Annulph, who has not been identified.
101 Governing Body Minutes, 25 March 1908. The individual courses suggested were in Rusting and Corrosion of Metals, Manufacture of Azo Dyes and Gas Manufacture. Minutes of the Organization Committee, 12 May 1909. Second Annual Report, pp.7-8.
102 Governing Body Minutes, 11 June 1909.
103 E.R. Roberts, 'A History of the Chemistry Department at Imperial College' (1963), typescript held in the Archive Department, Imperial College, pp.74-5. Thorpe (1845-1925) was the editor of a large Dictionary of Applied Chemistry, first published in 1890, and frequently reprinted. DNB.
104 Governing Body Minutes, 13 May 1909.
105 Imperial College of Science and Technology, Third Annual Report, Cd.5511, p.7 Report of the Special Organization Committee, 25 July 1910. Governing Body Minutes, 10 June 1910.
106 Governing Body Minutes, 11 November 1910.
107 On Hinchley (1871-1935) see E.M. Hinchley, John William Hinchley, Chemical Engineer. A Memoir (1935).
108 Imperial College Archives, KCT10/3/1956. Press release dated January 1911.
109 Ibid., Hinchley to Pearce, 5 January 1910.
110 Ibid., Hinchley to Thorpe, 14 December 1911. Some insight into Hinchley's approach at about this time can be gained from a series of articles which he published in 1913: J.W. Hinchley, 'Notes on Chemical Engineering', Chemical World 2 (1913), pp.25-7, 65-7, 100-02 etc.
111 J.W. Hinchley, 'Factory Organisation and the Technologist', Chemical Engineer and the Works Chemist i (1911-12), pp.424-8.
112 Compare S. Webb, The Works Manager Today (1917).
113 Governing Body Minutes, 13 May 1910. On Divers (1837-1912) see PIC (June 1912), p.8.
114 KCT10/3 Thorpe to Keogh, 26 December 1910. Divers to Keogh, 6 January 1911, 11 January 1911.
115 Ibid., Divers to Keogh 15 January 1911.
116 Governing Body Minutes, 10 February 1911, Appendix iv. On Keogh (1857-1936) see DNB.
117 KCT10/3/1956 Sequence of letters. Part-time postgraduate students were however subsequently admitted.
118 Meldola to Keogh, 20 December 1910. Parallels with this and other aspects of the present study exist in the growth of technical optics at Imperial College. M. Williams, 'Technical Optics: the Creation of an Academic Discipline', paper to British Society for the History of Science Meeting, University of Leeds, 17 May 1986.
119 KCT10/3/1956 Hinchley to Thorpe, 25 March 1911. Governing Body Minutes,

15 April 1911. In his commentary on the 1911 papers Bone had noted that chemical engineering was 'introductory and supplementary to all courses of study in Applied Chemistry'. p.5.

120 Governing Body Minutes, 10 March 1911.

121 KCT10/1/1601, Meldola to Keogh, 13 February 1911; Keogh to Meldola 14 February 1911; Keogh to Beilby, 30 June 1911. 'Second Report of Sir Arthur Rucker's Committee in Respect of Chemical Technology' (May, 1911); manuscript notes of meetings of the committee, 28 April and 27 June 1911. KCT10/3/1956 Witt to Thorpe, 16 April 1911. Bone (1871-1938) was then Professor of Fuel and Metallurgy at Leeds University.

122 KCT 10/1/1601 Tilden to Gow, 25 July 1911.

123 Governing Body Minutes, 29 September 1911. Glazebrook to Gow, 31 July 1911. Draft report by Glazebrook no date, KCT10/1/1601.

124 KCT10/1/1601 'Notes on the Sub-Committee's and Sir T.E. Thorpe's Reports', 6 March 1911.

125 KCT10/3/1956 Bone to Thorpe, 1 June 1911.

126 Keogh to Bone, 20 December 1911. Governing Body Minutes (Report of the Executive Committee) 14 December 1911, 26 January 1912.

127 Governing Body Minutes (Report of the Executive Committee) 24 May 1912. KCT10/3/1956 booklet dated 17 July 1912.

128 KCT10/1/1601 Ramsay to Keogh, 7 October 1911.

129 KCT9/1/2 Bone to Gow, 15 December 1913.

130 Imperial College of Science and Technology, Calendar. Session 1913-1914 (1913), pp.28-9.

131 Board of Studies Minutes, 27 May 1913.

132 KCT/10/3/1956 Gow to Hinchley, 6 April 1913.

133 J.W. Hinchley, 'The Work of the Imperial College in the Training of Chemical Engineers', in Faraday Society, op.cit. (1917-18), pp.87-8.

134 KCT9/1/2 Bone to Keogh, 25 June 1914. Governing Body Minutes, 26 June 1914. Seventh Annual Report PP (1914-16) xx, pp.23-4.

135 KCT9/1/2, Keogh to Roscoe, 29 June 1914.

136 Hall, op. cit. (1982), p.55.

137 On the role of chemistry during the war see Haber, op. cit. (1971), chap.7, and on more general issues Sanderson op. cit. (1972), chap.8 The process was centred on the demands of Moulton's Ministry of Munitions, but it had an influence on a wide range of initiatives. It was associated with a major nationalization in the form of British Dyes Limited, with the formal intervention of government in industrial research through the Department of Scientific and Industrial Research, and eventually with the reorganization and expansion of government funding of the universities through the UGC. There were also deep shifts in experience and attitude. On the boosterism associated with chemistry see for example W.J. Pope, 'The National Importance of Chemistry' in Science and the Nation. Essays by Cambridge Graduates, ed. A.C. Seward (Cambridge, 1917), pp.1-23 and R.B. Pilcher and F. Butler-Jones, What Industry Owes to Chemical Science (1918). On the DSIR see H. Melville, The Department of Scientific and Industrial Research (1962) and I. Varcoe, Organizing for Science in Britain (Oxford, 1974). On the UGC see E. Hutchinson, 'The Origins of the University Grants Committee' in Minerva ciii (1975), pp.582-620. The attempts by academics to exploit the situation to gain government and other finance led to conflicting pressure groups such as the Neglect of Science Committee, the Conjoint Board of Scientific Societies and the Council for Humanistic Studies. See Jenkins, op. cit. (1979), pp.54-5; D. Layton, 'The Schooling of Science in England, 1854-1939' in The

Parliament of Science ed. R. MacLeod and P. Collins (1981), pp.188–210 (201). The supposed threat to "pure" science by technology led also to a Scientific Research Association established in Cambridge: *JSCI* xxxviii (1919), pp.26R–27R.

138 Hinchley, op. cit. (1916–17).

139 'Memorandum as to the Future Requirements of the Department of Chemical Technology', 15 March 1917. KCT10/4/1603.

140 University College London, Professorial Board Minutes, 11 October 1916, 30 October 1916. University College London, *Calendar. Session 1917–1918* (1917), p.73.

141 *Nature*, xcix (1917), p.207.

142 KCT9/1/3/1601, Bone to Gow, 18 May 1917; Bone to Gow 19 June 1917. Governing Body Minutes, 22 June 1917.

143 *Nature*, xcix (1917), p.325. Gow to Nature, 29 June 1917.

144 KCT10/4/1603, 'A Further Memorandum upon Post-War Developments in the Department of Chemical Technology', 6 July 1918.

145 Governing Body Minutes, 28 February 1919.

146 Senate Minutes, University of London, Minute 2322, 28 May 1919.

147 University College London, DMS Watson Library, College Correspondence, Letters of Application for the Chair of Chemical Engineering, 1923.

148 Imperial College of Science and Technology, Board of Studies Minutes, 1 June 1926.

149 Numerous letters and other documents between Hinchley, Bone and various others in KCT9/1/4, 1921–27.

150 KCT9/1/4 Gow to R. Hill Dawe, 17 November 1921.

151 Executive Committee Minutes, 4 June 1926.

152 Board of Studies Minutes, 1 June 1926. Bone to Rector, 3 June 1926.

153 University College Committee Minutes, 6 February 1923 "Report of the Chemical Engineering Sub-Committee", Appendix IV.

154 Ibid., 1 May 1923.

155 University College London, DMS Watson Library, College Correspondence, Letters of Application for the Chair of Chemical Engineering, 1923. On Williams (1892–1973) see *Journal of the Ramsay Society of Chemical Engineers* xxiii (1976), p.59. It is typical that he had studied chemistry rather than applied chemistry at Manchester University.

156 "It is in the hope of being able to short-circuit some of this 'experience' that this department has been formed to train men in the fundamentals of chemical engineering." E.C. Williams, *The Aims and Future Work of the Ramsay Memorial Laboratory of Chemical Engineering* (1924), p.22–3, 24.

157 "We are passing through a stage in England which you passed through in which the college authorities think that chemical engineering is a combination of engineering and chemistry. Quite recently we were elated by the fact that Glasgow University granted the degree of Bachelor of Science to a student of chemical engineering. Yet that particular University has no recognized school of chemical engineering...the teaching of chemical engineering in that institution omits all of those special processes and unit operations that are essentially a feature of chemical engineering". *Transactions the American Institute of Chemical Engineers* xxi (1928), pp.81.

158 Institute of Chemistry, *Conference on the Place of Applied Chemistry in the Training of Chemists* (1925), p.55.

159 Ibid., pp.12–14.

160 *Transactions of the Institution of of Chemical Engineers* ix (1931), pp.14–20

161 Bohme et al., op. cit. (1983). Hougen, op. cit. (1977). Buchholz, op. cit. (1979).
162 Transactions the American Institute of Chemical Engineers xxi (1928), p.82.
163 Chemical Engineering and the Works Chemist 1 (1911-12), p.1. Its Council members were mainly chemical works employees. There will be no attempt here to give an account of the history of the Association of Chemical Technologists. The figurehead of the Association appears to have been CA Cassal (1882-1922, PIC (1922), pp.59-60). It is not clear who was the motive force behind its establishment. It survived, as the Institution of Chemical Technologists from 1913, to have a role in the public argument surrounding the formation of the British Association of Chemists in 1917. CTJ lxi (1917), p.266, 328. CN cxi (1915), p.236, and cxii (1915), p.160.
164 The journal was eventually published independently as Chemical Engineering and the Works Chemist by SS Dyson. After two years of publishing its transactions here the Association began to produce a separate periodical entitled Journal of Chemical Technology. This ceased publication in 1917.
165 See chapter 3 note 243.
166 Though they were quite well represented on Council (3 out of 25 members). It is worth noting that 12 out of 25 Council members were owners, partners or directors of works, but none were "analysts or assayers". The latter was the largest single group (16%) of the UK membership as a whole. (Based on a sample of 674 members with surnames beginning A, B or C for 1900 and 1915.)
167 JSCI, xxxv (1916), p.147. CTJ lvii (1915), pp.546, 563, 585 and lviii (1916), p.74.
168 CTJ lxiii (1918), p.79. The Chemical Industry Club was founded in London in 1917. Its character is not clear. By 1920 it had 715 members and accommodation in Whitehall Court. JSCI xxxviii (1919), pp.411R-2R, xxxix (1920), pp.395R, 393R.
169 EA Alliott, HJ Bush, CJ Goodwin, AJ Liversedge, WR Ormandy, FH Rogers, and possibly CS Garland and H Talbot were consultants. Proceedings of the Chemical Engineering Group i (1919), p.5.
170 Chemical Age xi (1924), p.656.
171 CTJ lxiii (1918), pp.254, 324. For the early steps see JSCI xxxvii (1918), pp.296R, 391R, 413R, 467R.
172 JSCI xxxix (1920), p.192R. Hinchley was Chairman of the Group.
173 JSCI xxxviii (1919), p.97R. "The problem of defining the chemical engineer and his status does not appear to be an object of immediate importance, but it is essential that everyone should realise that the Chemical Engineering group is open to all industrial chemists who have an interest in engineering, and to all engineers who have an interest in industrial chemistry...".
174 JSCI xxxviii (1919), pp.100R-101R.
175 Chemical Age ii (1920), p.552.
176 'Training and Functions of the Chemical Engineer', Chemical Age iii (1920), pp.32-3. The author refers to an article recently published by a Committee member, which it has not been possible to identify.
177 JSCI xxxviii (1919), p.160R.
178 Ibid., xxxix (1920), p.179R.
179 A summary of the talk is given in Chemical Age ii (1920), pp.301-2. The full text appears in Transactions of the Institution of Chemical Engineers xvii (1939), pp.186-91. At the inaugural meeting of the

Institution of Chemical Engineers Hinchley suggested that Moulton was "largely the inspiration for the Institution".

180 CTJ lxviii (1921), p.710-11. See J.W. Hinchley, 'The Need for an Institution of Chemical Engineers', CTJ li (1921), p.31.

181 Chemical Engineering and the Works Chemist xii (1922), p.119.

182 On Woolcock (1878-1947) see JSCI Special Jubilee Number (1931), p.89. On Duckham (1879-1932) see Chemistry and Industry x (1932), p.167.

183 J.B. Brennan, 'The First Fifty Years. A History of the Institution of Chemical Engineers 1922-1972' (typescript at the Institution of Chemical Engineers), p.16. 'The History of the Formation of the Institution of Chemical Engineers', Transactions of the Institution of Chemical Engineers i (1923), pp.vii-x.

184 This was the first point which he emphasized in an informal interview on the proposed institution printed in Chemical Age. 'A Chat with Professor Hinchley', CA v (1921), p.621.

185 CTJ lxiii (1918), pp.248, 289. Hinchley (who often seems ubiquitous at this time) was Chairman of the Executive Committee of the British Association of Chemists.

186 Chemical Age vi (1922), p.43.

187 Ibid., vi (1922), p.588-9.

188 On the Association of British Chemical Manufacturers see C. Bedford, 'The Organisation of British Chemical Manufactures', JSCI xxxv (1916), pp.1040-45, and ibid., pp.561-2, 995.

189 JSCI xxxv (1916), p.562.

190 Sanderson, op. cit. (1972), chapter 8.

191 Duckham argued that "(e)very engineer must, in the future, have a knowledge of chemistry, and every industrial chemist must have a knowledge of engineering". Sir Frederick Nathan, late of Nobel's, told the inaugural meeting of the Institution: "...we in this country were badly in need of men trained not only as engineers, but also as chemists. At present we only had engineers with a smattering of chemistry, or chemists with a smattering of engineering, whereas we wanted men trained with a good knowledge of both". Chemical Age vi (1922), p.289. On Nathan (1861-1933) see Chemistry and Industry (1933), p.1019.

192 Ibid., iii (1920), p.33. It should be added that this is a hostile commentator's gloss on the actual view.

193 Hinchley, op. cit. (1921).

194 Transactions of the Institute of Chemical Engineers ix (1931), p.15.

195 Consultants: FG Rogers, FA Greene, JA Reavell, CS Garland. Academics: Hinchley, SGM Ure, DM Newitt. Others: D Brownlie, W MacNab, J MacGregor, EW Smith. Ibid., vi (1922), p.588.

196 Brennan, op.cit., pp.20-2.

197 Institution of Chemical Engineers, Nomination Committee report, 24 July 1923, Council Minute 98.

198 "He was directly associated with the 'works', or commercially productive side of the manufacture, and not at all directly with the research or routine laboratory aspect of the industry". CA ii (1920), p.552.

199 London University, Senate Minutes, 28 May 1919.

200 Compare Reynold's view of developments in the USA, op. cit. (1986), pp.702-5.

201 Chemical Age vi (1922), p.589.

202 Whitt, op. cit. (1969).

203 'Memorandum and Articles of Association of the Institution of Chemical

Engineers (with Bye-Laws)', Bye-Law 12. The requirements for Graduate status are typical of those for the various classes of membership: "Every candidate for election or transfer to the class of graduate shall be at least twenty years of age, and shall satisfy the Council by personal interview or otherwise, either:-

I. That he
   (A) Has received a good general and scientific education
       and
   (B) Is employed or is being trained as a chemical engineer or in such branches of scientific and technical work as are directly connected with the chemical industry;

Or

II. That his admission as a graduate would conduce to the interests of the Institution;

Or

III. That he has passed an examination in chemical engineering approved by the Council as a qualification for graduates."

Chapter 8. Conclusion

Writing of the role of education in the industry of nineteenth-century Germany Peter Lundgreen has remarked that it was the labour market rather than industrial practice which underwent "scientification".[1] This description does not, of course, exhaust the changes involved. Nevertheless the shifts which occurred in the mechanism for the production of the industrial workforce have been one focus of the present study. The location of this mechanism was transferred from the domain of private relations into that of public institutions. The route to employment was to be mediated by a public validation of competence based around curricula devised by 'experts'. In these comments 'public' does not necessarily mean the state or local government, though it was increasingly only here that the necessary resources were deployed. The fact that such training occurred in public institutions had implications for the curriculum which could be constructed. However many other forces were in play as academics extended claims to devise curricula and undertake validation in relation to increasing areas of industrial practice. Such claims were not unconstrained, and involved negotiations of authority within and outside academe. The way in which curricula related to industrial practice was problematic cognitively, and more than one curricular response was possible. However formulated, these responses contributed to a disruption of existing workplace organization. Changes in the mode of producing the workforce both caused and depended on a restructuring of that workforce. This concluding chapter will focus on this complex of issues in its relation to chemistry.

Academic chemistry began to develop independent institutional forms in Britain during the mid-nineteenth century. The leaders and spokesmen of the embryonic profession drew on German models to argue the importance of academic training for what the 1868 Select Committee called "the industrial classes". This model of unconstrained chemical teaching and research generally involved employment in public institutions. The emphasis of the academics on the general economic benefits to society reflected the need to obtain resources for such an institutional foundation. This programme was formulated most clearly by Playfair in 1852:[2]

> The establishment of Industrial Colleges will materially aid the progress of Science by creating positions for its professors and for those who would willingly cultivate Science, but are scared from it by the difficulties they have to encounter in its prosecution.

Playfair's emphasis on the need for state support was unambiguous, though the notion of public (in the sense of state) intervention to generate workplace competence was a delicate one, and sat uneasily within a framework of 'liberal' ideology. However there were other forms of semi-public, corporate intervention. The Society of Arts, the City and Guilds, the locally-controlled activity of the mechanics' institutes, university colleges and technical schools were of this type. All were mobilized and acted in the long term as mediators for the involvement of local and national government. Rothblatt has emphasized the diversity of the mechanisms for state involvement in science and higher education in nineteenth-century Britain.[3] By the beginning of the First World War a substantial 'system' of university and technical education was in place, most of it derived from such semi-public activity.

This approach to preparing men for industrial employment can be seen as merely one example among many of attempts to reconstitute problems in the operation of an increasingly complex society as amenable to solution by novel classes of expertise.[4] It would therefore be mistaken to present the propaganda efforts of academics as having a key role in promoting public intervention for industrial purposes. However academic science had a prominent role in some aspects of the process, and perhaps provided the exemplar of expertise. Physical science was the archetypal form of certain and communicable knowledge of an instrumental kind.

The programme of the academics can be seen as one of building on this base to displace traditional locations and forms of knowledge in favour of academic-led 'expertise'. In the mid-century they began this process by identifying an "abstract chemistry", narrowing it to the subject matter and outcomes of academic activity and distinguishing it from "practical" chemistry (of which the industrial manipulation of materials was perhaps the archetype). Adding to scientific knowledge, even as a by-product of employment as a professional teacher, was never entitled a 'practice': it was presented as operating in a higher mode.

A series of arguments was developed. These had been implicit in some earlier accounts of the relations of "philosophical" knowledge and industry. However in the mid-century they had the beginnings of an institutional underpinning. One argument rested on the generality of the knowledge involved: academic chemistry could be deployed in numerous industrial and other contexts, using especially the increasingly standardized analytical methodology. A second concerned its power. It was claimed that chemistry gave a direct control of industrial processes: chemical knowledge was able to subsume that associated with industrial practice and with the "practical" man. Industrial 'knowledge' was merely the application for which chemistry provided the principles. Here the language of the mid-century regularly went beyond the claims which had been made for "philosophical" chemistry in the past. A third argument concerned progressiveness: chemistry allowed not merely the understanding and control of existing processes and materials, but gave a systematic basis to invention. This complex of related claims gave the academics' language a peculiar power, while the over-riding need to gain a material support for their practice gave them a particular urgency and conviction. Finally their position as "experts" gave them access to important public forums when the issue received attention in the 1860s and 1870s.

However the economic rationale of public educational activity which was fostered could put the academics in a difficult position, illustrated by the ambivalence of Frankland's inaugural lecture at Owens College in 1851. Attempts were made to place the ultimate degree of economic relevance in an inverse relationship with freedom of research and generality of curricula. The basis of such efforts became clearer as the century progressed. It has been suggested that the thrust towards public and corporate action had deeper roots than the self-interest of academics. The possibility of producing and defining the industrial workforce through public educational activity could generate alternative curricular solutions. Industrial relevance could lead to constrained research and teaching. This introduces the major tension, which has been apparent throughout this study, between curricula based directly upon industrial technique and those based on chemistry as an independent discipline under academic control. Where industrial capitalists had an influence on institutions (as at the Andersonian, the City and Guilds Institute and the Manchester Technical School) and often where their influence could be felt indirectly (as at Owens College and University College London) a pressure for more 'technical' curricula was often exerted. This influence could, however, be ambivalent, as will be discussed below.

These alternative curricula were not generally successful. The immediate reason was lack of students, but this was merely a function of other difficulties. Of particular interest are the curricular implications of a public intervention in the training of individuals. Though it received little comment, the force of the claims of chemistry as understood academically drew on the fact that the knowledge generated by academic practice was 'public' in a fundamental methodological sense: it was validated in and thus necessarily occupied the public domain. Attempts to create technical curricula set out to establish a pedagogy of such public knowledge, in effect following the model of academic chemistry, but in fields which had cognitive foundations in technical practice. This boundary was to some extent coincident with those between good and bad, profitable and unprofitable, and innovative and static technique. Hostility was repeatedly expressed by manufacturers to the possibility of making public through technical curricula the practices which differentiated works economically. A related tension stemmed from the important place of research within academic practice. There were practical and ideological difficulties in establishing a domain of public research in technological fields. The alternative of private commercial research was, if anything, still more problematic. Even undertaking private analytical work provoked hostility. Each of these strains undermined embryonic technological fields.

A number of other important difficulties existed: the specificity of accounts of industrial processes, their proneness to becoming outdated, the resources involved in curricula which required materials or apparatus on an industrial scale, the difficulty of recruiting appropriate staff and, not least, the need to maintain a differentiation from the manual operation of plant. Each of these arguments or material pressures was observed in chapter 4, and each had an influence on the character of institutional developments, the recruitment of students and the general failure of academic courses in chemical technology.

In responding to the pressure for a more technological orientation, those involved with courses in 'pure' chemistry were frequently pragmatic. It was often possible to set up curricula which focused on analytical techniques and generally uncontroversial descriptive accounts of industrial processes. Indeed it was observed in chapter 4 that the boundary between such activity and technological curricula was fluid. Nevertheless a continuing rearguard of more aggressive action was fought. The alternative domain to "abstract principles" was described as "mere empiricism", "grind...without any principles" or "manual skill". These three contemporary phrases each have their underlying messages, but the third points the discussion towards a relationship with workplace hierachies which is increasingly significant in understanding curricular and institutional change.

In the early part of the nineteenth century the industrial role of science was not strongly represented as having a cognitive dimension based on class of industrial worker. Ure's famous comment on the role of science in teaching "docility" to the industrial workforce referred to the situation of explicit industrial conflict. Even in the mid-century the Society of Arts presented its examinations as unifying rather than differentiating classes.[5] However, by the 1860s the movement for increased science education which Playfair led was clearly targetting its industrial arguments on entrepreneurs, managers and to some extent foremen (a targetting which was routinely transferred to their children). At this time the justification for science education underwent a partitioning and, paradoxically, that based on a directly instrumental role in manufacturing industry became focused on the upper reaches of the "industrial classes". The working classes, by contrast, were represented as requiring only a low-level scientific education, the function of which was close to that of a general (in modern terms) secondary education: the creation of an "intelligent" workforce.

It was high-level education in chemistry which was justified in terms of a directly industrial function. The connection of this with the need to support academic research is clear enough. Education for the working classes was certainly not associated with institutionally-supported research facilities. The emphasis was based less on any 'objective' analysis of the industrial role of science than on the need to underpin high-level research and teaching. This is reflected in the rapid decline, later in the century, in the industrial claims which had been made during the mid-century for training in analytical chemistry, as such training became widely available. What had been the key to the use of chemistry in industry became the mark of an incomplete chemical education. There were however other elements. The power claimed for unalloyed science was clearly marked out for masters and those closest to them. The opposition to mere "manual skill" was easily transformed into the need for a curriculum appropriate to those who would oversee such skill. The novel conceptualizations of industrial practice to be supplied by "abstract science" could be presented as providing routes for the replacement for such skill. In some cases the languages of scientific education and industrial domination were intertwined: "educate your masters and exact obedience from the workman" was one phrase used at a meeting of the Society of Chemical Industry in 1889.

One striking characteristic of accounts of the industrial functions of science till about 1890 was that they rarely envisaged any novel class of industrial worker. While the representation of science's role stressed a cognitive and technical dynamism, and often tacitly endorsed the ejection of manual skill, it was largely conservative in relation to the broader organization of industry. However, though this type of public representation held the field, concrete changes were occurring in industrial practice. Academics and those who took a similar view were not altogether ingenuous about this. The coyness of Roscoe over the employment of his ex-students was noted in chapter 3. In chapter 6 it was seen that the main industrial employment for chemically-trained men without family connections was in analytical work. A general recruitment occurred from around 1860 in those industrial fields where the categories of analytical chemistry could be applied unproblematically to the main substances involved. Sectors such as manufacturing chemistry, the iron and steel industry and textile-dyeing and -printing all began to employ the chemically-trained products of the new colleges. These sectors were building on an older tradition, which was surveyed in chapter 2. The contrast with the accounts just discussed is strong. Industrial capitalists appropriated chemical knowledge on their own terms. Those terms meant that its primary use was in monitoring chemical transactions within and between works, and acting in a service role to process managers. The first widespread use of academically-derived chemical knowledge precipitated a form of functional specialization, based on a very specific expertise which that knowledge conferred. It involved not a seminal contribution to invention, but a focused activity which could be utilized relatively easily within firms.

These analytical chemists were of low status in the works: they usually received relatively small salaries, limited facilities and had little independence. Their work was repetitive and undemanding of novelty and initiative (if not chemical knowledge and manipulative skill). They had two main routes out of this condition. One was into independent practice, usually analytical, though occasionally individuals set up consultancy practices in the actual techniques of industries. The alternative to consultancy was a move into management of some aspect of the works proper. (The establishment of a technical, as opposed to analytical, consultancy practice also required this type of experience.) Such a trajectory led into a 'traditional' position within the works, though from a novel direction. This reflects the fact that the process by which specialisms other than analytical work were created was slow, and heterogenous across sectors.

As early as the 1870s some of the men employed as analysts were undertaking what can loosely be described as research and development work. This was integrated with the type of innovatory activity which had often been undertaken by senior personnel in progressive firms. It continued to be temporary, *ad hoc*, informally located within the firm's activities and often associated with a shift into process management or the utilization of time which could not be filled by routine work. The extent to which 'research' (usually closer to a loose amalgam of research and development) was established in a more formal position within firms cannot be separated from wider changes in their organization, or from the circumstances of each industrial sector. In the organic field all firms appear to have undertaken some kind of 'research' on a permanent basis (if the title 'research' can be given to such activity as attempting to reproduce patented dyestuffs). At

Brunner, Mond the activity was focused on Mond himself. At the United Alkali Co. and less clearly at Nobel more formal activity was inaugurated in the late 1880s and 1890s. At the former it was precipitated by the commercial and organizational upheaval in the Leblanc industry, and at Nobel by such factors as the early dependence of the firm on salaried managers and the need to meet tight public controls on its products.

However this activity was institutionalized as research and development very slowly. Even at the United Alkali Company, a major function of the "Central Research Laboratory" (sometimes called merely the "Central Laboratory") established in 1891 seems to have been to distribute chemists employing a standardized methodology and competence around geographically-dispersed plants. Elsewhere it has not proved possible to identify research and development as a component of formal bureaucratic apparatuses (in the Weberian sense of integrated systems of rule-governed operations) in any firm before the First World War, though the language of departments was common, and separate financial arrangements can be detected (just) at Brunner, Mond in the 1890s.[6] Around the turn of the century the over-riding trajectory of men from the analytical laboratory who stayed with firms (and many appear to have been mobile) was from analytical work, through some kind of intermediate status, into process management. A man like Bagnall at Levinstein's could combine analytical work (in the somewhat complex area of organic dyestuffs) with process control, undertaking no research work whatsoever, and receiving a considerable salary.

Recent studies on the growth of technically progressive industries (notably in chemicals and electrical engineering) around the turn of the century have focused on the extent to which their major firms sought to replace market competition by planned growth. This situation can also be found in industries which were less dynamic in physical technique, such as railways and mechanical engineering. It involved the creation and integration of new knowledges in technical, commercial and financial domains.[7] Such an approach is in part predicated on the presence of salaried managers and the partial separation of ownership and control. An over-riding orientation towards growth and profit was supplemented by an emphasis on the firm as a matrix for semi-bureaucratic career structures. Within this component of what Galambos has termed an "organizational synthesis" the role of scientific knowledge shifts from that of the initiator and key component of technical and economic change, towards one among a number of relevant knowledges to be marshalled. The trained specialist occupies a parallel position.[8] The picture presented above of the analytical chemist fits almost too well within this view of the early industrial role of science. The analysts' appearance within works at such an early stage can be considered as a primitive manifestation of this approach. The aim was to regularize transactions and generate a routine, everyday knowledge rather than revolutionize practice. It is possible to speculate that the focusing by industrial capitalists and managing directors on what Rosenberg has called "academically 'low-brow' activities" reflected an alternative (if not publicly articulated) view of the industrial role of science.[9]

Individuals working in this area have found heterogeneity across countries. Locke has attempted to explain differential industrial developments across Europe in terms of educational provision. Germany is generally recognized as showing the greatest movement towards bureaucratization before the First World War. Kocka has seen this growth as supported by the transference of models and men from public bureaucracy in Germany. Chandler has argued that developments in the USA were precipitated by the formation of multidivisional firms and their need to co-ordinate vertical and horizontal activity.[10] It is noticeable that even the primitive and rambling empire of the United Alkali Co., which has some formal similarities to the firms decribed by Chandler in the USA, instituted a Central Laboratory in 1891 ostensibly for these reasons. In the UK the contemporary accounts of research organization which began to appear in the early years of the new century had their origins in the United States.[11]

An important element in the overall process of change was the financial reorganization of private firms into limited liability companies. This opened new routes to capital, facilitated the emergence of salaried managers and encouraged the growth of formal divisions of responsibility among senior employees in relation to boards of directors. In undertaking this study it was anticipated that such financial reorganization was a necessary and perhaps sufficient condition for the growth of scientific and technical bureaucracies within firms. Chapter 6 has indicated that, while perhaps necessary, this change was certainly not sufficient to precipitate the growth of the functionally-specialized use of scientifically-trained men beyond analytical work. At Brunner, Mond the simplest formal recording of technical decisions did not begin until Mond's influence was in decline (judging, that is, from documents and accounts which have survived). Torstendahl has seen the growth of the research function as a necessary condition for the emergence of "professional careers" for trained men. The applicability of this statement to Britain depends upon how the term "professional" is interpreted.[12] Salaried employees were certainly progressing through British firms in the late nineteenth century without having undertaken institutionalized research, and even in the absence of formal bureacracies.

Recalling the dangers of generalizing, then, it can be argued that the situation which has been described in this study for British firms is one in which a single dimension based on status and decision-making authority dominated other characteristics. 'Status' is a difficult term, but is exemplified in Reader's account of the Winnington Hall Club at Brunner, Mond. These comments apply even to (especially to?) 'advanced' firms such as Brunner, Mond. Only after having reached a sufficiently responsible position in process control by 1899, could HA Humphrey gain permission to undertake informal research. Humphrey's work was, in a sense, entrepreneurial on a 'micro' scale within the firm. He began on his own initiative and without a formally-defined role. Even in 1912 FA Freeth undertook research on a semi-independent basis, and needed to reject the move (essentially a promotion) into the works proper in order to continue to do so. The tension between the laboratory (even the 'research' laboratory) and the works, which dominated the trajectory of trained men, was essentially an hierarchical one. Elements of hierarchy had a key place also in firms' relations to what was increasingly an educational 'system', and in the internal relations of that system. They can even be seen as more important than curricular content.

It was argued in chapter 4 that the class of student (understood in terms of full-time and part-time attendance and potential authority within works) which each institution might legitimately target was the clearest focus of the negotiations between Manchester Technical School and Owens College around the turn of the century. Here and elsewhere, what counted as appropriate for a "university" curriculum was more negotiable than what counted as a university student. The distinction between technical and university education had taken on a strategic status around turn of the century. The wide range of institutions which the Samuelson Commissioners could convene under the title of technical education was broken down. A class of "technical" studies and institutions was defined and associated with narrowness of curriculum, emphasis on manual skill and subordinate works position for its students.

Each industrial sector has its own characteristics in relation to this division. In the chemical field the shift was particularly associated with the growth of a body of intermediate laboratory workers undertaking routine analytical work, rather than with manual workers as normally understood. The failure of chemical aspects of the City and Guilds Technological Examinations, and the absence at the turn of the century of co-operation between chemical employers and technical institutions, reflects the absence of a category of manually-skilled men within the industry. As Meldola observed, there was no equivalent to the skilled artizan-engineer in the chemical industry (qua chemical). The type of routine activity just referred to was based rather upon a kind of focused 'pure' chemistry. By the second decade of the twentieth century, and in some cases before, there is evidence from firms such as Levinstein, Read, Holliday, Brunner, Mond and the United Alkali Co. which indicates the reworking of analytical activity along these lines. Men from high-level institutions were partially displaced. The existence of a self-conscious body of men in more routine positions would be reflected during 1916 in their organization as the National Association of Industrial Chemists. An attempt was made to rationalize the educational apparatus for the production of such men on a national scale in the early 1920s by means of the National Certificate scheme.

Some commentators on the historical relations between education and the workplace, notably David Noble, have strongly emphasized the way in which the growth of modern institutions and curricula was consciously designed to reproduce the hierarchical relations of a capitalist organization of production.[13] It is also argued that curricula were 'technicalized' so as to focus on areas of knowledge defined by industrial requirements. Unlike these accounts, the present study does not claim to enter into the detailed affective and social influences of educational activity. Nevertheless some parallels to such arguments are evident. The limited restructuring of the workplace was broadly mirrored in the types of educational institutions which were developed. Yet, at a curricular level, matters are less clear cut. So far as the chemical industry is concerned the findings of this study generally undermine any claims for a widespread and successful imposition of routine, technically-focused curricula in British higher education for the period under consideration. 'Pure' chemistry maintained a dominant position among full-time students in key institutions such as Manchester University, with "technological" activity restricted to a position in which it was derivative within the curriculum and numerically inferior. Thus, at Manchester around 1910, at a time when about 70% of chemistry students were entering industry, 27 men took the B.Sc. degree with Honours in chemistry, compared with 2 taking the equivalent B.Sc. Tech. in applied chemistry.[14]

This situation can be explained in various ways. It is not necessary to attempt to rely on Cardwell's view that the 'industrial scientist' (to use a very definite anachronism) was effectively a spin-off from teacher training. Certainly recruitment into teaching did provide a central support for the 'pure' discipline. Indeed this is a special case of the general point that 'pure' chemistry was a less limiting study than any technical course. Nevertheless it was suggested in chapter 5 that a substantial proportion of all chemistry students from the major institutions (and a majority of the most committed students) was recruited by industrial firms throughout the period under discussion here. In any case numerous other factors helped determine 'pure' chemistry's relations to emergent technical fields and to industrial recruitment.

The fact that within the manufacturing process proper the chemical industry was polarized between unskilled manual and managerial activity meant that movement from the former to the latter was rare. The route into managerial activity went through some form of non-manual work. By the turn of the century this was usually through the laboratory. The process was probably encouraged as firms ceased to be controlled by the families of founders, and men who had themselves begun in laboratories reached senior positions. This route was also promoted by the fact that the products and raw materials, if not the processes themselves, were increasingly understood in laboratory terms. Within such a trajectory a preparation in mainstream academic chemistry was as appropriate as any technical curriculum. For manufacturing chemistry at least, technical chemistry curricula had not defined bodies of knowledge which would provide alternative routes into intermediate managerial positions, though this was not a merely cognitive issue. In the early twentieth century the arguments from the mid-nineteenth continued to be deployed, presenting pure chemistry as more appropriate for men destined for managerial positions, because of its potential as a "liberal education", its remoteness from the manual operations which were to be controlled and its abstraction and generality. In addition there were such factors as the well-established position of the older field in institutions like Owens College. 'Pure' chemists such as HB Dixon at Owens ensured the inclusion of large amounts of what the *Chemical Trade Journal* called "useless ballast (of) theoretical studies" in technical courses. In sum, and recalling again that these remarks are intended to apply more especially to manufacturing chemistry, the situation obtaining in the UK immediately before the First World War was one in which curricular and institutional hierarchies displayed a considerable degree of mapping. To a degree this was carried over into the workplace. For many reasons, then, 'pure' chemistry occupied a position within this system which enabled it to resist much of the pressure from embryonic technological fields.

One such field was chemical engineering. The term "chemical engineering" grew initially during the late nineteenth century as descriptive of the complex of knowledge associated with the design of chemical plant. Curricula in technical chemistry began to include courses with this title, and it was briefly adopted by the City and Guilds Central Institution. However, in an academic environment, the field was marked by tensions. On the one handit could be treated as based on an amalgam of mechanical engineering and chemistry. On the other it could refer to a more integrated treatment based directly on industrial chemical operations. A conceptualization of chemical engineering in the latter sense was constructed by men active in a field of industrial practice: that of consultancy. It was based around generalized accounts of the manufacturing chemistry plant identifiable across specific sectors of the industry: recognizable prototypes of what would later be called "unit operations". Chapter 7 argued that this approach to chemical engineering resolved some, though not all, of the curricular tensions of technical chemistry. In particular, the field's emergence from consultancy and focus on chemical plant was seen as engendering a body of knowledge with a relatively public and general character. Chemical engineering began to develop in the high-level environment of Imperial College in 1910. Here, despite employing a phenomenological approach to chemical operations often bearing little resemblance to 'applied chemistry', it occupied a highly derivative position. It existed only as a postgraduate course--students must have studied chemistry (or, occasionally, engineering) to degree level before they began a study of industrial operations, in however generalized a form. Nationally it was not until 1931 that the Institution of Chemical Engineers placed the possibility of undergraduate courses firmly on the agenda, and even then it was controversial.[15]

This situation stemmed partly from the wider institutional weakness of new fields which has already been referred to. At Imperial College JW Hinchley was generally willing to acquiesce in the model of chemical engineering as the application of chemical and physical theory. Even so, tensions can be discerned. Hinchley also stressed the aim of reproducing in an academic environment the experience of works practice. He argued that chemical engineering practice frequently "cannot be deduced from physical or chemical knowledge". Both Hinchley and EC Williams of University College, the first occupant of the other early Chair, recognized limitations in any view of chemical engineering practice as derived from general principles. Williams argued that the key problems occurred "where theories break down and principles are incompletely known". Equally, however, these two seemed aware of the importance of the 'derivative' model in maintaining the institutional position of their field. It was perhaps essential if chemical engineering was to claim a place in university institutions rather than technical colleges, and if the chemical engineer was not to be a "technician".

Donald Schon has explored the tension between, on the one hand, a view of professional practice as the implementation of standardized rules designed to minimize uncertainty ("technical rationality") and, on the other, that "artful" practice which, he suggests, the practitioner brings to bear on those non-standard situations with which she or he is usually confronted.[16] This seems to match well the tension which the early academic protagonists of chemical engineering perceived in their own practice. The appeal to naturalistic 'unit operations' as a conceptual basis stood uneasily between the two positions. The first (largely unarticulated) approach to the curriculum emphasized the unity of technical practice and the impossibility of reducing it to the application of general principles. The second identified a "technical rationality" in which the fundamental position was held by a body of physico-chemical theory, independently constructed within older disciplines. It is difficult, with limited information on the way in which teaching was actually undertaken, to know how these public stances were represented in the pedagogy of the period. In the early 1920s the field had achieved an uneasy stability. Bohm and his co-workers have described the growth of "technical theories" in the period after that with which this study is concerned. It can be argued that this development, while to some extent usurping the fundamental claims of physico-chemical theory, was a component of the resolution of this issue pedagogically on the model of "technical rationality".[17]

The account of the professional and curricular development of chemical engineering took this study through the years of the First World War, though only on this narrow front. It is difficult to overestimate the influence of the War in promoting new models of industrial organization and new industrial techniques, and in precipitating consciousness of the possibilities of organized investigation of industrial problems. The removal of practitioners from industry, and the increased involvement there of academics, sharpened consciousness of industrial chemistry as an independent domain. There was an increased use of the term chemical engineering as descriptive of the expertise involved in operating industrial chemical processes, and a renewed interest in chemical engineering education. Nevertheless, both at this time and earlier in its history, chemical engineering challenges the view that radical curricular change, even in so clearly technological a domain, was driven by industrial demand. This refers both to the direct imposition of curricular blueprints on academe and the more indirect impact of a demand for novel industrially-defined occupational categories.

Attempts to gain support for the more radical or directly industrial curricular interpretation of chemical engineering, displaying independence from chemistry and engineering, often received hostility rather than support from industrial capitalists or senior managers with educational connections. Still less did such men initiate curricular change. Even the dichotomized view of the field was frequently seen by these groups as reducing competence in the more traditional disciplines. Similarly the evidence of the personnel demands from even the most technically-advanced of British firms does not indicate the creation of or demand for a novel occupational specialism. The new academic field, certainly in its more radical form, emerged under essentially academic pressure. Its growth involved a negotiation mainly with the 'parent' disciplines of chemistry and mechanical engineering. During this negotiation the novel concept of 'unit operations' occupied an important early position, which differentiated the new field. Chemical engineering also attracted the hostility of more sector-specific academic fields, since claims were made that it was the 'primary' technology of industrial chemical operations.

The early history of chemical engineering as an industrial category or 'profession' cuts across the professional/employee boundary which is often the focus of sociologies of scientists and technologists in industry.[18] The establishment of the Institution of Chemical Engineers around 1920 drew on a complex body of support. Industrial employers were enlisted at the highest level, with the apparent aim of influencing educational practice. Professional academics sought to legitimate and stress the independence of the new field. Among the bulk of the Institution's early members, however, it appears that the motivation was to certify an occupational shift within industry (from the analytical laboratory, to process control in the works proper) and an elevation within the decision-making hierarchy of the workplace. This signified a shift from precisely the activity for which the academically trained 'pure' chemist was best qualified and through which he was most frequently inducted into the works, but where he was close to being compromised by association with the growing output of routine analysts from the technical colleges. The early conceptualization of chemical engineering, developed by academics and consultants, had been orientated towards plant design rather than plant operation. While these groups were strongly represented among the founders of the Institution of Chemical Engineers, they reacted pragmatically to the shifting balance between design and operation. No attempt was made to impose any narrowly-defined qualificatory criteria. Overall the Institution successfully welded a diverse set of interests into a workable constituency.

The well-documented routinization of analytical chemistry must not be confused with the deskilling of the manual workforce. Noble has drawn a parallel between Frederick Taylor's "scientific management" (which was largely focused on standardizing the activities of artizan mechanical engineers) and the concept of unit operations. On the face of it there are few parallels between unit operations, which applied to machinery-based operations, and Taylor's techniques for the control and measurement of psycho-motor activity, though it is not possible to be positive on this. Detailed information on the manual operation of works processes in the chemical industry by this time is lacking (these comments are not intended to apply to the older Leblanc-type operations). It is perhaps conceivable that some body of manual skills had grown up around chemical machinery, to be displaced by the new approach. However there does not appear to be any evidence to substantiate Noble's claim. It seems probable that the skilled manual worker was already largely expropriated from manufacturing chemical operations. Unit operations served different purposes from this, as outlined previously.

When describing the history of the relations between chemical engineering, 'pure' chemistry and industrial activity around 1920 it is apparent that a very specific complex of forces is in play. Some aspects of those forces have been examined here, but many avenues exist for further exploration. The _Journal of the Society of Chemical Industry_ has provided a valuable source of information, but little attention has been given here to the Society itself. The possible tensions on its Council between academics, employees and industrial capitalists have been touched on. There is some evidence of the Society resisting the 'professional' organization of chemical engineers. The forces in what was the major public body in industrial chemistry and the largest technical/scientific society in the country at the turn of the century would doubtless repay a thorough study. Chemical engineering offers a field for investigating the negotiation between a well-established discipline and a small but powerful technological newcomer. The growth of the latter during the 1930s would provide a valuable case study into the threeway tension and interactions between the worlds of industrial technique, academic technology and academic science. The expansion of chemical engineering within academic institutions and the role of the "technical theories" referred to earlier in promoting institutionalization and independence would constitute one possible line of enquiry. This could be complemented by a study of the field's, perhaps differential, growth within different industrial sectors and categories of industrial personnel. The concrete meaning of chemical engineering in institutional, cognitive and personnel terms could be investigated through the shifts in the balance of power between the various constituencies referred to in chapter 7.

Relatively little attention has been given to the municipal technical colleges. Yet while the universities developed semi-independent systems of academic government the technical collegs remained wholly integrated into the network of local political and economic power. What forces underpinned the construction of the National Certificate system, which sought to rationalize the diversity of local forms of certification? What response did it provoke among those responsible for local activity? The characteristics of the curricula worked out within the local framework could be examined and the impact of that framework assessed. The role of the conflicts, if any, between teachers and the forms of non-academic authority in determining the nature of 'chemical' knowledge in this environment could be examined.

Finally, the comment from Lundgeen with which this chapter began can be recalled. Whatever may have been the situation in nineteenth century Germany, in early twentieth century England the "scientification" of the labour market went hand in hand with that of the technique of the chemical industry and with the restructuring of its personnel. The process was, however, heterogeneous and involved many centres of power. Well before the beginning of the First World War the role of public certification seems to have been recognized by industrial firms as providing a tool for controlling recruitment, without this recruitment necessarily leading into a formal bureaucratic organization. The ultimate question perhaps concerns the driving force for the wholesale transfer, or attempted transfer, of the process by which the industrial workforce was produced into public institutions with codified, 'objectively' assessable curricula. Some aspects of the growth of chemical education can be interpreted as orientated towards stratification of the workforce and routine curricula. Yet the forging of the new technological discipline of chemical engineering cannot be construed in this way, or merely as the implementation of the plans of industrial capitalists and managers for creating educational structures which would service existing or planned forms of industrial practice. Nor can wholesale pressure for technicalizing the chemistry curriculum be detected. Sometimes resistance to this can be found. Overall, the formulation by industrialists of their curricular 'requirements' must be seen as problematic. It may be that control, as much as stratification or technicalization to any pre-existing plan, was a major underpinning aim. Such questions can only be addressed through studies which integrate historical aspects of industrial technique, academic technology and technical and scientific education.

Notes to Chapter 8

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3 S. Rothblatt, 'The Diversification of Higher Education in England' in Jarausch, op. cit. (1983), pp.131-48.
4 S. Hall and W. Schwarz, 'State and Society, 1880-1930', in Crises in the British State 1880-1930, ed. M. Langan and S. Hall (1985), pp.7-32.
5 JSA iv (1855-6), p.219.
6 M. Weber, The Theory of Social and Economic Organization (1947), pp.329-33.
7 L. Galambos, 'The American Economy and the Reorganization of the Sources of Knowledge' in The Organization of Knowledge in Modern America, 1860-1920, ed. A. Oleson and J. Voss (Baltimore, 1979), pp.269-82. A.D. Chandler, The Visible Hand. The Managerial Revolution in American Business (Cambridge, Mass., 1977). Managerial Hierarchies. Comparative Perspectives on the Rise of Modern Industrial Enterprise, ed. A.D. Chandler and H. Daems (Cambridge, Mass., 1980). A.D. Chandler and S. Salsbury, Pierre S. Du Pont and the Making of the Modern Corporation (New York, 1971). J. Kocka, 'Family and Bureaucracy in German Industrial Management, 1850-1914: Siemens in Comparative Perspective', Business History Review lv (1971), pp.133-56. Idem., 'Capitalism and Bureaucracy in German Industrialization before 1914', Economic History Review xxxviii (1981), pp.453-68. L. Hannah, The Rise of the Corporate Economy (1976).
8 L. Galambos, 'Technology, Political Economy, and Professionalization. Central Themes of the Organizational Synthesis', Business History Review lvii (1983), pp.470-93.
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10 Locke, op. cit., Chandler, op. cit. (1977), Kocka, op. cit. (1981).
11 W.H. Nichols, 'The Management of a Chemical Industrial Organisation', JSCI xxiv (1905), pp.707-12. Henry Roscoe was "almost overcome" by the value of the address.
12 R. Torstendahl, 'Engineers in Industry, 1850-1910: Professional Men and New Bureaucrats. A Comparative Approach', in Bernhard et al., op. cit. (1982), pp.253-70.
13 Noble, op. cit. (1979). S. Bowles and H. Gintis, Schooling in Capitalist America. Educational Reform and the Contradictions of Economic Life (New York, 1975).
14 Manchester University, Calender 1911-12 (Manchester, 1911).
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16 D. Schon, The Reflective Practitioner. How Professionals Think in Action (New York, 1983).
17 Bohme et al., op. cit. (1978).
18 See for example S. Marcson, The Scientist in American Industry (Princeton, 1960); W. Kornhauser, Scientists in Industry. Conflict and Accommodation (Berkeley, 1963); S. Cotgrove and S. Box, Science, Industry and Society (1970).

Appendix 1. A Note on Methodology

It will be evident from the data in Chapter 5 that the attempt to gain information on students' occupations directly was only a partial success. In this Note the intention is to survey the empirical sources and rationale of the exercise.

Institutions Surveyed The insititutions represent a cross-section of those existing during the period, namely:

- -an ancient university, with Cambridge chosen because of its more scientific orientation.
- -a London college: University College was chosen because it was generally more effective than King's at this time.
- -the Royal College of Science, as the major government-supported establishment of the period.
- -a provincial college, with Owens the obvious choice because of its size and maturity.
- -the City and Guilds Central Institution because it represents the highest level explicitly technological institution of the period.

The intention to use a sample of students from 1880, 1900 and 1910 stemmed from the important changes which were occurring around 1880, and the interest of the immediate pre-War period. The original intention to obtain a sample for 1920 proved impossible at Cambridge (examination registers of the NST remain closed after 1909) and Imperial College (student registers are closed after 1907, and thus a compromise was necessary even for 1910, when only Associates in chemistry for the period 1909-1911 were used). Moreover, sources become more diluted and sometimes non-existent by 1920, while student numbers were still inflated by ex-servicemen.

Students The central aim was to identify a body of students for each period who were studying chemistry as an important component of an academic course, or as a specialist subject. Women have been excluded from the sample on the grounds that it appears to have been more or less impossible for them to obtain industrial employment during this period. They represented a small proportion of the students even at those institutions where significant number were to be found (University College, London and Owens College). Of course they are included in all statistics not based directly on this sample. The groups used for the sample are as follows:

Cambridge University: men examined in chemistry for the NST (parts I or II) for the periods

-1880-2)
-1900) identified from NST Mark Book Min.viii 56
-1909) (Cambridge University Archives)

University College London:

-chemistry, analytical chemistry and chemical technology students 1881-2
-chemistry students 1899-1901
-1st, 2nd and 3rd year B.Sc. students in chemistry classes 1910-11.

All from the relevant annual volumes of the Professors' Fee Books.

Royal College of Science:

-chemistry students for 1879-80 (Royal School of Mines Journal (ms) D7/2 350)
-candidates for the Associateship in Chemistry (1900), or for other Associateships who studied chemistry in their 2nd or 3rd year (1900-3) (Royal College of Science, Records, 36 D7/6.)
-Associates in Chemistry 1908-11 (Governing Body Minutes, 20 July 1911; Imperial College of Science and Technology, Annual Report PP 1909, xix)

Owens College:

-men registered for the Senior class in Systematic Chemistry, Analytical Chemistry or Technological Chemistry, 1880-1
-1st, 2nd and 3rd year classes in chemistry for Honours students, 1900-1 and 1910-11.
In each case from the student registers RA/1/11 and RA/37/1.

City and Guilds Central Institution:

Students attending chemistry classes (excluding First Year engineering students whose attendance was compulsory), as listed in:
1886-8 (Board of Studies Minutes; call numbers had not been allocated when these records were used)
1898-9 (Typescript mark lists, MS 21,908.)

Qualifications of Students These were obtained from the following sources:

Cambridge University, Calendar

University of London, The Historical Record (1836-1912) Being a Supplement to the Calendar Completed to September 1912 (1912).

(London University), London University Gazette. Published by Authority, (1911-1914).

Univrsity of London, Calendar for 1915-1916 (1915).

City and Guilds of London Institute for the Advancement of Technical Education, Report of the Council upon the Work of the Institute for the Year Ending..., Appendices A on the Central Institution in each case.

T.G. Chambers, Register of the Associates and Old Students of the Royal College of Chemistry, the Royal School of Mines, and the Royal College of Science... (1896).

M. Reeks, Register of the Associates and Old Students of the Royal School of Mines... (1920).

Royal College of Science, London, Register of Old Students Compiled by the Old Students Association. First Issue (1909).

Royal College of Science Association, Register of Old Students and Staff of the Royal College of Science (6th edn., 1951).

J. Walker, Register of Students of the City and Guilds College, 1884-1936 (1936).

Victoria University, Calendar.

Victoria University, Register of Graduates up to July 1st, 1908 (Manchester, 1908).

Manchester University Register of Graduates and Holders of Diplomas and Certificates. 1851-1958, (Manchester, 1959).

Occupations of Students Some of the items referred to above contain occupational information. Further information has been obtained from obituary notices in Journal of the Chemical Society, Journal and Proceedings of the Institute of Chemistry and Journal of the Society of Chemical Industry. However few individuals received full obituaries from these sources. The other major sources which have been used for this survey are:

J.A. Venn, _Alumni Cantabrigiensis. A Biographical List of All Known Students, Graduates and Holders of Office at the University of Cambridge from the Earliest Times to 1900. Part II. From 1752 to 1900_ (Cambridge, 1940-1954).

Institute of Chemistry, _Official Chemical Appointments_ (1908, 1924 and 1931 edns.)

Institute of Chemistry, _Register of Fellows, Associates and Students_ (1902, 1912, 1914, 1919, 1930).

Chemical Society, _List of Officers and Fellows_ (1884, 1900, 1912, 1919).

Society of Chemical Industry, lists of members published with the Society's _Journal_. (The last published list is that for 1917, and no details are extant after that date, because of war damage.)

Society of Dyers and Colourists, Membership lists, 1884, 1895, 1905, 1920.

The Medical Directory (1916).

The Schoolmasters' Yearbook and Directory (1904, 1922).

Institute of Mining and Metallurgy, Register, 1894.

Manchester Municipal School of Technology (University of Manchester), _Register of Graduates, Associates and Other Former Students_ (Manchester, 1913).

Publications and Patents on Chemical Subjects. The Index to the _Journal of the Society of Chemical Industry_ was the source for this information. This index includes patents and abstracts of papers appearing in the _Journal_. The cumulative indices for 1884-96 and 1897-1906, and the annual indices for 1914, 1920, 1921, 1922 and 1923 were used. In order to avoid redundant checking, a trial was made for 1914, and it was established that individuals identified as schoolteachers or doctors of medicine were almost entirely absent from the lists. For this reason these individuals were excluded from the checks undertaken for the remaining years.

General Points. The students on whom this survey was intended to be based were anticipated to have at least some potential specialist interest in chemistry. There are difficulties in defining appropriate "target" student bodies in some cases. The large number of elementary chemistry students at Owens around 1880 has not been included, since there is no evidence that they had any real commitment to the subject, and the level of the chemistry involved appears to have been relatively low. At the Royal School of Mines and Royal College of Science, and the City and Guilds Central Institution, groups taking "foundation" courses in chemistry have been excluded, as noted above. At University College, London, for 1880 and 1900, it is possible that many students of the above type have been included. However, the status of any such individuals would be unclear. As observed in Chapter 5, Table 6, all science degrees obtained were recorded and no students obtained arts degrees.

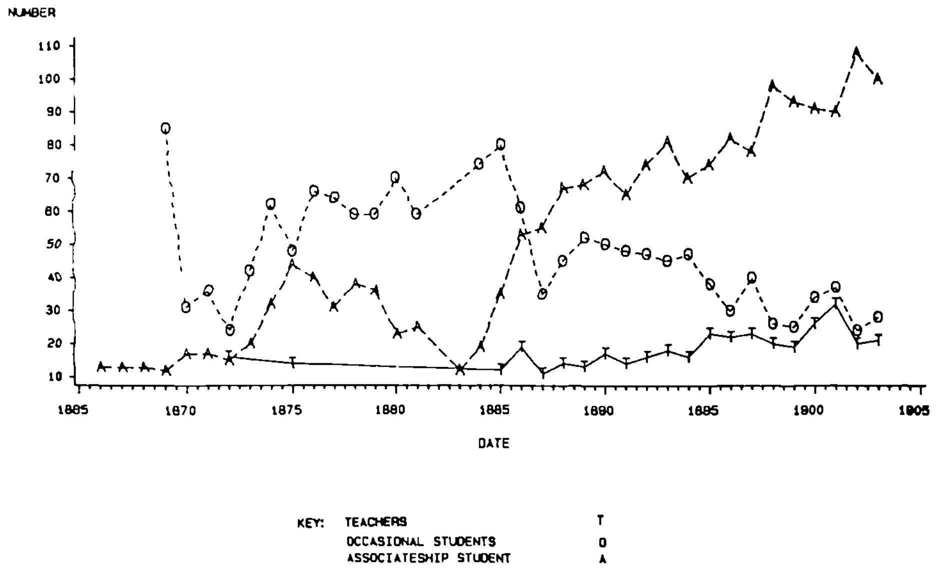
The main aim in this survey was to identify students' earliest 'stable' occupation. The general absence of obituary data meant that students' occupations were often identified at a specific point in time. For this reason it was sometimes necessary to allocate students to a single category when conflicting data existed. In general the earliest available occupation was used except where this was evidently temporary (postgraduate students are the obvious example of this, signalled by an institutional address without an entry in Official Chemical Appointments). Potentially more serious was the situation where only a 'late' occupation was available (around 1930 in some cases), since it is uncertain what relationship this bears to the original occupation. A survey of individuals for whom full obituaries were available suggests that movement between secondary education and industry was rare. Movement between higher education and industry was relatively more common, though the absolute numbers appear small. The most common transfer was that from industrial employment towards independent consultancy. Among students still not in 'stable' occupations by 1914 the First World War had a considerable influence, with considerable movement into industrial and public employment being triggered. This comment is however mainly applicable to students graduating fairly close to 1914.

Overall, the proportion of students which proved identifiable was disappointing, though quite large numbers were detected as having a 'professional' connection with chemistry. Unless some hitherto unrecognized source of data is to be uncovered it seems unlikely that this type of direct enquiry into the significance of education from a prospographical direction will be an appropriate technique for institutions beyond the late nineteenth century. The increasing scale of activity, and the cessation of some sources, as this scale and economic constraints rendered publication impractical, together with the loss of manuscript records, are the major reasons for this.

Appendix 2: Selected Statistical Information

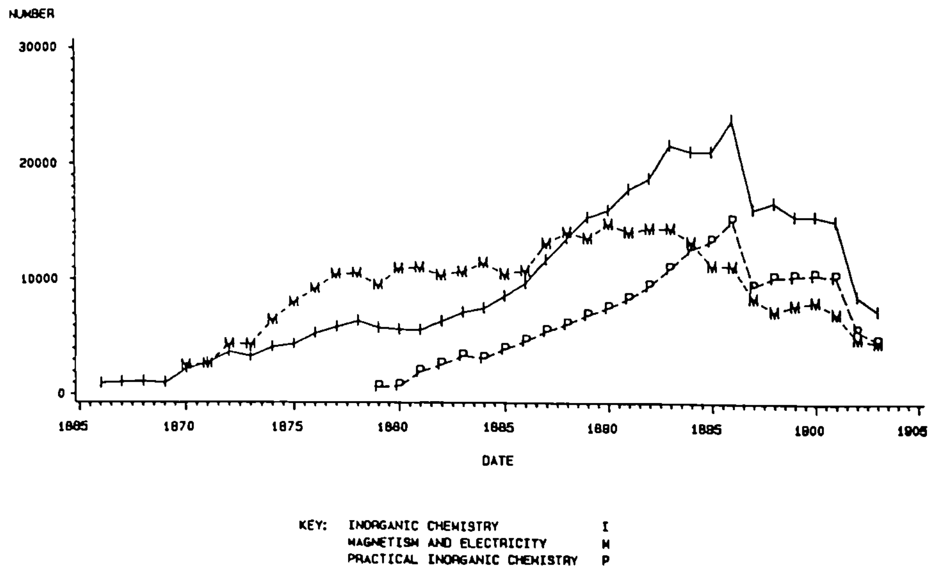
In this Appendix, data are presented which form a general background to the thesis, but are of particular relevance to chapter 5. The sources of information are indicated. In a number of cases the series are interupted. There are also changes in the basis on which data are reported in the sources. Where possible, roughly equivalent groups have been used to complete the series, and in each case the alteration is indicated by the key.

1. Types of Chemistry Student at the Royal College of Science, 1866-1903.



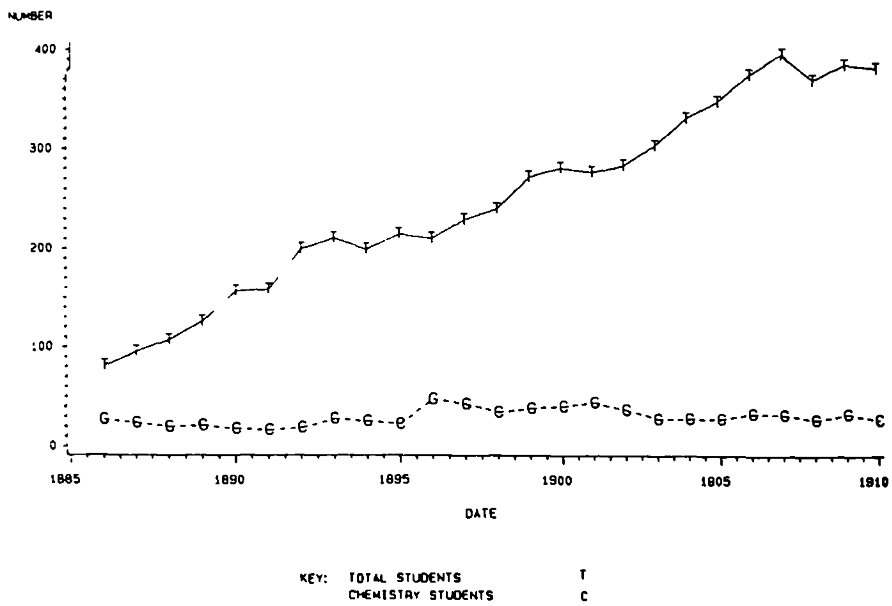
Source: DSA Annual Reports

2. Numbers Taking Selected DSA Examinations, 1865-1903.



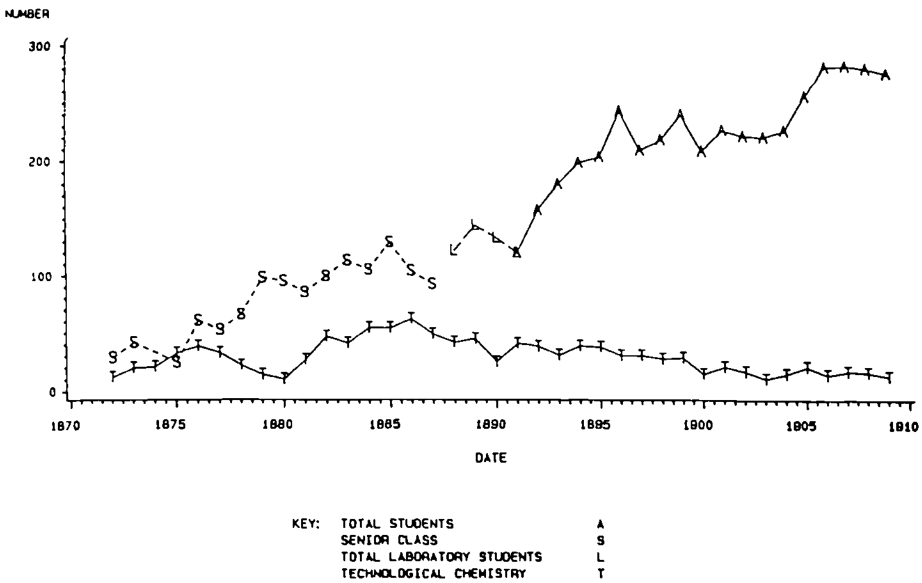
Source: DSA, Annual Reports

3. Student Numbers at the Central Institution, 1885-1910.



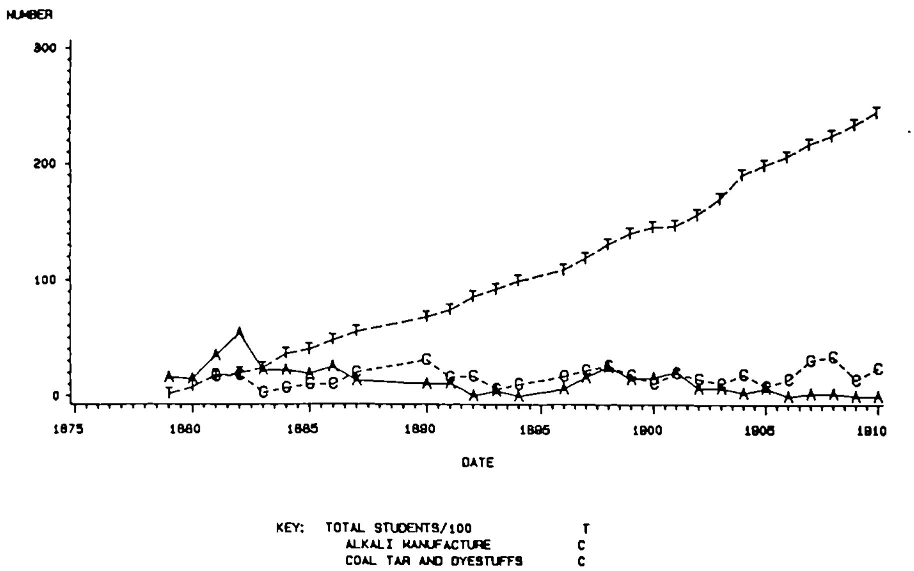
Source: Reports of the Council upon the Work of the Institution

4. Student Numbers at Owens College, 1872-1910.



Source: Reports of the Council to the Court of Governors

5. Numbers Taking City and Guilds Examinations, 1879-1910.



Source: Reports of the Council upon the Work of the Institution

6. The 1902 BAAS Survey of the Qualifications of Industrial Chemists

Industry	University Graduates			Non-graduates				
	UK	UK & Foreign	Foreign	University or University College	Technical College	Foreign University or Technical College	Evening classes	Total
Acids, alkalis & inorganic salts	9	3	5	20	19	2	20	78
Metallurgical	1	-	4	19	13	-	14	51
Explosives	6	-	1	4	28	1	6	46
Dyeing & printing	3	-	-	13	16	-	5	37
Oils, fats, soap & candles	2	1	3	11	9	1	5	32
Colours, pigments oils & varnishes	8	1	2	6	5	-	6	28
Brewing & distilling	3	-	4	8	12	-	1	28
Fine chemicals, confections & pharmaceuticals	7	-	-	9	6	-	4	26
Sugar, starch, salt, glucose	3	2	1	2	8	-	3	19
Cement, tiles pottery	-	1	1	5	10	-	1	18
Aniline colours	2	3	7	2	2	1	-	17
Tar distilling	-	-	-	5	8	-	3	16
Paper	-	-	2	3	3	-	-	8
Glue, gelatine size	-	1	-	4	2	-	-	7
Paraffin & paraffin oil	-	-	-	3	4	-	-	7
Dyewood, & tanning extracts	-	-	-	5	2	-	-	7
Cyanides & ferrocyanides	3	1	-	-	2	-	-	6
Glass	2	-	-	2	1	-	1	6
Coal gas	-	1	-	-	3	-	2	6
Miscellaneous	10	2	2	16	12	3	14	59
Total	59	16	32	137	165	8	85	502

Source: BAAS, 'Statistics Concerning the Training of Chemists Employed in English Chemical Industries', Report of the Seventy-Second Meeting... (1903), pp.97-8.

Appendix 3: A Note on Sources

The available sources have strongly influenced the final structure of this thesis. In particular the original intention was to maintain a more even balance between industrial and educational activity. The industrial archive, while rich, is uneven and often frustrating. Arbitrary bodies of letters, minute books and other records are usual. Unfortunately in many cases no records appear to have survived. Often those that do exist focus on financial and commercial rather than organizational and technical matters. The academic archive is more complete and predictable across institutions. Both industrial and academic materials suffer from the perennial problem that minute book entries do not communicate underlying forces, or even the discussions which took place in meetings themselves. It is clear that there are many sources yet untapped. The heterogeneity of the industrial field makes it the more likely to contain unexpected information. The author suspects that most sources will not be qualitatively different from those he has explored.

One source of information of a different kind is the material relating to the Alkali Inspectorate and the Ministry of Munitions at the Public Record Office. The author judged, from the published reports, that the former would contain little of relevance to this type of enquiry, but the latter is more problematic. Publications by L.F. Haber, notably his recent history of the development of gas warfare, suggest that detailed searches may reveal accounts of works organization, if in an idiosyncratic period. The potentially richest source of information on industrial personnel among scientific societies, the Society of Chemical Industry, has an archive limited to minute books from the period under consideration here. The Institute of Chemistry and the Chemical Society are useful but had a smaller and generally less relevant membership.

It was hoped to undertake a prosopographical study of industrial personnel which paralleled that for chemistry students. This aim has not been wholly abandoned. A considerable database exists (stored on the Amdahl mainframe computer at Leeds University and comprising some

1500 names). The difficulty with such a project is twofold.

The first is statistical. It is necessary to assess the representativeness of any sample of individuals against the industrial population as a whole. This would be a two-stage process. The first would involve identifying a representative sample of firms. The second would require that the individuals associated with such firms were either randomly sampled or fully identified. Both requirements are problematic, but particularly the latter. The available data on firms are unsatisfactory, partly through losses of records, but also because much important information was simply not recorded.

The second general point follows from that just made. Even when an individual is identified in a firm, as often as not one is dealing with a name only. Minute books and correspondence identify individuals, but success in obtaining information on their background and position in the firm is largely a matter of chance. If they joined the Institute of Chemistry or the Chemical Society the problems about identifying background are often reduced. There is however little information on the much larger membership of the Society of Chemical Industry, and that Society gave obituaries only to its most prominent or oldest members. The Society has no records of its membership in the early twentieth century and before. Indeed, after 1917 it ceased to publish membership lists and, later, lists of new members. Any attempt to look systematically at the structure and training of industrial personnel is then very difficult , perhaps impossible, unless some source of information unknown to the author exists.

Appendix 1 indicates that tracing the destinations of chemistry students has similar, in some respects greater, difficulties. However, there is one great advantage: it is usually possible to work from a well-defined sample of students. In general the records of academic institutions in relation to students are well-preserved. Committee minutes too are usually complete. There are exceptions. Without wishing to refer gratuitously to specific institutions, the author feels compelled to note that the preservation of archival material at UMIST was much the worst he observed among industrial firms or academic institutions. Because of the possibility of operating with a clear sample of students, and despite the difficulties of identifying careers, the author went ahead with the analysis of their subsequent activity. However the study of industrial employees remains in abeyance.

Periodicals provide a rich and largely untapped source of information, which the author has attempted to survey systematically. The _Journal of the Society of Chemical Industry_, and major commercial periodicals such as _Chemical News_, the _Chemical Trade Journal_, _Chemical Engineering and the Works Chemist_ and _Chemical Age_, and more short-lived journals such as _Chemical Review_, the _Journal of Chemical Technology_ and _Chemical World_ are all valuable, if uneven. Sometimes they contain obituary material and accounts of research undertaken which are unavailable elsewhere.

The author has attempted, within the limits of what was practicable for him, to survey as wide a range of primary material as possible for this study. As this Note has indicated, much material still remains available for exploration.

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- I Manuscript and other archival material:
  - a. academic
  - b. industrial
  - c. other.
- II Parliamentary and other governmental publications.
- III Contemporary publications:
  - a. periodicals of which some general use has been made
  - b. papers
  - c. books, pamphlets etc.
- IV Modern publications:
  - a. papers
  - b. books.
- V Theses.

The boundary between contemporary and modern publications has been set at 1930, though some publications by individuals referred to in the text appear after that date.

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