From King's Instrument Repository to National Physical Laboratory: Kew Observatory, physics and the Victorian world, 1840-1900

Lee Todd Macdonald

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The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others.

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Research and writing for this thesis has resulted in two papers being accepted for publication in academic journals. The first, ‘Making Kew Observatory: the Royal Society, the British Association and the politics of early Victorian science’ (based on Chapter 2), appeared in the *British Journal for the History of Science*, Volume 48, Part 3, September 2015, pages 409-433. The second, ‘“Solar spot mania”: The origins and early years of solar research at Kew Observatory, 1852-1860’ (based on part of Chapter 4), has been accepted for publication in the *Journal for the History of Astronomy* at the time of writing. Comments by the anonymous referees of both papers helped to sharpen my thinking when writing the thesis, as well as when resubmitting the papers. The editors of both journals – Charlotte Sleigh for *BJHS* and James Evans for *JHA* – also provided helpful comments. I must also thank Dr David Willis of the Rutherford Appleton Laboratory, Oxfordshire, for reading through and commenting on the manuscript of the *JHA* paper.

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Working for a PhD at Leeds has enabled me to gain valuable experience in teaching undergraduate students in History and Philosophy of Science. In accordance with the Latin saying, *docendo discimus* – 'we learn by teaching' – running tutorials, giving lectures, interacting with students and marking their work has had the effect of broadening my perspective on the history of science. Here I must thank the module leaders of the following courses and all the students who attended my lectures and tutorials: Introduction to the History of Scientific Thought; Nature, Knowledge and Power in Early Modern Europe; Magic, Science and Religion; and Science, Technology and Culture in the Industrial Age.

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Lee T Macdonald

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Abstract

This thesis attempts to fill a notable gap in the literature on nineteenth-century science, by writing the history of Kew Observatory between 1840 and 1900 as an institution. I frame this institutional history within three overall questions:-

1) What can the history of Kew Observatory tell us about how the physical sciences were organised in the Victorian era?

2) How did the 'observatory sciences' (defined by historian David Aubin as sciences practised within the observatory, of which astronomy is just one) at Kew develop over the course of the nineteenth century?

3) How did standardisation develop at Kew in the context of the culture of the physical sciences between 1840 and 1900?

I demonstrate that throughout the period 1840-1900, the organisation of science at Kew was thoroughly a part of Victorian *laissez-faire* ideology. Indeed, *laissez-faire* dictated the emphasis of the work at Kew later in the century, as the observatory was forced to concentrate on lucrative standardisation services.

I show that until the 1871 transfer of Kew from the British Association for the Advancement of Science to the Royal Society, the work at Kew expanded to include several observatory sciences, but that after 1871 Kew became a specialist organisation that concentrated principally on just one of these: standardisation. I show that Kew did not simply reflect contemporary trends in the observatory sciences but that it actually helped to set these trends.

Finally, I show that as early as the 1850s, the standardisation work at Kew was an essential service to the London instrument trade, private individuals and government departments. I use this, plus archival evidence, to argue that the National Physical Laboratory evolved as an extension of Kew Observatory. I thus argue that the origins of the NPL in Kew Observatory represent one of the last triumphs of *laissez-faire*.

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List of Abbreviations

BAAS	British Association for the Advancement of Science
BAAS:AR	Annual Report of the British Association for the Advancement of Science
BAAS:CM	British Association for the Advancement of Science, Minutes of Council. Bodleian Library, Oxford
IET S.C.Mss.1	Institution of Engineering and Technology, London: Papers of Sir Francis Ronalds
KCM	Kew Committee Minutes. National Meteorological Archive, Exeter
KCR	Report of the Kew Committee
KD	'Kew Diary', 27 August 1850 – 31 October 1851. National Meteorological Archive, Exeter
MMC	Minutes of the Meteorological Committee. The National Archives, Kew, TNA:BJ 8
NPL	National Physical Laboratory
OED	Oxford English Dictionary
RAS	Royal Astronomical Society
RGO	Royal Greenwich Observatory Archives, Cambridge University Library
RS:CM	Royal Society: Minutes of Council (printed)
RS:CMB/284	Royal Society: Minutes of Committee of Physics and Meteorology, 1839-1845
RS:EC	Royal Society: Election Certificate
RS:HS	Royal Society: Correspondence of Sir John Herschel
RS:MC	Royal Society: Miscellaneous Correspondence
RS:MM	Royal Society: Miscellaneous Manuscripts
RS:MS.538	Royal Society: National Physical Laboratory Papers
RS:MS.843	Royal Society: Secretarial Correspondence, 1854-1871
RS:Sa	Royal Society: Correspondence of Sir Edward Sabine
TNA:BJ 1	The National Archives, Kew: Kew Observatory Papers
TNA:BJ 3	The National Archives, Kew: Papers of Sir Edward Sabine
TxU	Harry Ransom Humanities Center, University of Texas at Austin, USA: Correspondence of Sir John Herschel

Chapter 1

Introduction: Kew Observatory, Victorian science and the 'observatory sciences'

> One more recent instance of the operations of this Society in this respect I may mention, in addition to those I have slightly enumerated. … I mean the important accession to the means of this Society of a fixed position, a place for deposit, regulation, and comparison of instruments, and for many more purposes than I could name, perhaps even more than are yet contemplated, in the Observatory at Kew.
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> 'Address by Lord Francis Egerton' to British Association for the Advancement of Science, June 1842[1]

1.1 Questions raised by a study of Kew Observatory

When in 1842 Lord Egerton, President of the British Association for the Advancement of Science (BAAS), announced the Association's acquisition of Kew Observatory (Figure 1.1), he heralded the inauguration of what would become one of the major institutions of nineteenth-century British – indeed international – science. Originally built as a private observatory for King George III and long in a moribund state, after 1842 the Kew building would, as Egerton predicted, become a multi-functional observatory, put to more purposes than were even imagined in 1842. It became distinguished in several sciences: geomagnetism, meteorology, solar physics and standardisation – the latter term being used here to refer to testing scientific instruments and developing new types of instruments, as well as establishing and refining standards. Many of the major figures in the physical sciences of the nineteenth century were in some way involved with Kew. For the first eighteen months of the twentieth century, Kew was the site of the National Physical Laboratory (NPL), before the new organisation moved to its present location at Teddington.

For all that, little has been written about Kew Observatory – indeed, there is no book-length work at all on its history. For this reason alone, given its importance as a nineteenth-century scientific institution, a thesis on the subject would fill a major gap in the literature on Victorian science. The history of Kew Observatory

[1] BAAS:AR, 1842, p. xxxv.

also allows us to tackle some major issues that are of great current interest to historians of science in the nineteenth century. The history of the observatory from its acquisition by the BAAS in 1842 to its becoming a part of the NPL in 1900 is almost exactly coincident with the reign of Queen Victoria (1837-1901) and thus practically the entire span of what we might call ‘Victorian science’. In this thesis, I will address these issues by asking three major questions about Kew Observatory.

Figure 1.1 Kew Observatory in 2012. Photograph by Lee Macdonald.

1) What can the history of Kew Observatory tell us about how the physical sciences were organised in the Victorian era?

The issue of the organisation of the physical sciences can be divided into three sub-questions. First, how were the physical sciences funded? Secondly, how were they managed? Finally, what kind of people worked in these sciences? The patronage of science and to what extent this changed over the Victorian period has long featured prominently in the secondary literature (see Section 1.2). Kew offers a good case study that can further develop our knowledge as to how patronage worked in the physical sciences, particularly as Kew is not easy to categorise: it was not a publicly-supported observatory, like Greenwich; nor was it a private observatory belonging to one of the wealthy devotees of science who played a leading role in Victorian scientific discovery. Kew can also tell us much about which individuals and organisations managed science. In particular, it has the potential to throw new light on the nature of the ancient Royal Society (founded in 1660) and the much newer BAAS (founded in 1831), plus their relationships with each other, because both organisations were heavily involved with Kew.

Finally, a study of Kew can offer much insight into who was involved in the physical sciences. The historian David Philip Miller has identified three groups of practitioners in the physical sciences that came to prominence in Britain in the decades after the Napoleonic Wars: the 'mathematical practitioners', the 'Cambridge network' and the 'scientific servicemen'. The mathematical practitioners worked in the military colleges, such as the Royal Military Academy at Woolwich; otherwise, they came from commercial backgrounds, often in the City of London, and put the skills they had learned in professional life to use in mathematical sciences such as astronomy. The Cambridge network comprised those who had studied for the Cambridge Mathematical Tripos following the reforms to the mathematics syllabus in the 1810s, and who remained close friends throughout their careers. John Herschel, George Airy and Charles Babbage can all be considered members of the Cambridge network. The scientific servicemen were army and naval officers employed in scientific surveys and other projects, especially after the end of the Napoleonic Wars freed up some military resources.[2] Other historians have identified a fourth group: physicists based in the new research and teaching laboratories that emerged later in the nineteenth century.[3] I have also adopted the term 'gentlemen scientists' to describe the many wealthy devotees of science who had time and leisure to pursue their own research interests.[4] Some of these also belong to the other categories: for example, Miller classes the stockbroker-turned-astronomer Francis Baily as one of the 'mathematical practitioners'. All these groups had much involvement with Kew. Overall, Kew Observatory between 1840 and 1900 may

[2] Miller (1986), esp. pp. 107-119.
[3] Sviedrys (1976); Gooday (1989).
[4] For the early part of the 1840-1900 period, I use the term 'devotees of science' instead of 'gentlemen scientists'. The word 'scientist', although coined by William Whewell in the 1830s, did not come into common use until later in the nineteenth century (Ross, 1962, pp. 75-82). 'Gentlemen scientists', however, makes a useful contrast with the 'university physicists' who emerged later in the century.

help shed light on the question of to what extent the social organisation of the physical sciences changed over this period.

2) How did the 'observatory sciences' at Kew develop over the course of the nineteenth century?

In the popular imagination – and even in some scholarly histories of science – an observatory is typically seen as a place devoted solely to astronomical observation. Until recently, most of the literature on the history of observatories concentrated mainly, sometimes exclusively, on astronomy. Yet at most observatories in the nineteenth century – especially national observatories founded by the state – those who worked in them did other sciences as well, notably meteorology, geomagnetic observations and standardisation work, such as testing chronometers for their countries' navies and merchant shipping. Some historians, notably David Aubin, are now starting to address this overwhelming dominance of astronomy in the historiography of observatories – especially with the development of the concept of 'observatory sciences', defined as sciences involving observation, such as meteorology as well as astronomy, that are practised within the common space of the observatory and share the same set of techniques.[5] Aubin has argued that the nineteenth century was a time of triumph yet also of crisis for the observatory, as these institutions had to adapt in order to accommodate new fields of work and communicate the results of that work through new media such as photography and the electric telegraph. Meteorology, for example, became a central part of the programme of work at many observatories, including Kew; the results of meteorological observations were communicated and coordinated via the expanding telegraph network. Yet by the end of that century, the situation had changed again: observatories tended to specialise in just one observatory science, while each of the observatory sciences had come to be managed by separate, specialised institutions of state.[6]

Kew offers a better case study than most observatories with which to trace the evolution of the observatory sciences, because a wider variety of these sciences were practised at Kew than at most observatories of its time. In fact, after 1842 astronomy was not Kew's main purpose, but was just one of a diverse range of

[5] Aubin et al. (2010), pp. 2-4; Aubin (2011).
[6] Aubin (2011), pp. 115-119.

activities there. Kew became a national nerve centre for several sciences that today are administered by five separate institutions: meteorology (now under the Meteorological Office); solar physics (run by the Science and Technology Facilities Council); standardisation (National Physical Laboratory); and geomagnetism (British Geological Survey and Natural Environment Research Council). Yet as we shall see, it became less of a nerve centre and more specialised as the century drew to a close: in meteorology it became an outstation, reporting to the Meteorological Office in London; solar astronomy moved to Greenwich; geomagnetism became predominantly routine work, under the control of university physicists; while standardisation emerged as much the most important activity at Kew. Although it was still called 'Kew Observatory' in the late 1890s, by then it was primarily a standardisation laboratory: only a small portion of the work carried out there involved observation of external phenomena. The balance of observatory sciences carried out at Kew had shifted from the work of an observatory towards that of a laboratory. In Kew Observatory we have a case study in the process of specialisation in the observatory sciences during the late nineteenth century. It allows us to study the history of how these sciences evolved over the course of this period – with the added benefit that we do not have to take into account the many variables involved when considering the history of more than one institution in more than one country.

3) How did standardisation develop at Kew in the context of the culture of the physical sciences between 1840 and 1900?

Precision measurement in the nineteenth-century laboratory has been well covered in modern scholarship with respect to universities – in particular, the rising generation of university physicists referred to above. In six case studies of university laboratories, Graeme Gooday has shown how these teaching laboratories trained undergraduates in the skills of laboratory measurement that were essential to the training of – and satisfying the growing demand for – school science teachers and entrants to the burgeoning electrical engineering profession.[7] Similarly, Simon Schaffer has described the rise of measurement science at the Cavendish Laboratory in Cambridge and its relation to industry; he has also argued the case for the

[7] Gooday (1989); Gooday (1990).

importance of metrology in the political economy of Victorian science and industry more generally.[8] However, what of the institution that provided the precision instruments and in some cases the constants that were so essential, not only to the university teaching laboratories, but also public institutions like the Meteorological Office, the Admiralty and the merchant marine? Before the NPL opened in 1900, that institution was Kew Observatory. Yet practically nothing has been written on standardisation at Kew, its relation to the wider world of Victorian science and industry, and its role in the origins of the NPL – either in the histories of the NPL or in the wider literature on Victorian physics.

In this chapter, I will first set Kew Observatory in the context of the physical sciences in nineteenth-century Britain, especially our current knowledge and understanding of the organisation of the physical sciences in general and the observatory sciences in particular (Section 1.2). I will then discuss our current knowledge of observatories in nineteenth-century Britain, focusing on the origin of the Kew building as King George III's private observatory (Sections 1.3 and 1.4). In Section 1.5, I will survey the current literature on Kew Observatory, observatories in general, the various observatory sciences and the major figures connected with Kew. Finally, in Section 1.6, I will hone some more specific questions on Kew Observatory in the 1840-1900 period, before describing the methodology and sources that I propose to use in order to tackle these. I will address these specific questions about Kew in chapters 2 to 6, the main body of the thesis. In the concluding chapter (Chapter 7), I will return to the three fundamental questions that I have outlined above and use my findings to show how the history of Kew Observatory in the Victorian period can advance our research into these larger problems.

1.2 *Laissez-faire* and the physical sciences in the nineteenth century

Historians generally agree that the governance of science in Britain underwent profound changes in the decades between 1840 and 1900. Since the 1820s, attempts had been made to reform the Royal Society, Britain's most prestigious scientific

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[8] Schaffer (1992); Schaffer (1997).

body and the one with the most influence over government, from what some perceived as a club for wealthy gentlemen into a learned body representing the most serious and able practitioners of science. This change did not come easily: only in 1847 was the Society's constitution amended so that admission to Fellowship was granted on scientific merit alone.[9] Long after 1847, the issue of who should run the Royal Society was sometimes a contentious one.[10] In the meantime, the British Association for the Advancement of Science had emerged as a rival organisation. The BAAS was founded in 1831 after a failed attempt by some leading men of science to reform the Royal Society. It had a much more democratic structure than the older body, in that all decisions taken by its Council had to be ratified at the Association's annual meetings, which were held in a different provincial town each year, a deliberate break away from the Royal Society's image of an exclusive London club. Yet the distinction between the two bodies was not as clear-cut as might at first appear. In the absence of regular government grants, the BAAS still needed to have wealthy aristocrats on its Council in order to gain influence and money.[11] In practice, many leading men of science, whatever their social position, belonged to both organisations – something that would have a strong influence on the development of Kew Observatory at various times in its history after 1842.

Systematic government grants to the Royal Society only commenced in 1850.[12] Before then, with the exception of scientific organisations connected with the army and navy, government financial support for science was on a strictly *ad hoc* basis, gained largely through lobbying and persuasion by grand figures, usually via the Royal Society. Failing this, funding had to come from private individuals or, after 1831, from the BAAS's limited funds, which originated largely from members' subscriptions and private donations. Significantly for the history of Kew Observatory, the BAAS's usual policy was to fund individual projects of limited duration, or perhaps make grants to allow the purchase of equipment for specific purposes, but not to support permanent scientific programmes or institutions.[13] Therefore the attempts to gain financial support to transform Kew Observatory in the

[9] See, for example, Hall (1984) and MacLeod (1983).
[10] Hughes (2010) describes an attempt by some Fellows in the 1930s to make the Royal Society more democratic.
[11] Morrell and Thackray (1981).
[12] MacLeod (1971a), esp. pp. 325-337.
[13] Howarth (1931), pp. 151-154.

early 1840s – and to keep it running later that same decade, when it was threatened with closure – can tell us much about the various alternative sources of patronage that devotees of science had to find in the second quarter of the nineteenth century, before government money became available on a regular basis.

There is broad agreement among scholars that in the first two-thirds of the nineteenth century, science-government relations followed the prevailing economic system of *laissez-faire* – the doctrine that government should not interfere in an economy that was presumed to be self-regulating.[14] Even the £1,000 Government Grant given to the Royal Society each year from 1850, if anything, encouraged this system: individuals could apply for money out of this grant to buy equipment for their own research and so it rewarded individual enterprise. The grant was never intended to fund salaries or long-term projects, as I shall describe in more detail in Chapter 3 (Section 3.2). This situation began to be challenged in the late 1860s. At the BAAS's 1868 annual meeting, Lieutenant-Colonel Alexander Strange, a former inspector of scientific instruments for the Indian trigonometric survey, gave a paper whose very title expressed Strange's views in one sentence: 'On the necessity for state intervention to secure the progress of physical science'.[15] Strange believed that the government had to invest more money in scientific education and research institutions if it was to keep up with increasing overseas competition in science and – particularly close to the heart of this former army officer – govern the British Empire effectively. Prominent among those agreeing with Strange was Lyon Playfair, who had helped to organise the 1851 Great Exhibition at South Kensington and who afterwards had campaigned for greater government input into science education. Both Playfair and Strange had gone on to serve as jurors in the 1867 International Exposition in Paris, after which Playfair famously expressed alarm at how far foreign inventions had caught up with Britain since the 1851 exhibition.

Graeme Gooday has challenged Playfair's allegations of poor British performance in 1867, arguing that Playfair was selective in his assessment in order to strengthen his case for increased support for science education.[16] Strange's views, however, caught on at the BAAS and his paper was enthusiastically taken up by

[14] Cardwell (1972), p. 70; Alter (1987), p. 138; Moseley (1976), pp. 1-15; Moseley (1978), pp. 222-224. The definition of *laissez-faire* broadly follows that in *OED*.
[15] Strange (1869).
[16] Gooday (2000).

some senior BAAS members and Fellows of the Royal Society. This led to a successful lobby for a Royal Commission to look into the state of science education and – most importantly for the history of Kew Observatory – that of institutions for scientific research. The Commission, which ran from 1870 to 1875, was chaired by William Cavendish, seventh Duke of Devonshire (himself a Cambridge mathematics Wrangler) and hence became known as the Devonshire Commission. Its final report, published in 1875, recommended the establishment of more government-funded laboratories, including a new observatory dedicated to the physics of astronomy.[17]

Some well-known twentieth-century works on the organisation and funding of science see the period of the Devonshire Commission as representing the start of organised science – meaning professional scientists working in government institutions or large companies, in contrast to the earlier regime in which science had largely been carried out by wealthy amateurs. For Donald Cardwell, in particular, there was no such thing as 'the social organisation of science' before the mid-nineteenth century. The history of British science before then was just a 'preface' to it: 'important and not without historical interest, but still a preface'.[18] Authors of Cardwell's generation all wrote during the third quarter of the twentieth century, a time when science in Britain was generally well-funded and so many historians took a teleological view, seeing large-scale government investment in research institutions as inevitable. These authors generally admit that the initial impact of the Devonshire Commission on governments was small and that only slowly were its recommendations taken up. Yet they treat the end of the nineteenth century as a time in which twentieth-century state-supported science finally began to triumph over nineteenth-century *laissez-faire* – as symbolised by the establishment in 1900 of the National Physical Laboratory, an institution founded as a British answer to Germany's generously state-funded Physikalisch-Technische Reichsanstalt.[19]

Kew Observatory, however, does not fit into this tidy picture. In addressing the issue of the organisation of science, one of my aims in this thesis is to use the history of Kew Observatory to challenge the idea that *laissez-faire* – and the physical

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[17] No book-length study of the Devonshire Commission has yet been published, but its origins and work are discussed in, for example, MacLeod (1971), pp. 202-207; MacLeod (1976) and Cardwell (1972). Meadows (2008), pp. 75-111, discusses the Commission at some length as part of a biographical study of its secretary, the astronomer Norman Lockyer.
[18] Cardwell (1972), p. 70.
[19] Cardwell (1972), esp. pp. 177-178; Moseley (1976); Moseley (1978); Alter (1987), pp. 138-149; Pyatt (1983), pp. 12-33; Magnello (2000), pp. 11-30.

sciences' consequent reliance on private sources of patronage – went out of fashion before the end of the nineteenth century. For in the chapters that follow I show how right up until it became part of the NPL in 1900, Kew remained an exemplar of the *laissez-faire* system in action. Before 1900, it received relatively little money from government grants. Most of its work was funded from private sources and – increasingly important later in the century – from the fees it charged for testing instruments on behalf of manufacturers and government bodies. In particular, I shall contend that the birth of the NPL was facilitated not by a change in the government's attitude but rather by the sheer lack of government support for observatories and laboratories. As the nineteenth century drew to a close, the ever-pressing need to make money forced Kew to turn itself effectively into a national standardisation laboratory and form the basis of a ready-made NPL. Historians of the NPL have shown that even after 1900 it retained many of the characteristics of Kew Observatory in the nineteenth century: its leaders continued to grumble about lack of funding and its standardisation department was expected to be self-supporting through the fees it charged for instrument tests.[20] Thus in this thesis I challenge and revise the view of Cardwell, Alter and others as to the demise of *laissez-faire* with regard to scientific funding in the late nineteenth century. Rather, I aim to present a sense of continuity between Kew Observatory and the NPL and hence to show that in government support for the physical sciences, *laissez-faire* remained predominant into the first years of the twentieth century.

1.3 Observatories in nineteenth-century Britain

Susan Faye Cannon and David Philip Miller have both pointed to the three decades following the end of the Napoleonic wars as a period of expansion and increased cooperation in the physical and mathematical sciences.[21] A notable feature of this movement was the construction of many new observatories and the adaptation of older ones to new purposes, among them non-astronomical sciences. Dieter Herrmann has shown how the establishment of new observatories increased exponentially during the nineteenth century, from 31 in 1810 to 199 in 1900.[22] It

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[20] Moseley (1978), esp. p. 249.
[21] Cannon (1978); Miller (1986).
[22] Herrmann (1973); also cited in Aubin et al. (2010), p. 2.

was also during the nineteenth century that the word ‘observatory’ became common in English literature – and therefore culturally significant – as David Aubin has demonstrated using Google Books.[23]

Observatories in the nineteenth century can be grouped into three broad categories: national, university and private observatories. Steven Dick has suggested that the nineteenth century saw the second wave of an overall ‘movement’ to build national observatories; this movement began in the sixteenth century and was still continuing in the late twentieth century.[24] National observatories were founded by governments for very specific purposes, of which the main one was usually the measurement of celestial positions to supply data for navigation. Much the most prestigious national observatory in Britain was the Royal Observatory at Greenwich. Founded in 1675 to solve the problem of finding longitude at sea, by the 1830s Greenwich was a world standard in navigational astronomy. The observatory provided data for the production of tables of stellar, planetary and lunar positions that enabled sailors to find their position at sea quickly and accurately.

By the early 1830s, Greenwich was in some disarray. The reductions of observations into a form usable for longitude tables had fallen into arrears and relations between the Astronomer Royal, John Pond, and his staff were poor. In 1835, the Admiralty, the Royal Observatory’s governing body, replaced Pond with the thirty-four year old Cambridge mathematician George Biddell Airy. As Robert Smith and others have shown, Airy quickly turned the Royal Observatory into a factory-like regime that efficiently produced quality data for navigation and, later on, a national time service. Airy saw himself primarily as a public servant. He believed that research with no immediate utilitarian purpose, such as sweeping the heavens for new nebulae or planets, lay outside this remit and should be left to private or university observatories that did not spend the state’s money.[25] Yet he did not take kindly to criticism, nor to incursions by other public institutions onto territory that he felt was his. This would have an important bearing on the history of Kew Observatory from the 1840s onwards, as will become clear in the following chapters.

Roger Hutchins has described how six British and Irish university observatories were established between the late eighteenth and early twentieth

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[23] Aubin (2011), p. 111.
[24] Dick (1991), pp. 2-3.
[25] Smith (1991); Chapman (1988a); Chapman (1988b); Schaffer (1988).

centuries. Their principal purpose was to facilitate undergraduate teaching in astronomy. In theory they also did research into non-utilitarian branches of astronomy, such as stellar cataloguing, measurements of double stars and observations of comets, but in practice the demands of teaching often left little time for such work.[26] Forming a third category of observatories were the private observatories owned by wealthy devotees of science who spent their own money on astronomy. These 'gentlemen scientists' (see Section 1.1) were free to pursue their own agendas, as they were not required to teach or to do utilitarian work for the state.[27] Private observatories were not new in the nineteenth century, but many more of them were built after 1800. In the most comprehensive general survey of nineteenth-century amateur astronomy, Allan Chapman notes that in 1884, Armagh Observatory director John Louis Emil Dreyer published a list of some 26 private observatories that had done important work in the United Kingdom over the previous 100 years.[28]

Until the early nineteenth century, all three types of observatories concentrated more or less exclusively on astronomy – and mostly one type at that: the 'classical' astronomy of positional measurement.[29] This was dictated by the need of national observatories to serve the state, but the other types of observatories tended to concentrate on classical astronomy too, partly because before the advent of photography and spectroscopy, it was difficult to find out anything new about the physical nature of astronomical objects. The research on nebulae by the Herschels and Lord Rosse was an exception to this general rule. Then, in the 1830s, some observatories, including Greenwich, began serious work in two sciences that hitherto had not necessarily formed part of their routine – or, at most, had been incidental to that routine: geomagnetism and meteorology. At the beginning of the nineteenth century, geomagnetism and meteorology hardly existed as sciences organised on a national scale. In Britain, this situation persisted into the early 1830s, with geomagnetic work being done by isolated individuals such as the Royal Artillery officer Edward Sabine at Woolwich and Humphrey Lloyd at Dublin.[30] Elementary meteorological observations were being carried out at a small handful of locations,

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[26] Hutchins (2008).
[27] See also: Lankford (1981), p. 275; Chapman (1998), p. xii.
[28] Chapman (1998), p. 26.
[29] Smith (2003).
[30] Cawood (1977).

such as the King's Observatory at Kew, the Royal Society's headquarters at Somerset House and the Radcliffe Observatory at Oxford, as well as by a few private individuals, but the science was not organised on a national scale until the 1850s.[31] But when these two observatory sciences did take off, they did so together. They were seen as being closely connected, for several reasons. Many thought that the weather and the Earth's magnetic field were subtly related to each other, or that both had astronomical origins, and in any case temperature and pressure were found to affect magnetic compass readings. Both sciences had clear importance to navigation in an age when Britain was the world's chief maritime power. In particular, the reasons for the behaviour of the compass aboard ships were poorly understood, as were the weather and currents in many parts of the oceans. It was in this context that, as we shall see in Chapter 2 (Section 2.2), some observatories began making systematic meteorological observations and also began monitoring the Earth's magnetic field as part of a global campaign known as the 'Magnetic Crusade'.

1.4 The origins and early history of the 'King's Observatory'

The origins of Kew Observatory are well known and well documented. Nineteenth-century sources agree that it was originally known as the 'King's Observatory'; it came to be called the 'Kew Observatory' some years prior to 1840.[32] In an 1839 letter to John Herschel, Admiralty Hydrographer Francis Beaufort remarked: 'Perhaps I should have called it the Kew Observatory' – suggesting that the building had only recently come to be known by this name.[33] It was built in 1768-1769 for King George III to enable him to observe the transit of Venus on 3 June 1769. The building, designed by the eminent architect Sir William Chambers (who went on to design Somerset House), was completed in time for the transit, which was successfully observed by the King and others in a clear sky.[34]

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[31] Anderson (2005), esp. pp. 11-12; Walker (2012), pp. 9-10; Wallace (2005). Jankovic (2006) has argued that there was widespread dissatisfaction with meteorology at the beginning of the nineteenth century, because it had only recently shrugged off its Aristotelian heritage and lacked a sound theoretical basis. See also Jankovic (2000), pp. 156-167.

[32] Scott (1885), p. 37 and 42; Rigaud (1882), p. 282; Jacobs (1969), p. 162.

[33] Beaufort to Herschel, 22 July [1839], RS:HS 3.407.

[34] Jacobs (1969), pp. 162 and 163-164.

However, this spectacular beginning to the observatory's career was not matched by the work done in the years that followed, for it was not used, nor even intended for, astronomical research or navigational astronomy of the kind being done at Greenwich. To run the observatory the King appointed his former tutor, Stephen Charles Triboudet Demainbray, a much-travelled university lecturer of French Huguenot descent, as his 'King's Observer'. After the transit (which Demainbray observed with the King), Demainbray's duties seem to have been light. His principal duty was to take daily transit timings of the Sun as it crossed the meridian; these observations were used to regulate high-quality clocks which kept standard time in the observatory and at several prestigious public places in London, among them the Houses of Parliament.[35] Basic meteorological observations, including recordings of temperature and rainfall, were commenced in 1773 and continued until 1840, with the thermometers placed in a north-facing window and the rain-gauge mounted on the roof.[36] The observatory was also used as an instrument repository and a place where members of the Royal Family received tuition from Demainbray. Kew was included in a 1777 survey of observatories by Copenhagen Observatory director Thomas Bugge, who noted that the building contained numerous instruments, including a transit telescope and a large mural quadrant. Bugge also noted that the basement contained 'mathematical workshops'.[37]

When Demainbray died in 1782, the King appointed Demainbray's son, the Reverend Stephen Demainbray, as his Observer at Kew. Both Demainbrays were assisted in the observations by fellow Huguenot and family relative Stephen Peter Rigaud. Upon Rigaud's death in 1814, the job of assistant went to his son, Professor Stephen Rigaud. Rigaud junior had been Savilian Professor of Geometry at Oxford since 1810, before he became Savilian Professor of Astronomy in 1827. He took over the running of Kew Observatory during the university's summer vacations, thus allowing the Reverend Demainbray to live in his Wiltshire parish during the summer months. Demainbray, Rigaud, an assistant and a servant all appear to have drawn salaries for their work at Kew.[38] In 1827 Rigaud's wife died, leaving him to bring up his children on his own as well as perform his academic duties at Oxford. Although

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[35] Rigaud (1882), p. 282.
[36] Jacobs (1969), pp. 165-6.
[37] Rigaud (1882), pp. 282-283; Bugge (2010), pp. 77-81; Hutchins (2012), p. 2.
[38] Rigaud (1882), p. 283; Hutchins (2012), p. 3.

still officially an observer at Kew, he was seldom able to go there from then on. By this time, too, George III was dead and his successors to the throne took less interest in the observatory. This, plus the observatory's substantial salary costs, may have been a motive for the government to no longer support Kew.

It is easy to think of these shared jobs of the Demainbrays and Rigauds as sinecures and that the King used the building as little more than a showcase for his instrument collection. Yet Bugge's survey notes that the observatory contained some of the best equipment that money could buy at the end of the eighteenth century, including a mural quadrant and a precision measuring telescope, both made by leading astronomical instrument maker Jonathan Sisson.[39] A list of the observatory's astronomical instruments presented to the Royal Observatory at Armagh in 1841, when the government withdrew its support from Kew, also includes some high-quality instruments.[40] It was in Kew Observatory that John Harrison's 'H.5' marine chronometer was given its final successful test that enabled Harrison to claim the remainder of his share of the £20,000 'Longitude Prize'. The chronometer was tested in the observatory over a ten-week period between May and July 1772. It was regularly compared with the Kew Observatory clock, which was itself checked with meridian transits of the Sun.[41] The transit timings were taken with a transit telescope suspended between two massive masonry piers on the ground floor of the observatory. This provided as good a time service as any at the end of the eighteenth century: before the advent of telegraphic communications, Greenwich was remote from Kew and central London, so time had to be determined and distributed locally.[42] Bugge noted that the foundations of the building 'were laid 20 to 30 feet below the ground', in order to ensure a stable platform for the astronomical instruments.[43] In 1843, soon after becoming honorary superintendent at Kew under the BAAS, Francis Ronalds would make a remark that corresponded exactly with Bugge: that the building's foundation was 'of an extremely solid and costly kind'.[44] In the mid-1840s, Ronalds would adapt the transit pillars to another type of precision

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[39] Bugge (2010), pp. 79-80.
[40] Lindsay (1969), p. 67.
[41] Quill (1966), pp. 189-195.
[42] Rigaud (1882), p. 282.
[43] Bugge (2010), p. 81.
[44] Ronalds (1845), p. 121.

measurement: the monitoring of tiny variations in the Earth's magnetic field using a magnetometer suspended between these pillars (Chapter 3, Section 3.4).

Thus in Kew Observatory, the BAAS and the Royal Society had a ready-made space for precision measurement; it is clear from the evidence above that Ronalds was well aware of this. The building's suitability for precision measurement would have an important bearing on its history after 1842. Some modern scholarship has discussed how buildings such as the Physikalisch-Technische Reichsanstalt in Berlin were deliberately designed and built with metrology in mind.[45] Kew provides us with an opportunity to see how an existing building, constructed for astronomical and meteorological observations in an earlier age, was adapted for the measurement sciences of a later era.

1.5 Literature review: observatories in the nineteenth century

As noted in Section 1.1, no book-length work has ever been written specifically on Kew Observatory. Indeed, while its importance is often acknowledged in works dealing with the physical sciences in the nineteenth century, there are no published works at all by science historians solely and specifically on Kew. Part of the problem with the historiography of Kew Observatory is that Kew has always meant different things to different people. To the astronomer, it is the place where Warren De La Rue began the first systematic effort to photograph the Sun. To the geophysicist, it is associated with Edward Sabine and his projects to map the Earth's magnetic field. To the meteorologist, it is an almost holy place, where new types of equipment were trialled and innovations in meteorological observation pioneered. The building remained in use as a meteorological observatory until 1980, enabling some meteorologists today to look back on it with nostalgia, because they themselves worked there while students or trainees.[46] Finally, science historians sometimes cite it as a 'public observatory' where a new type of experimental astronomy was pioneered, or as a site where data was collected in the hope of refuting Victorian materialist cosmologies.[47]

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[45] Cahan (1989a).
[46] Walker (2012), p. 398; Galvin (2003).
[47] Schaffer (1995); Gooday (2004).

The most extensive history of Kew Observatory is the 1885 paper by Robert Henry Scott.[48] This is a very basic chronology, with no attempt at analysis or contextualisation. It is certainly not a scholarly history of Kew Observatory; it is uncritical and reads very much like an official history. At the time, Scott was director of the Meteorological Office, which used Kew as its central observatory, where instruments for the Office's outlying meteorological stations were tested and calibrated (see Chapters 4 and 5). Scott was also secretary of the 'Kew Committee', a committee of the Royal Society responsible for running the observatory. We do not know why Scott wrote this official history, though it appears that some of the work of putting the paper together was done by one of the assistants at Kew – perhaps not surprisingly, given Scott's busy position.[49] That Scott did not have much time might help explain why he did not delve deeper into the behind-the-scenes history of the observatory. Scott's paper is a contemporary account by a practitioner of science and so lacks the historian's perspective. It offers no analysis, or even mention, of many of the politics behind the various changes in the running of Kew Observatory in the nineteenth century. Scott was personally appointed as director of the Meteorological Office by Edward Sabine,[50] one of the most influential figures in the development of Kew Observatory in its first thirty years after 1842. Therefore we can hardly expect his account to contain criticism of Sabine. Furthermore, many characters in the nineteenth-century history of Kew were still alive in 1885, restricting Scott's access to primary sources. Scott's paper offers perhaps an extreme example of internal history of science – uncritical histories that tell the story of scientists, their institutions and instruments, without taking account of external factors such as the general history of the period or the interaction of social and political issues with the organisation of science.

No further attempt was made to write a general history of Kew Observatory until 1922, when O J R Howarth devoted a chapter to the subject in his history of the BAAS, of which he was then a secretary.[51] Howarth's treatment is necessarily brief, though he makes use of the Association's annual reports and some committee reports as sources, which highlights the importance of BAAS papers as primary sources in a

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[48] Scott (1885).

[49] KCM, 27 March, 3 July and 27 November 1885.

[50] Burton (2004).

[51] Howarth (1931), pp. 154-169. This is a revised edition of a book originally published in 1922.

full investigation. Like Scott's account, Howarth's chapter on Kew is an uncritical, internal story that portrays Kew Observatory as a straightforward exemplar of the success story of the Association. For example, he calls the BAAS Council's 1842 decision to take on the running of Kew 'a commendable decision which did not even wait for an estimate of the annual cost to the Association'.[52] As described in Chapter 2 (Section 2.5) of this thesis, the decision was in reality much more complex. Although the BAAS ran Kew Observatory for nearly thirty years in the nineteenth century, surprisingly little attention is paid to Kew in the volume of essays that was published in the year of the Association's sesquicentenary.[53] Morrell and Thackray's account of the Association's early years has more to say about the BAAS takeover of Kew in 1842, though in this one-volume general history the discussion is inevitably brief.[54] Morrell and Thackray do, however, cite copious lists of correspondence on Kew and magnetic observatories, providing an invaluable starting-point for archival research.

In 1969 L. Jacobs (first name unknown) wrote a general history of Kew Observatory, one of a series of articles in a special issue of *Meteorological Magazine* (published by the Meteorological Office) celebrating the observatory's bicentenary. Jacobs provides a clearer and more concise account than Scott, dividing the article into the various areas of work carried out at Kew.[55] The list of published and archival sources at the end of the article is, like those cited in Morrell and Thackray's 1981 work, invaluable for further research. But as with Scott, Jacobs' account is brief and somewhat hagiographical. Again, it is uncritical, internal history.

Nearly all the modern literature that mentions Kew Observatory concentrates on just one of the sciences practised there. Some substantial work has been done on terrestrial magnetism in the nineteenth century, yet John Cawood's well-researched, archive-based account of the origins of the Magnetic Crusade[56] says little about Kew. Nor does Christopher Carter's more recent work, which is further hampered by gaps in its archival source base: for example, he misses some important correspondence of George Airy about the possibility of a new magnetic observatory

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[52] Howarth (1931), p. 157.
[53] MacLeod and Collins (1981). In one of these essays, Pancaldi (1981), p. 154, does acknowledge the importance of Kew in the Magnetic Crusade and in the growth of international scientific cooperation more generally.
[54] Morrell and Thackray (1981).
[55] Jacobs (1969).
[56] Cawood (1979).

near London in 1840 (discussed in Chapter 2, Section 2.3).[57] Katharine Anderson's major cultural history of Victorian meteorology[58] devotes a scant few pages to Kew Observatory, both its early years under the BAAS and its later role as the central observatory of the Meteorological Office. Part of the problem with Anderson's book, from the viewpoint of the historian of Kew Observatory, is its very wide scope. It considers meteorology in institutions such as Kew as just a small part of a much larger history and mostly relies on published sources, including Scott's account. More recently, in the tradition of uncritical internal history, Malcolm Walker has published a chronological history of the Meteorological Office,[59] in which Kew Observatory as a meteorological station and central observatory weaves in and out of the story. Jim Burton's unpublished PhD thesis on the Meteorological Office – on which Walker's book is partly based – similarly suffers from an internalist approach.[60] In fact, the works by Walker and Burton complement that of Anderson: whereas Walker and Burton provide narratives that abound with dates and facts, Anderson analyses the relations between the institutions of Victorian meteorology and their interactions with the wider world of Victorian science.

Hufbauer's general history of solar astronomy[61] duly acknowledges the importance of Kew as the first observatory in which a systematic photographic watch was kept on sunspot activity. The treatment is brief, however; indeed, pre-twentieth-century solar astronomy, especially in Europe, effectively forms an extended introduction to a book dominated by the history of American solar physics after the Second World War – not surprising in a book written under contract from NASA. Holly Rothermel's essay on De La Rue's solar photography is historically and sociologically well-informed, yet it takes no account of the circumstances at Kew surrounding the introduction of solar photography, taking for granted that this was simply John Herschel's idea.[62] Simon Schaffer's 1995 book chapter sets Kew in the context of a new type of 'experimental astronomy', yet he conflates Kew with the new 'public observatories' that emerged in the nineteenth century without assessing in detail to what extent Kew was really 'public', in the sense of being a government

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[57] Carter (2009).
[58] Anderson (2005), esp. pp. 90-94 and 138-149.
[59] Walker (2012).
[60] Burton (1988).
[61] Hufbauer (1991), pp. 49-52.
[62] Rothermel (1993).

observatory.[63] Schaffer does, though, acknowledge the significance of Kew Observatory, both in this 1995 piece and more recently in an essay on Paramatta Observatory in New South Wales, which describes Kew as an important imperial centre for the observatory sciences.[64]

Although Kew Observatory itself is poorly covered in the literature, there is a large literature on observatories. Greenwich is probably the most discussed of all national observatories, yet the most detailed general history of Greenwich in the nineteenth century is by Jack Meadows, one of three slim volumes published to coincide with its tercentenary in 1975. It is supported by references to primary sources, but the entire volume runs to just 129 pages. There is a fascinating but tantalisingly brief description of the struggles between Greenwich and Kew for control of the solar observations in the 1870s; its very brevity leaves us feeling that there is far more to be discovered about this in the primary sources.[65] Also, like many celebratory institutional histories, Meadows's book concentrates on the observatory's successes and avoids the failures and the political wrangles. Several other works on Greenwich are important for providing insights into the relation of Kew to Greenwich. Robert Smith, Allan Chapman and Simon Schaffer have described how the regime at Greenwich was reformed by Airy into something resembling a factory, which Airy jealously guarded from what he saw as competition from observatories such as Kew.[66] Rebekah Higgitt has discussed how Greenwich was again changed under Airy's successor, William Christie, particularly with the construction of a building purportedly for astrophysics.[67] Greenwich astronomer E. Walter Maunder's contemporary account unwittingly gives some useful insights into the work at Kew, especially in comparison with Greenwich.[68] Yet few works make a serious attempt to compare Greenwich with other observatories. In his 1991 article on Greenwich, Smith notes that 'the lack of more analyses comparing the Royal Observatory [at Greenwich] to other observatories, especially national observatories, is perhaps the chief weakness of the Greenwich historiography.'[69] With the

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[63] Schaffer (1995). See esp. p. 259 and pp. 276-283.
[64] Schaffer (2010), pp. 138-9.
[65] Meadows (1975), p. 119-20.
[66] Smith (1991), esp. pp. 10-12; Chapman (1988a); Chapman (1988b); Schaffer (1988).
[67] Higgitt (2014).
[68] Maunder (1900), esp. Chapter 9 on magnetism and meteorology and Chapter 10 on solar photography.
[69] Smith (1991), p. 18.

exception of Roger Hutchins' 2008 volume on university observatories (see below), this lack of comparisons between Greenwich and other observatories still holds true.

The American equivalent of Greenwich, the United States Naval Observatory, has been treated by a very detailed history.[70] Written by a trained science historian – though employed by the Naval Observatory – *Sky and Ocean Joined* tells a much fuller story than most institutional histories; in particular, Dick does not shy away from detailed descriptions of political intrigues, even when these are to the discredit of the Naval Observatory and its personnel. The book's only weakness is that, as an institutional history written from the inside, it again does not attempt any detailed comparison of the Naval Observatory with other observatories. Nor does it fully assess its significance in the context of nineteenth-century science. Rather better in this regard is Howard Plotkin's in-depth analysis of the attempt by civilian astronomers to wrest control of the Naval Observatory from the military in the late nineteenth century.[71] Pulkovo, Russia's national observatory from 1839, has also been analysed by historians. Simon Werrett has shown how Pulkovo, although a very successful observatory in its own right and almost worshipped by foreign astronomers as the ideal of what an observatory should be, was very much a showpiece in the Russia that Tsar Nicholas I wanted to present to the world, with outlying observatories (like the rest of Russia's infrastructure) languishing in a state of disrepair.[72] A similar point is made by Mari Williams through a study of the architecture of Pulkovo.[73] Jim Bennett's bicentennial history of Armagh Observatory contains some fine scholarship based on primary sources, but yet again is a celebratory institutional history that makes little attempt to set the observatory at Armagh in the context of other observatories and nineteenth-century science.[74]

Roger Hutchins' detailed survey of six key university observatories in the British Isles offers a comparison of these observatories with Greenwich as well as with each other – though once again, there is very little here about Kew.[75] Both here and in a separate volume, Hutchins has written about the Radcliffe Observatory at

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[70] Dick (2003).
[71] Plotkin (1978).
[72] Werrett (2010).
[73] Williams (1988).
[74] Bennett (1990).
[75] Hutchins (2008).

Oxford.[76] Superficially the Radcliffe resembles Kew in that it did both meteorology and astronomy. Both meteorological and astronomical observations were carried out at the Radcliffe Observatory from 1772 until it moved to South Africa in the 1930s and the site remains to this day an official meteorological station. Until the 1920s it was a premier astronomical observatory, although it was never really in competition with Greenwich or Kew. Its main achievement was the production of star catalogues, in the service of pure astronomy rather than navigation, and it did not branch out into solar physics, geomagnetism or any attempts to find correlations between solar activity and terrestrial weather. Much of the Burley and Plenderleith volume, of which Hutchins's essay forms one chapter, emphasises the architectural and conservational aspects of this observatory.[77] This volume is nevertheless a rare book in that it gives as much attention to the meteorological as to the astronomical work of an observatory: a separate article gives a concise history of meteorology at the Radcliffe, usefully adding to our understanding of the meteorological work at Kew as the centre of a national network of meteorological stations.[78]

We can learn much about the workings of observatories by studying the history of the instruments that were used in them. Much the most comprehensive history of astronomical telescopes is Henry King's *The History of the Telescope*, which includes histories of a great number of individual instruments, including the Kew photoheliograph. These histories are necessarily brief, although King is very useful in setting individual telescopes in the historical context of instrument-making. Brevity is also a characteristic of the volume by Derek Howse on the buildings and instruments at Greenwich, the third volume in the Greenwich tercentenary series, which is essentially a catalogue of the instruments belonging to the Royal Observatory (including the Kew photoheliograph, which was transferred to Greenwich in 1873) with brief chronologies of their use.[79] Knowles Middleton has provided detailed standard histories of the thermometer and barometer that include the key instruments used or developed at Kew.[80] As with some of the institutional observatory histories, Middleton writes from the point of view of a scientist rather than a historian, but his works contain a great detail of information on instruments

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76 Hutchins (2005).
77 Burley and Plenderleith (2005).
78 Wallace (2005).
79 Howse (1975). See pp. 92-4 and 118-9 for notes on the Kew photoheliograph.
80 Middleton (1964); Middleton (1966).

and their physical workings not easily found elsewhere. A more rounded analysis is provided by Mari Williams, who discusses the relationships between instrument makers and the scientific institutions that used them.[81]

Two important figures in the history of Kew Observatory wrote autobiographies: George Airy and Francis Galton. Airy, in fact, only wrote his autobiography up to the early 1860s; the account of his later years was written up by his son, Wilfrid Airy. George Airy's antagonism towards Sabine and Kew Observatory is emphasised by the fact that Kew is hardly mentioned in these memoirs: the most extensive treatment of Kew here is a scant few lines describing Airy's 1862 conflict with Sabine over continuing the Kew magnetic observations (see Chapter 5, Section 5.3 in this thesis). The only mention of Kew in the part of the book written by George Airy himself is in his reflections on the year 1860: in a few words about Sabine, he refers to Kew dismissively as '(his [Sabine's] observatory)' – the parentheses only further emphasising his low opinion of it. In his description of the 1860 solar eclipse, Airy writes that 'the most important' observational results 'were Mr De La Rue's photographic operations' – he makes no mention of the Kew photoheliograph that De La Rue used to photograph the eclipse. Only in the early 1870s do the words 'Kew photoheliograph' make a brief appearance – and even then the description is limited to its triumphal arrival at Greenwich.[82] As noted above in Section 1.3, Airy clearly felt that Kew encroached on territory that he felt was his, though for much of the time he could do little about it. In his autobiography, however, he was able to remove Kew from the picture as he would have wished to have done in real life. Francis Galton devotes part of a chapter in his *Memories of My Life* to his involvement with Kew Observatory, yet naturally he emphasises his own role in innovations at Kew, such as the testing of sextants and watches. He also glosses over some important behind-the-scenes moves in the 1890s to make Kew the site of the proposed National Physical Laboratory.[83] Airy's and Galton's memoirs demonstrate an important limitation of autobiographies as historical sources: the tendency of their authors to play up their own roles at the expense of their rivals and to leave inconvenient complexities out of the story.

[81] Williams (1994).
[82] Airy (1896), pp. 247-248, p. 241.
[83] Galton (1909), pp. 224-229.

Biographies written by modern historians with scholarly insight and access to their subjects' papers have the potential to tell us more about the major players in the history of Kew Observatory, but there are surprisingly few of them. There are currently no book-length biographies of Airy, Sabine or De La Rue, for example. Perhaps the best such work is A. J. Meadows's scientific biography of solar physics pioneer Norman Lockyer, who used his journal *Nature* to popularise the work of Balfour Stewart and sided with Stewart in his controversies with Sabine (see Chapter 4, Section 4.4 of this thesis).[84] Meadows offers much more than a biography of Lockyer, as he goes into great detail about the circle of scientists and civil servants in which Lockyer moved, the issue of government support for science (of which Lockyer was a leading advocate) and, of course, the early development of solar physics and astrophysics. It is effectively a history of nineteenth-century solar physics and science funding as seen from Lockyer's viewpoint. Scholarship on John Herschel has tended to focus on aspects and periods of his life and scientific work, particularly its relation to imperialism – such as Ruskin on Herschel's 1830s voyage to the Cape of Good Hope, Musselman on Herschel and good imperial management and Ashworth on Herschel and the relationships between the physical sciences and the state more generally.[85] The only book-length biography of John Herschel is by Gunther Buttmann.[86] Although presenting a well-balanced general coverage of Herschel's life and work, Buttmann's biography is quite brief and now rather dated (the original German edition was published in the 1960s). Very noticeably, Buttmann had to rely on the very limited primary sources then available to him: he makes relatively little use of Herschel's vast surviving correspondence, which is now so accessible to the scholar. For the other major characters, we have to rely on their relatively brief entries in references such as the *Oxford Dictionary of National Biography* and the *Dictionary of Scientific Biography*, or their obituaries in contemporary publications such as the *Proceedings of the Royal Society*.

Thus there is now plenty of literature on nineteenth-century astronomy and observatories, especially national observatories. In recent years the literature has extended beyond inward-looking, uncritical institutional histories of major observatories into areas such as observatory practice, other types of observatories

[84] Meadows (2008).
[85] Ruskin (2004); Musselman (1998); Ashworth (1994); Ashworth (1998).
[86] Buttmann (1974).

(such as university observatories) and the role of the gentlemen scientists in the origins and development of astrophysics. The literature on Kew Observatory itself, however, is very limited. What little there is tends to be chronological and offers little analysis; often it is as uncritical as some of the older institutional histories of national observatories. Some excellent work has been done on, for example, the National Physical Laboratory and its German counterpart, the Physikalisch-Technische Reichsanstalt,[87] yet there is very little on the role of Kew Observatory in the origins of the NPL. A secondary literature comprising chronological histories of Kew and the wider historiography of observatories, instruments and practice in the nineteenth-century physical sciences, is both our starting point and framework for research into the history of Kew Observatory using primary sources.

1.6 Primary sources and outline of the thesis

The volume of primary-source material on Kew Observatory increases as we progress through the nineteenth century. We can learn much even from published primary sources, as few of them have ever been cited by historians. Reports of the Kew Committee appear regularly in the BAAS *Annual Report* from 1850 until 1871 inclusive; thereafter they can be found each year in the *Proceedings of the Royal Society*. These reports run to several (latterly over twenty) pages each and describe the previous year's activities at Kew in some detail. From the late 1850s they contain detailed financial accounts, including lists of the observatory's employees and their salaries. The volumes of the BAAS *Annual Report* also contain many papers on specific projects at Kew, as do the Royal Society's *Proceedings* and *Philosophical Transactions*. But the value to the historian of these published sources is limited by their containing only what the members of the Kew Committee wanted their readers to hear. Like Scott's 1885 history (which is largely based on these reports), they frequently gloss over key developments, such as how and why John Peter Gassiot set up the trust that enabled the Royal Society to take over the running of Kew in 1871. Furthermore, very little primary-source material has been published at all on Kew before 1850. Therefore, to build a fuller picture of what happened at Kew in the period under discussion, we must turn to unpublished sources.

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[87] Cahan (1989a); Cahan (1989b). See Section 1.2 and Chapter 6, Section 6.1 for literature on the NPL.

A large amount of archival material has survived, in the form of voluminous correspondence and minutes of meetings. The most important sets of minutes for the historian of Kew Observatory are the minutes of the BAAS Council, held at the Bodleian Library in Oxford, and the minutes of the Kew Committee, kept in the National Meteorological Archive in Exeter. The BAAS Council minutes are essential for establishing the basic narrative of events relating to Kew Observatory before the regular publication of Kew Committee reports began in 1850, especially as the correspondence for these early years is sometimes scattered and hard to find. These minutes were printed, but not published, and so were not intended for general circulation. Those at the Bodleian Library are mostly complete to 1868; copies relating to the years from 1868 to 1871, the period leading up to the handover of Kew from the BAAS to the Royal Society, are preserved in the files of the ever-meticulous George Airy.

The Kew Committee began taking formal minutes of its meetings from October 1849 onwards, and so from this date we can assemble a more detailed narrative. The minutes of the Kew Committee were handwritten in minute books and never printed, so they contain many details of the observatory's history that were confidential at the time. Furthermore, these minutes have never been used by *any* previous scholar, enabling us to discover vast amounts of new information and gain important new perspectives. The minutes for the post-1871 period are especially useful, because they frequently refer to numbered correspondence. These letters are preserved at the National Archives at Kew and many of them still bear their original index numbers. Having read the minutes in Exeter, it is easy to relate them to the relevant letters at Kew. This is how I was able to track down some hitherto undiscovered correspondence important to my argument in Chapter 6 as to the centrality of the Kew Committee to the origins of the National Physical Laboratory. Minutes for the 1840-1900 period tend to record merely a summary of what was agreed at a meeting, rather than what was actually discussed. Like the published sources, they sometimes present only an official version of events, leaving out the arguments and disagreements.[88] Nevertheless, due to their confidential nature, they

[88] Higgitt (2014), p. 618, notes that the minutes of the Greenwich Observatory Board of Visitors 'are frustratingly uninformative about discussion and disagreement among the Board's members'. The same might be said about the minutes of the BAAS Council and the Royal Society Council. Those of the Kew Committee, never having been printed, are somewhat more revealing.

contain many telling details that have been left out of the published record of events – such as the true nature of the 'resignation' of Kew Observatory superintendent Samuel Jeffery in the mid-1870s, described in Chapter 5, Section 5.5.

The richest – and most revealing – set of unpublished sources is the correspondence of the numerous individuals who were involved with Kew Observatory. The letters of Francis Ronalds, Kew's first superintendent, kept at the Institute for Engineering and Technology, provide important insights into Kew's very first years under the BAAS, especially when read in conjunction with the BAAS Council minutes. The most useful correspondence for these early years is that of John Herschel, not only because of his views on physical observatories and his involvement in so many of the behind-the-scenes moves regarding Kew Observatory in the 1840s, but also because of his centrality to – and perceived authority in – so many of the physical sciences in these years. His approximately 15,000 incoming and outgoing letters are made all the more accessible by the invaluable *Calendar* of his correspondence, which outlines the location, reference, date and brief details of each letter.[89] This allows Herschel letters referring specifically to Kew Observatory and kindred subjects to be accessed very efficiently in the Royal Society archives and elsewhere.[90] The correspondence of George Airy, held at the Royal Greenwich Observatory archives in Cambridge, is indexed online, with brief details of each file, allowing us to access relevant letters quickly by ordering specific files. Airy's correspondence is especially useful in that Airy kept carbon copies of his outgoing letters, enabling us to read Airy's replies without having to visit the papers of the people he was writing to. This is especially important in the case of the many private individuals involved with Kew whose papers are now difficult to find.

The official papers of Kew Observatory at the National Archives are voluminous and the files are indexed online, albeit with no details. Some of the files, especially from the 1870s, mostly describe trivial day-to-day matters that add little to our overall understanding. Yet we can learn much from the correspondence of John Welsh and Balfour Stewart, most of it unread by modern scholars. The Kew

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[89] Crowe et al. (1998).

[90] The largest of the other major repositories of Herschel letters is the Harry Ransom Humanities Center at the University of Texas, from which scans of specific letters can be ordered online at minimal cost.

Observatory papers contain no files devoted to the correspondence of Charles Chree, the final superintendent before Kew became part of the NPL in 1900, though the observatory's last years under the Kew Committee are very well documented in the files of general Kew Committee correspondence. The Kew Observatory papers are part of a larger collection of papers of the Meteorological Office, which includes some important correspondence of Edward Sabine. Both these Sabine papers and the Kew Observatory files at the National Archives are important for including some letters from John Herschel that are not indexed in the Herschel *Calendar*. Much the largest repository of Sabine's correspondence is held in the Royal Society archives. These letters are not indexed, but they are filed alphabetically by correspondent, allowing us to easily find letters to Sabine from Herschel, Gassiot and many of the other principal actors in the history of Kew Observatory between 1840 and the early 1870s.

The total volume of correspondence, even that relating directly to Kew Observatory, runs to many thousands of letters. Only those letters most helpful to my arguments and research questions have been cited in this study. The value of such a large volume of correspondence to the historian is twofold. First, we can use it to establish an almost day-by-day chronological narrative that can give a sharper picture of the development of Kew Observatory than can ever be put together from the published sources, or has ever been attempted by modern historians. Secondly, we can discover those *unofficial* views that the actors in the story of Kew Observatory might never have wanted to reveal to many of their colleagues or the wider public, more than we can ever find in minutes.

From this correspondence, as well as unpublished minutes, we can challenge and revise the received views about Kew Observatory, especially when informed by the recent scholarship on nineteenth-century observatories, laboratories and physical sciences generally that I have described in Sections 1.2 to 1.4. This allows us to tackle the three great questions about Kew that I have outlined in Section 1.1. To do this, I have divided this thesis into five large chapters, each covering a distinct period, in part because for each period we can ask some specific questions. I have arranged my chapters chronologically, in order to show how Kew evolved over time.

Chapter 2 covers only five years (1840-1845), but this short period deserves a chapter of its own because it was in these years that the Kew Observatory of the Victorian era was founded. Moreover, the political machinations that culminated in its takeover by the BAAS have never been discussed in any detail by historians. This chapter asks the question: how and why was the Kew building transformed from a disused royal instrument repository into what some in the BAAS claimed was a ‘physical observatory’? It then asks: what work did Kew Observatory carry out during its first years? I address the question of the organisation of science by demonstrating the importance of Edward Sabine as the prime mover behind the project to turn Kew into a magnetic and meteorological observatory and showing how he used the interchangeability between the Royal Society and the BAAS to his advantage. I show that lack of government funding did not prevent Sabine from setting up his own observatory at Kew, independent of Greenwich. I also critically assess claims that Kew was a physical observatory of the kind described by historians writing about the observatory sciences, or of the kind advocated by Herschel.

Chapter 3 covers the period 1845-1859, from the first attempts by the BAAS to close down Kew Observatory up to the death of John Welsh, its first paid superintendent, in 1859. I ask how Kew withstood the moves to close it and relate this to the introduction of the Royal Society Government Grant in 1850. Secondly, I chart how the observatory sciences at Kew expanded to include a full geomagnetic programme as well as the meteorological work. Also in this chapter, I begin to address the third of our fundamental questions: how and why did standardisation originate and develop at Kew? I argue that the reasons for the introduction and expansion of instrument verifications at Kew were due to factors of both demand and supply. On the one hand the government, with the setting up of the Meteorological Department of the Board of Trade in 1854, needed large numbers of thermometers, barometers and hygrometers, all tested to an agreed standard. Even before 1854, however, Kew began testing instruments in return for fees because it brought in much-needed extra income.

Chapter 4 describes the period of Kew Observatory’s history that is already been most discussed by historians: the pioneering programme carried out in the 1860s to photograph the Sun and to relate sunspot periodicities to terrestrial magnetism and weather. The narrative begins in the early 1850s, overlapping with the time-span of Chapter 3, in order to address a question that has not been tackled before: how and why did solar photography begin at Kew? I also ask how the photoheliograph was used in practice. I show how the solar photography programme was largely a private enterprise, directed by gentlemen scientists and implemented by little-known figures. Finally, I explore how this new observatory science of solar physics interacted with Sabine's magnetic and meteorological agenda. I build on the existing historiography in this field to show that Stewart's conflicts with Sabine owed as much to Stewart's vastly increased workload following the Meteorological Department's reorganisation as to Sabine's disagreement with Stewart's theory-driven approach.

In Chapter 5, covering the years from 1871 to the publication of Robert Scott's history in 1885, I ask how and why the BAAS decided to stop supporting Kew and what were the circumstances surrounding Gassiot's donation that was supposed to allow the Royal Society to run it. In this chapter, too, we see Airy winning a partial battle in his long rivalry with Kew: I ask why the Kew photoheliograph was transferred to Greenwich and why Airy nevertheless failed to wrest control of the Kew meteorological observations. This provides significant new insights into the changing organisation and specialisation of the sciences from the 1870s onwards, as does my finding that by the 1880s Kew was no longer taking the lead in the observatory sciences of magnetism and meteorology; rather, its work in these sciences was increasingly in the service of other organisations. I also show that by 1885, standardisation had become the most important branch of the work at Kew and argue that the standardisation question is intertwined with the organisation of science question. Contrary to assertions that Gassiot 'came to the rescue'[91] in setting up his trust to run Kew, the Gassiot fund was never sufficient to support the observatory and the Kew Committee needed to take on more standardisation work due to the money it brought in.

A central question in Chapter 6 is: how and why did Kew Observatory become part of – and the first site for – the National Physical Laboratory? Related to this is the question: how did the observatory sciences and standardisation at Kew evolve after 1885? I argue that, contrary to assertions by historians that the NPL was a triumph of government-supported science over prevailing *laissez-faire* attitudes, the existence of Kew Observatory was essential to the establishment of the NPL. Thanks to the shortage of funds discussed in Chapter 5, Kew by the late 1890s was already principally a standardisation centre that funded itself by charging fees for

[91] This exact phrase is used both by Walker (2012), p. 102 and by Jacobs (1969), p. 163.

testing instruments, and so had many of the elements of a ready-made NPL. I thus argue that the NPL evolved within the *laissez-faire* system rather than triumphing over it.

In Chapter 7, I conclude by returning to my three overall research questions:-

1) What can the history of Kew Observatory tell us about how the physical sciences were organised in the Victorian era?

2) How did the 'observatory sciences' at Kew develop over the course of the nineteenth century?

3) How did standardisation develop at Kew in the context of the culture of the physical sciences between 1840 and 1900?

In this concluding chapter, I will attempt to answer each of these questions using the findings I have presented in Chapters 2 to 6 and will thereby assess the importance of Kew Observatory in the history of the physical sciences in the nineteenth century and also the beginning of the twentieth century. My conclusions will challenge and revise some currently accepted views, especially as to the origins of the NPL and, more broadly, the evolution of the observatory sciences and their relations with government in Britain during the Victorian era. I will also point up some possible avenues for further research that have been suggested by this study.

Chapter 2

From King's Observatory to 'Physical Observatory': Kew, the Royal Society and the British Association, 1840-1845

> The observations most appropriate for the ready and exact determination of physical data are ... those which it is most necessary to have performed with exactness and perseverance. Hence it is, that their performance, in many cases, becomes a national concern, and observatories are erected and maintained, and expeditions despatched to distant regions, at an expense which, to a superficial view, would appear most disproportioned to their objects. But it may very reasonably be asked why the direct assistance afforded by governments to the execution of continued series of observations adapted to this especial end should continue to be, as it has hitherto almost exclusively been, confined to astronomy.
>
> John Frederick William Herschel, 1830.[1]

> ... Ld. Dungannon had examined the house late the Kew Observatory, and finds it in such excellent order that he will not pull it down as intended – he asked Beaufort if he knew any use that could be made of it...
>
> Edward Sabine, 1841.[2]

2.1 Introduction

When John Herschel wrote *A Preliminary Discourse on the Study of Natural Philosophy* in 1830, he was very widely respected and arguably Britain's foremost practitioner of the physical sciences. The first epigraph above is from Part II of the *Preliminary Discourse,* in which Herschel made a plea for state-funded observatories that collected not only astronomical data but also 'physical data' like meteorological observations and data for the determination of physical constants such as mean sea levels. As we shall see, in the years after 1830 John Herschel's call was enthusiastically taken up by his colleagues and the term 'physical observatory' was coined. In this chapter I hope to show how in the early 1840s the former King's Observatory at Kew was transformed into what some claimed to be a physical

[1] Herschel (1830), pp. 213-4.

[2] Edward Sabine to John Herschel, 5 February 1841, RS:HS 15.123. References to the correspondence of Herschel and Sabine here follow the conventions used in Crowe et al. (1998).

observatory. How and why this happened has hitherto not been analysed in detail. I will begin by assessing the state of geomagnetism and meteorology in the early nineteenth century and how the concept of a physical observatory was developed by Herschel and others. I will then use a chronological framework to show how the Royal Society, after an abortive attempt to establish a physical observatory, in the end turned down the government's offer of the Kew building, which was then taken up enthusiastically by the British Association for the Advancement of Science (BAAS). Finally, I describe and assess the programme of work implemented at Kew up to the mid-1840s. We will see that the institution that emerged was different in many ways to Herschel's vision of a physical observatory: in particular, none of the work being done at Kew up to 1845 was funded by the government.

Although the *Preliminary Discourse* was clearly an inspiration behind the relaunched Kew Observatory, the story of its transformation is a complex one that owes as much to the personalities and politics of the physical sciences in the 1840s as it does to Herschel. Through Kew Observatory we can learn much about the organisation of the physical sciences in the 1830s and 1840s. The tale especially illuminates the role of the military in securing patronage for, and organizing, science in this period. It might build on David Philip Miller's important synoptic survey of the physical sciences in the early nineteenth century, which highlights the under-appreciated role of the 'scientific servicemen' in addition to that of the better-known 'mathematical practitioners' and 'Cambridge network' (see also Chapter 1, Section 1.1).[3] In particular, it will become clear from this chapter that the prime mover behind the Kew project was the scientific serviceman Edward Sabine, who, as suggested in the second epigraph above, saw the building's potential as an observatory very early on. As I will describe in Section 2.2, Sabine was the chief mastermind behind what came to be known as the 'Magnetic Crusade' and by 1840 had become at least as distinguished as a political maneuverer as he was as a man of science. I will also argue that although only a limited range of observatory sciences was practised at Kew before 1845, the very lack of government funding in the age of *laissez-faire* gave Sabine a free hand to establish his own research programme there, independent of his rival at Greenwich, the Astronomer Royal George Airy.

[3] Miller (1986), pp. 107-134, esp. pp. 112-119.

2.2 'Perhaps all this is dreaming': magnetism, meteorology and physical observatories

As discussed in Chapter 1 (Section 1.3), at the beginning of the nineteenth century geomagnetism and meteorology were not organised on a national scale. Calls for improvements to meteorology were beginning to increase from the 1820s onwards. However, practitioners of science realised that little progress could be made while meteorological instruments and observations remained in their existing state. In 1823 the battery and hygrometer inventor John Frederic Daniell drew attention to the poor state of the Royal Society's meteorological instruments at Somerset House and the inaccuracy of the observations made with them. Daniell was a council member of the short-lived Meteorological Society of London, which in 1824 anticipated future events by calling for accurate series of meteorological observations to be made throughout the British Empire and made comparable with each other using standardised instruments; for this to be possible, the society 'should set the example of the requisite precision by establishing a Meteorological Observatory in the metropolis, or its vicinity'.[4] Indeed, Daniell was later a member of the Royal Society Council and the Committee of Physics, both of which deliberated as to whether to take on Kew Observatory in the 1840s (see below). The Meteorological Society proved to be short-lived and its proposals came to nothing, but meteorology was on the agenda of the BAAS soon after its formation in 1831. The shambolic state of meteorology was stated more bluntly than Daniell by the Edinburgh natural philosopher James David Forbes in a report read to the 1832 BAAS meeting, in which he lamented that 'meteorological instruments have been for the most part treated like toys, and much time and labour have been lost in making and recording observations utterly useless for any scientific purpose'.[5] Forbes went further at the 1840 BAAS meeting, calling for the establishment of well-equipped 'public observatories' which would 'furnish standards of comparison, to establish the laws of phaenomena and to fix *secular*, or normal data'.[6] That same year, at the Royal Society, Forbes called for one such meteorological observatory to be set up near

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[4] Quoted in Walker (2012), p. 14.

[5] Forbes (1833), p. 196. Part of this is quoted in Anderson (2005), pp. 87-88; and Walker (2012), p. 15.

[6] Forbes (1841), p. 144; Walker (2012), pp. 15-16.

London, setting off a chain of events related directly, and intimately, to the relaunching of Kew Observatory in the 1840s, as we shall see in Section 2.3.

Geomagnetism began to gain prestige and public importance thanks to the well-publicised works of the Prussian explorer and scientific polymath Alexander von Humboldt. Observational work was stimulated by both Humboldt and the mathematical physicist Karl Friedrich Gauss, when they began to give the subject a firm theoretical basis and demanded large quantities of accurate data with which to test their theories. They asked that this data be produced by a system of geomagnetic observatories scattered across the globe. Within a few years, such a system of observatories became a reality across the German lands and beyond, including Russia.[7] In Britain, many were of the opinion that the UK was in danger of being left behind in this promising new field of research. Several prominent figures in this field began calling for a system of magnetic observatories across Britain's imperial possessions. Arguably the loudest of these voices was Edward Sabine (Figure 2.1), who had extensive experience of making magnetic observations during the Arctic naval expeditions of the 1810s and 1820s. A Royal Artillery officer who was given generous leave from military service to undertake scientific research, Sabine was based at the Royal Military Academy in Woolwich and was a prominent example of a 'scientific serviceman' (see Chapter 1, Section 1.1).[8] In addition to an array of fixed observatories worldwide, Sabine also called for an Antarctic naval expedition which would survey the Earth's magnetic field in the southern hemisphere and find the as yet unknown location of the southern magnetic pole (or poles[9]).

[7] Cawood (1977), pp. 583-584.

[8] Biographies of Sabine are all very brief. The most substantial are Anon. (1892), Good (2004) and Reingold (1975).

[9] Some geophysicists at this time, including Sabine, believed that each hemisphere might have two magnetic poles. See Enebakk (2014), esp. p. 599.

Figure 2.1 Edward Sabine at the Southampton meeting of the BAAS, September 1846. Image courtesy Royal Astronomical Society.

John Cawood, and also Jack Morrell and Arnold Thackray, have claimed that the politically-astute Sabine lobbied for this dual project in geomagnetism by putting Humboldt up to writing to the Royal Society, urging Britain to join in the worldwide magnetic campaign and at the same time appealing to British nationalist sentiment by claiming at BAAS meetings that Britain was being left behind in science by its European neighbours.[10] Sabine moved deftly between the Royal Society and the BAAS to achieve his aims: when the Royal Society was not initially interested, he took his campaign to the BAAS, before going back to the Royal Society to seek its authority when applying to the government for funds. In the event it was John Herschel who in 1838-9 finally secured funding for the Antarctic expedition and magnetic observatories. Fresh from his successful four-year observing expedition at the Cape of Good Hope, Herschel was lionised as a scientific and national hero. He also had class connections at the highest level which enabled him to lobby for the magnetic project over dinner with Queen Victoria and the Prime Minister, Lord Melbourne, as well as to negotiate with the aristocratic presidents of both the Royal

[10] Cawood (1979), pp. 502-507; Morrell and Thackray (1981), pp. 356-359. However, Carter (2009), pp. 16-17, doubts whether Humboldt was really urged by Sabine to write to the Royal Society's president.

Society and the BAAS.[11] The project that the Melbourne government eventually agreed to fund consisted of an Antarctic expedition under James Clark Ross, running from 1839 to 1842; concurrently with this, magnetic and meteorological observations were to be taken from fixed stations at Greenwich (under Astronomer Royal George Airy), Dublin, Toronto, St Helena, the Cape of Good Hope and Van Diemen's Land (now Tasmania). The observations were coordinated at Dublin by Humphrey Lloyd, in close collaboration with the Irish-born Sabine. This combination of an Antarctic expedition and a system of observatories has become known as the 'Magnetic Crusade'. It is important to remember, however, that 'Magnetic Crusade' was not a term used during the lobbying for funding.[12] In the late 1830s, contemporaries referred to it using language such as 'fixed stations of observations'.[13] Indeed, rather than the start of some grand new era with no definite conclusion, it was seen in 1840 as a fixed-term project. This helps us to understand Kew Observatory better, because Kew was in stark contrast to the Magnetic Crusade in that it was a permanent establishment and independent of the system of government-funded, temporary observatories.

Herschel, in his 1830 *Preliminary Discourse* quoted above, seems to have been the first to suggest the general concept of a government-funded physical observatory to provide long-term data for the use of theoreticians, not just in astronomy, but in physical sciences generally. Yet nobody could agree on an exact plan for what such an observatory should be doing. The earliest known use of the exact phrase 'physical observatory' seems to have been made by the Scottish natural philosopher David Brewster, who wrote William Vernon Harcourt – like Brewster, a leading light in the early years of the BAAS – that he had 'long thought that one of the greatest scientific desiderata in England is a *physical observatory*, erected and endowed by the government'. Specifically citing Herschel's idea as his inspiration,

[11] Cawood (1979), p. 507. Buttmann (1974), p. 121. Ruskin (2004), pp. 58-66 makes the case that Herschel's Cape voyage led to him being appropriated as a hero of British imperialism as well as science.

[12] The origins of the phrase 'Magnetic Crusade' are unclear. Carter (2009), pp. xv-xvi, finds no evidence that the phrase was used in the lobby for the project in the 1830s and that it was first used in 1842 in an American textbook on electricity and magnetism. Elias Loomis's 1848 call for a 'grand meteorological crusade' along the lines of the British magnetic effort strengthens the idea that the term 'Magnetic Crusade' was American in origin – see Fleming (1990), p. 77.

[13] Lord Minto to Lord Northampton, 7 January 1839, quoted in Morrell and Thackray (1981), p. 367.

Brewster suggested that in such an establishment his own experiments in optics could be carried out to a much higher standard than was possible in a private laboratory and that 'all the phenomena of magnetism, meteorology and electricity' could be observed as they were in the magnetic observatories then being established across Europe.[14] Harcourt agreed, though such a broadly-based concept of a physical observatory made no further progress with the BAAS at this time.

Herschel further developed his ideas on physical observatories in October 1835, in a long letter to Francis Beaufort, Hydrographer to the Admiralty, written while on his expedition to the Cape of Good Hope. By this time, Herschel had been calling for a more coordinated approach to meteorological observation, both in the *Preliminary Discourse* and in the form of an instruction manual for making and recording meteorological observations, originally published in Cape Town.[15] The views expressed in his letter to Beaufort correspond very well with his remarks in the *Preliminary Discourse* and are important in that they help us to understand his attitudes to Kew Observatory in the 1840s. Herschel advocated to Beaufort a hierarchical system of observatories worldwide, in which the great national observatories such as Greenwich formed a 'first class', with which those institutions 'of an inferior class' could and should not compete. However, there were many important tasks to be done by these lesser observatories. They should, said Herschel, carry out determinations of constants such as local gravity, mean atmospheric pressure and sea level (the 'absolute height above the level of the Sea of some natural unobliterable mark above or below the station of observatory'). Herschel now also proposed that an important part of these institutions' programmes would be to observe, with the most up-to-date instruments and methods available, 'magnetic intensity and direction', 'meteorology in all its extent' and tides. Thus Herschel's vision of a physical observatory involved routine monitoring of variables such as the Earth's magnetic field, as well as the establishment of constants. Herschel had no plans for how such a system of observatories should be put into effect and he concluded with the reflection: 'Perhaps all this is dreaming'.[16] We do not know the exact context of this letter to Beaufort, though at the end of the letter he remarks on a ceasefire in the frontier war then taking place in South Africa, suggesting that this

[14] Brewster to Harcourt, 28 April 1832, in Morrell and Thackray (1984), pp. 138-141.
[15] Good (2006), pp. 55-56.
[16] Herschel to Beaufort, 11 October 1835, RS:HS 21.188.

vision of a system of observatories was part of Herschel's view of enlightened imperial administration that he developed during his stay at the Cape of Good Hope in the 1830s.[17]

Figure 2.2 George Biddell Airy, Astronomer Royal 1835-1881.
Image courtesy Royal Astronomical Society.

Because of their importance to navigation, geomagnetism and meteorology technically came within the remit of Britain's 'first-class' observatory, the Royal Observatory at Greenwich, which from 1835 was headed by George Airy (Figure 2.2). As described in Chapter 1 (Section 1.3), Greenwich had been founded to assist navigation by solving the problem of finding longitude at sea. Edmond Halley (Astronomer Royal 1719-1742) had laid many of the foundations for geomagnetic research and for some years John Pond, George Airy's predecessor as Astronomer Royal, had run a magnetic observatory at Greenwich. But Greenwich had never done any magnetic work on a large scale and by 1835, when Airy succeeded Pond at Greenwich, it had ceased altogether. Airy supported magnetic work in principle, so long as it had a navigational purpose. In the 1830s, for example, he played a major part in investigating the corrections needed for magnetic compasses on iron ships.[18] In 1836 he agreed to support a limited programme of geomagnetic research

[17] Ruskin (2004), pp. 52-57; Musselman (1998).
[18] See Cotter (1977).

suggested by the Royal Society in response to Humboldt's letter of that year. It is clear, however, that from very early on in his time at Greenwich, Airy and Sabine did not get on. This animosity may have arisen because Airy saw Sabine as a rival and a challenge to his authority. It may also stem from the fact that Sabine, unlike Airy (and Herschel), was no theoretician. Sabine was fundamentally a collector of data, who had learned his art through his career in the Royal Artillery and on voyages of exploration. He had not been educated in the regime of reformed Cambridge mathematics in which theory, not empirical data-gathering, was seen as the all-important driving force in the physical sciences. David Philip Miller has noted the 'superior attitude' taken by members of the Cambridge network towards those outside this group;[19] Airy, in particular, was notorious for his insistence on training in higher mathematics as a prerequisite for a leading role in the hierarchy of the observatory.[20] In 1837 Airy refused to support the plan for an Antarctic voyage, apparently out of jealousy towards Sabine's increasing political power.[21] He did agree to take part in the Magnetic Crusade by building a wooden 'pavilion' for magnetic observations at Greenwich, one of the six 'fixed' observatories envisaged in the plan, for which the government allocated Airy £2,000 per year for the duration of the project. But he was never an enthusiast for the Magnetic Crusade as a whole, as is emphasised by the sour tone of his letter to a colleague in early 1840:-

> 'I have nothing to do with the new magnetic observatories, and know nothing about them.
>
> The supreme president over them is Professor Lloyd (Trinity College Dublin) who is certainly willing and I suppose able to tell what they are to be like.'[22]

Airy had less regard for meteorology than geomagnetism as a science, because he believed that meteorology lacked a firm theoretical basis.[23] But even before the Magnetic Crusade began, the Astronomer Royal had instigated a programme of meteorological observations at Greenwich. To run the new 'Mag. and Met.' department, as it became known, Airy recruited James Glaisher, an

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[19] Miller (1986), p. 110.
[20] Aubin (2011), p. 117. The importance of Airy's Cambridge education is described in Warwick (2005), pp. 72-75.
[21] Morrell and Thackray (1981), p. 364.
[22] Airy to W S Stratford, 27 February 1840, RGO 6/675/226.
[23] Meadows (1975), p. 103.

outstanding young observational astronomer whom Airy had taken with him from Cambridge when he was appointed Astronomer Royal. Although he remained loyal to Airy throughout his working life, Glaisher would prove to be a strong personality in his own right, establishing Greenwich as a centre of cutting-edge meteorological research in defiance of any competition. Thus by the time the Kew Observatory building became available in the early 1840s, a fully-functioning geomagnetic and meteorological observatory had been established at Greenwich, at government expense. This would have an important bearing on the history of Kew Observatory in the 1840s and its relationship with government, as I shall describe below.

2.3 'I think at Kew': the Royal Society's proposal for a physical observatory

In June 1840, during the same summer as Forbes's second call for an improved national system of meteorological observations, the Royal Society Council communicated to the government a proposal for something remarkably similar to what was eventually established at Kew: a magnetic and meteorological observatory in the vicinity of London, run by full-time staff and established on a permanent basis. This proposal was in contrast with the system, described above, of temporary magnetic observatories set up in various outposts of the British Empire. This episode – which involved a substantial funding application to the highest level of government – has been briefly noted by Marie Boas Hall, and also Morrell and Thackray, who have put the failure of the application down to the incompetence of the pre-1847 Royal Society.[24] Carter has discussed these events in more detail, but he has overemphasised the role of John Herschel, while attaching too little importance to that of Edward Sabine and overlooking evidence that the Royal Society withdrew its application to the government after the intervention of George Airy.[25] A further examination of the correspondence reveals some evidence, hitherto unnoticed by historians, that the Royal Society may possibly have had Kew in mind as a location for the proposed observatory. Certainly the similarity of the 1840 proposal to the programme of work eventually carried out there makes this episode

[24] Hall (1984), pp. 155-156. Morrell and Thackray (1981) refer to it as 'a gaffe of the first order' (p. 350).
[25] Carter (2009), pp. 108-113.

crucial to understanding the history of how the former King's Observatory was transformed into the Kew Observatory of the 1840s and beyond.

The immediate beginning of the episode can be traced to 4 June 1840, when Forbes, while in London, used the opportunity to launch another of his attacks on the state of British meteorology, particularly the meteorological observations still being carried out at the Royal Society's premises in Somerset House. The Royal Society's Committee of Physics and Meteorology decided to form a sub-committee with a brief to consider and report on this subject.[26] This met four days later and consisted of Forbes, Daniell and Sabine, plus the meteorologist and electricity expert William Snow Harris. The sub-committee resolved that the observations currently being made at Somerset House were 'unavoidably unworthy of the official character which they bear, in consequence of the imperfections of the locality and the multiplied duties of the observer'. They recommended that this system be replaced with something much more ambitious: the Royal Society Council should now apply to the government 'to establish a permanent Meteorological Register in connexion with some National Institution'.[27] By the next meeting of the Committee of Physics, on 17 June, this request had changed to 'a magnetic and meteorological observatory on the same plan as those already established in other parts of the globe ... in the neighbourhood of London'. The Council was 'recommended to apply to the Government to carry this purpose into immediate effect'.[28] This was duly ratified at a Council meeting the following day, Thursday 18 June, which was attended by twelve people, among them Edward Sabine. They requested that the President, Lord Northampton, bring the subject up with the Prime Minister, Lord Melbourne.[29]

Quite how, between 8 and 17 June, the plan was transformed from an improved version of the meteorological record kept at the Royal Society into a full-blown observatory doing magnetic work as well as meteorology, is not clear. However, some clues can be gained in a brief exchange of letters between George Airy – who was not a member of the Royal Society Council or the Committee of Physics – and his old friend, the noted astronomer Richard Sheepshanks. Sheepshanks reported that while walking home from the Athenaeum club on the

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[26] RS:CMB/284, 4 June 1840.
[27] RS:CMB/284: Report of Sub-Committee of Meteorology, 8 June 1840.
[28] RS:CMB/284, 17 June 1840.
[29] RS:CM, 18 June 1840.

evening of Monday 15 June, he had been informed by Ordnance Survey director Thomas Colby that 'there was some talk of the want of magnetic observatories at Greenwich & that there was & would be a considerable difficulty as to the regulation of the magnetic observatories recently established' (those of the Magnetic Crusade). In addition to this slight against Airy's magnetic establishment at Greenwich, Sheepshanks's informer also intimated that there was the possibility of a move to appoint a 'magnetic chief' – he named Sabine as a possible candidate – to run the magnetic observatories independently of Greenwich.[30] Sheepshanks's letter has the tone of a friendly warning to Airy, who seems to have been kept in the dark about the whole move. From this it seems possible that it was Sabine who turned the idea for an improved meteorological register into a magnetic as well as meteorological observatory. As we have seen, Sabine had long been a rival of Airy as well as the chief mastermind behind the Magnetic Crusade. He had attended all the various committee and Council meetings between 4 and 18 June. Moreover, with his long experience in magnetic survey work, he was an obvious choice for the post of 'magnetic chief'.

The application took the form, to begin with, of a deputation consisting of Lord Northampton, Edward Sabine, Royal Society Treasurer John Lubbock and Samuel Hunter Christie, Secretary of the Royal Society and a professor at the Royal Military Academy in Woolwich. These four visited Downing Street on 20 June – a Saturday, when Melbourne presumably had more time for such visitors. The Prime Minister would have been used to such a deputation applying for funds for scientific projects: the government's agreement in 1839 to finance Ross's Antarctic expedition and the magnetic observatories contemporaneous with it was partly the result of consistent lobbying by small groups of leading scientific personalities, Sabine prominent among them. John Herschel did not attend this meeting or any of the committee or Council meetings in June 1840. He was not a Council member by this time and only two months earlier he had moved into his secluded country residence in Kent and so he may well have been preoccupied with settling in.

The day after the meeting Lubbock reported that the Prime Minister had received the visitors well and that although no decision could be made there and then, Lubbock had 'no doubt that sooner or later it [funding] will be granted'. More

[30] Sheepshanks to Airy, 17 June 1840, RGO 6/675/228-230.

importantly, Lubbock's letter is the earliest evidence we have that this time the Royal Society was seeking funding for something very different from the temporary observatories of the Magnetic Crusade, which had an initial lifetime of three years. The proposed new observatory would be 'a permanent magnetic and meteor. observatory'.[31] According to a later letter from Lubbock, the observatory would need a director plus three assistants, giving a total annual salary cost of £2,000. The cost of printing the observations, together with various other expenses such as repairs, increased the cost estimate to a minimum of £3,000 per year. Lubbock emphatically stated that in addition to magnetic work, the observatory would also carry out 'meteorological observations similar to those now made at the Royal Society but on a more extended system'; in addition, 'it may be desirable to devise also observations of the electrical state of the air & others which the Royal Society did not furnish'.[32]

Sabine, in a letter to Herschel, claimed to have been 'perfectly ignorant of what had passed at the Council' on 18 June, and that Lubbock and the others had put him on the spot, forcing him to say to Melbourne that the Royal Society wanted a permanent observatory.[33] Sabine's name clearly appears on the list of those who attended the Council meeting,[34] so he could not have been as 'perfectly ignorant' of what had happened as he claimed. As Herschel was not a Council member, he would not have had access to the minutes of its meetings and so it would appear that Sabine was not telling the truth, either in this regard or in his claim to have been put on the spot by the others at the meeting with the Prime Minister. Moreover, on no other occasion did Sabine express misgivings as to the new observatory being a permanent establishment. These two factors, plus Sheepshanks's letter to Airy, as well as Sabine's track record of a poor working relationship with Airy, suggest that there is at least circumstantial evidence that Sabine colluded in the idea of a permanent observatory independent of Greenwich and may well have been central to the project.

Exactly how George Airy came to hear about the deputation to the government is not known. Certainly he was tipped off by Richard Sheepshanks on

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[31] Lubbock to Herschel, 21 June 1840, RS:MM 16.141.
[32] Lubbock to Herschel, 27 June 1840, RS:MM 16.142.
[33] Sabine to Herschel, 6 July 1840, TNA:BJ 3/26.
[34] RS:CM, 18 June 1840.

17 June about the Royal Society's plans, but by the time he wrote to Lord Northampton on 28 June he had more up-to-date knowledge:-

> I have just heard a very vague report that a recommendation has been addressed to the Government by the Council or by a Committee of the Royal Society, to the effect that a magnetic observatory should be erected or fitted up by the Government, I think at Kew.

Airy went on to describe his 'excellent Magnetic Observatory' at Greenwich, which had been built 'at considerable expense to the Government'. Asking Northampton for further information on the proposed new observatory, he emphasised the importance of saving the government expenses that were 'absolutely unnecessary' and that 'the machinery of a new establishment should be dispensed with when that of an old one can be made available'.[35]

In all the extensive correspondence on the 1840 magnetic observatory episode, Airy's 28 June letter is the only evidence we have that the proposed new establishment might be at Kew, and even this does not prove that the former King's Observatory was to be used as a site. None of the minutes and correspondence contain any suggestions for a site; indeed, just before the deputation Sabine claimed to Herschel that 'no one ... seems to have any distinct idea of where such an establishment can best be placed'.[36] Yet it is interesting that Lubbock's cost estimate details only the annual running costs and makes no mention of a suitable building or instruments. The latter might have been paid for out of private funds or the Royal Society's own coffers, but erecting a new, permanent building from scratch would have required a substantial capital investment beyond private or Royal Society means. If the Royal Society had in mind a ready-made building that was available free of charge, it is difficult to think of any building at Kew other than the King's Observatory. Moreover, there is evidence that several leading men of science had been alerted to the situation of the disused observatory in the weeks following the death in 1839 of Stephen Rigaud, who, as described in Chapter 1 (Section 1.4) had assisted with the running of the observatory. Shortly after Rigaud died the

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[35] Airy to Lord Northampton, 28 June 1840, RS:MM 11.145.

[36] Sabine to Herschel, 18 June 1840, RS:MM 16.139. However, according to Herschel, Sabine suggested that a temporary observatory might operate at Woolwich until a permanent establishment was completed. Herschel to Airy, 6 July 1840, RGO 6/675/239.

astronomer William Rutter Dawes had made enquiries about applying for Rigaud's vacant position at Kew.[37]

In a second letter to the Royal Society, Airy outlined an alternative plan: an extended magnetic and meteorological observatory at Greenwich, under his own direction, which would obviate the need for a new, separate establishment. Airy offered to use his existing magnetic and meteorological building and to carry out the same programme of work with fewer extra staff than the Royal Society's proposal, sharing some personnel with the main astronomical observatory.[38] His letter was read out at a meeting of the Committee of Physics on 9 July and at a meeting of the full Council held the same day. The minutes of the Council meeting quote a total extra staff cost of £550 per annum.[39] Even if we add the costs of extra instruments and printing, the total cost was obviously far less than the £3,000 per year quoted in Lubbock's plan. Again Airy made much of the need to save public money: 'as the Government have been led to expend a considerable sum on this building for this purpose, ... I do think that it would be most unfair towards the Government, and most injurious to the cause of science in future negociations [*sic*] with the Government, to set aside the consideration of this investment in judging what is best to do at present'. Airy concluded his letter by asking Lubbock to 'assure the Committee that, if they determine on not accepting my offer, I shall fully understand that the inconveniences attached to it do in their estimation exceed the conveniences'.[40] Airy may have sincerely thought that the committee might find his offer of an extended magnetic observatory inconvenient, perhaps for practical reasons, Greenwich being some distance from central London. But these words might have been a polite way of sending a different signal: if the committee were to reject Airy's offer, Airy would take it that they thought that he could not do as good a job as the Royal Society. The latter interpretation is especially plausible given that, as noted above, Sheepshanks had warned him of 'talk of the want of magnetic observatories at Greenwich', which would surely have perturbed Airy. Both of Airy's letters have a clear tone of anxiety about the very idea of a separate observatory. Clearly he wanted to keep the

[37] Dawes to Herschel, 1 April 1839, RS:HS 6.58; Dawes to Airy, 1 April 1839, RGO 6/245/61.
[38] Airy to Lubbock, 3 July 1840. Reprinted in RS:CM, 9 July 1840.
[39] RS:CM, 9 July 1840.
[40] Airy to Lubbock, 3 July 1840, reprinted in RS:CM, 9 July 1840.

permanent magnetic and meteorological observations under his own control and saw any separate observatory as a rival.[41]

Faced with Airy's offer to do the job more cheaply and just as efficiently, the Royal Society had no option but to back down. At the Council's request, Northampton wrote to Melbourne on or before 20 July, retracting the application made one month before, claiming that the request for a separate observatory had been due to concerns about Airy's lack of resources to do the extra work himself, but he was now pleased 'to find that we were mistaken as there can be no doubt of his entire fitness for the most satisfactory performance of such additional duties'.[42] Melbourne was no doubt relieved at the opportunity to save some £2,000 a year of public money, particularly as by 1840 he was leading a minority government. Only a year earlier his government had reluctantly agreed to support the extremely expensive Antarctic expedition and the accompanying magnetic observatories, so it must have been difficult for him to justify yet more spending on costly scientific projects – in this case, moreover, a permanent observatory, not a one-off series of temporary ones. Indeed, the political situation might well explain why the Royal Society acted with such haste in applying for funding in June 1840: if they did not move quickly, the government could fall and be replaced by a Tory administration under Sir Robert Peel, who had a reputation for being keen to reduce public spending.

Herschel might well have agreed with the Prime Minister about yet another substantial application for funding so soon after the Magnetic Crusade: 'it would not only <u>seem</u> but <u>be</u> importunate to press, just at present for further grants in this direction'. Herschel strongly supported, in principle, the idea of a permanent magnetic and meteorological observatory: he thought that such an institution would 'do honour to the country & confer great benefits on science'. According to Herschel, even more important than a physical observatory was what he termed an 'experimental Institute or College', which would do more general standardisation work: 'an institution destined for the systematic determination … of all the invariable elementary data of physical theories which admits of such determination such as atomic weights – specific heats – pyrometric changes – electric – thermotic

[41] Morrell and Thackray (1981), p. 350.
[42] Northampton to Lord Melbourne, RS:MM 16.145 (undated, but enclosed with a letter from Roberton to Herschel, 20 July 1840, RS:MM 16.144).

&c constants – such that is to say as are not of a local or temporary nature'. Yet most tellingly for the future of Kew Observatory, Herschel thought that 'the proper locale of a physical observatory should be on the Sea Coast – 1st for observation of the tides – 2d as a centre of departure of a general coastland-line – to be ultimately referred to the mean-sea level at that spot as a probably invariable standard'.[43] So it would appear that Herschel had good scientific reasons for not supporting Kew or anywhere else near London as a good location for a physical observatory: this was obviously the wrong location for a coastal observatory. Moreover, the vision expressed here of an observatory at a coastal location, measuring physical constants as well as making magnetic and meteorological observations, is entirely consistent with Herschel's earlier ideas for physical observatories in the *Preliminary Discourse* and his October 1835 letter to Beaufort.

Thus the Royal Society's failed application for a new government-funded observatory was likely not a 'gaffe', but rather a carefully planned manoeuvre by Sabine that was foiled only by Airy and his intelligence network. Before long, however, there would be a new possibility of an observatory at Kew and this time Airy would be powerless to do anything about it.

2.4 Sabine, science and politics: Kew Observatory and the Royal Society, 1841-1842

On 5 February 1841, Sabine wrote to Herschel with news from Francis Beaufort: a government official had told Beaufort that the former Kew Observatory building was in such excellent condition that it would not be pulled down, as had been intended, and had asked him if he could think of any use for it. According to Sabine, Beaufort had suggested a magnetic observatory, to which the official replied: 'well, so, so, & you will have it, most likely'. The availability of the building may not have been news to Sabine, who went on to say: 'for altho' the arrangement relative to Greenwich seems to have forestalled the use that could so well have been made of it as a Magnetc. & Meteor. Observatory, it seems a very suitable place for your ulterior project of a Physical Observatory'.[44] Beaufort had certainly been aware for some time that the building was disused: as early as 1839 he had reported to Herschel that

[43] Herschel to Airy, 6 July 1840, RGO 6/675/239.
[44] Sabine to Herschel, 5 February 1841, RS:HS 15.123.

it was to be pulled down.[45] This adds further weight to the idea that Sabine, at least, had had the Kew building in mind in 1840.

Nothing further then happened until 24 June. It may have been Sabine, who attended the meetings of the Committee of Physics and full Council that day, who informed the Royal Society that Kew Observatory was being made available by the government, apparently free of charge. In any event, the Committee of Physics passed a resolution in favour of acquiring it.[46] The Council duly adopted the resolution and once again the President was requested to make an application to the government,[47] though not for funding this time, only for possession of the building. But Northampton does not appear to have done this and instead there was another long delay. Nearly five months later the Council asked the Committee of Physics to report back as to 'what specific scientific purposes it would be desirable to appropriate the building formerly occupied by the Observatory at Kew' and to suggest 'what would be the probable annual expense of applying it to such purposes'.[48] The Committee of Physics duly appointed a sub-committee, consisting of Herschel, Sabine and Charles Wheatstone (professor of experimental philosophy at King's College, London since 1834), to draw up the report for the Council. These three met on 18 December, though their resulting report was not read to the Council until 10 February 1842. The report gave a mixed verdict on the observatory. To begin with, the sub-committee thought that Kew was not suitable for 'any regular and systematic course of physical observations' by the Society, due to its 'peculiar restrictions as to access and inhabitancy and other circumstances'. The report did, though, recommend several other uses for the building, such as a depository for Royal Society instruments and a place for comparison of instruments such as pendulums. The estimated costs were a salary of about £27 per annum for a caretaker and a mere £5 per annum for maintenance – a far cry from the £3,000 annual cost for the 1840 observatory and even the £550 for Airy's extended 'Mag. and Met.' establishment at Greenwich.[49]

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[45] Beaufort to Herschel, 17 July [1839], RS:HS 3.40.
[46] RS:CMB/284, 24 June 1841.
[47] RS:CM, 24 June 1841.
[48] RS:CM, 11 November 1841.
[49] RS:CM, 10 February 1842. The report is reproduced verbatim in Scott (1885), pp. 48-9. The original manuscript report is in RS:MM 16.189.

That the report dismissed Kew as unsuitable for regular, systematic observations may at first seem surprising, given that the building would be used for precisely that purpose later in the 1840s. There were indeed some genuine 'restrictions to access and inhabitancy', such as the building's remoteness from central London and the fact that an existing caretaker already occupied the basement, but these were not insurmountable, as we shall see in Section 2.5 below. We do know, however, that the report was drafted by Herschel,[50] who, as we have seen, would not have considered Kew a good site for a physical observatory. Probably no one at this time had greater authority in the physical sciences than Herschel and in a sub-committee of just three people Sabine and Wheatstone may have had no choice but to defer to his wishes. But the main reasons why the Royal Society decided not to use Kew as a magnetic and meteorological observatory – and, indeed, why the Council did not immediately go ahead with the proposal to acquire the building – might well have been financial and political. Given that the Council had specifically asked about the 'annual expense' and that the total cost of the watered-down proposal amounted to little more than £30, it is likely that a full-scale observatory, complete with staff and instruments, would have been too large an annual charge on the Royal Society's funds.

Herschel himself may well have shared the general consensus about costs: just before the December 1841 sub-committee meeting, he confessed to Sabine that he thought Kew Observatory 'likely to cause some degree of embarrassment' to the Royal Society.[51] If Kew were to cost £3,000 a year to run, the Royal Society would once again have had to apply for a hefty government grant little more than eighteen months after its retreat in 1840. Also, Herschel believed that large-scale physical observatories of the sort envisaged in the *Preliminary Discourse* should be run by the government, not scientific societies: much later, he expressed the belief that to take responsibility for an observatory or any other permanent institution would 'deprecate' the Royal Society.[52] To make matters worse, by the end of 1841 the political climate had now changed: Melbourne's Whig government had finally fallen and had been succeeded by the Tories under Peel. Herschel, for one, considered the outlook for science under the new government 'exceedingly ill-omened' and

[50] Sabine to Herschel, 13 January [1842], RS:HS 15.136.
[51] Herschel to Sabine, 2 December 1841, TNA:BJ 3/26.
[52] Herschel to Murchison, 15 February 1850, TxU:H/L-0269; Reel 1054.

bemoaned 'the good old Tory feeling of hatred and contempt for Science and its followers'.[53]

It is also possible that Sabine, who had ruthlessly used both the Royal Society and the BAAS in his lobbying campaign for the Magnetic Crusade, agreed to the watering down of the proposal in order to steer the Royal Society towards rejecting the government's offer, with the ulterior motive of making the observatory available to the BAAS, which he might well have thought would be more receptive towards it. We do not have any documentary evidence as to Sabine's and Wheatstone's motives, however. All we know is that at the Council meeting exactly one month later, with no reasons recorded other than consideration of the sub-committee's report, it was decided that 'it does not appear to the Council to be expedient for the Society to occupy the Observatory at Kew'. The Council requested the Treasurer, Lubbock, to communicate this decision to the government.[54]

2.5 The British Association: founding the 'establishment' at Kew, 1842-1843

On 28 March 1842, just eighteen days after the Kew building was finally rejected by the Royal Society, the possibility of acquiring it for the BAAS was formally raised at a BAAS Council meeting. The Royal Society's rejection was noted 'and that if an application should appear desirable on the part of the British Association, it was necessary that it should be made without delay'. Sabine and Wheatstone were both present at this meeting; indeed, Sabine attended most of the BAAS Council meetings over the next several years. At the 28 March meeting Wheatstone, who had been on the Royal Society sub-committee that had rejected Kew as a site for systematic observations, now read a statement 'of several important objects in the Physical Sciences' which the Kew building would offer to BAAS members 'in the prosecution of experimental inquiries'.[55]

Wheatstone appears to have drawn up this document, and it is apparent from it that the proposed programme of 'experimental inquiries' was very different from the Royal Society's watered-down proposal for an instrument store and small-scale standardisation centre. It stated unequivocally: 'It is proposed to establish, in

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53 Herschel to [Sabine], 5 September 1841, TNA:BJ 3/26.
54 RS:CM, 10 March 1842.
55 BAAS:CM, 28 March 1842.

connexion with the British Association, a Physical Observatory' in the Kew building. The objectives of this physical observatory fell under seven broad headings: a repository 'and place for occasional observation and comparison' of newly-invented meteorological instruments; the construction and trial of new self-recording meteorological instruments; a repository of standard instruments with which people could compare their own instruments; a place where magnetic instruments currently used 'in the various magnetic observatories' could be kept to enable people to learn how to use them; the setting up of apparatus for research into atmospheric electricity; a room for experimental work on optical astronomical instruments (an echo here of David Brewster's 1832 call for a large-scale optical laboratory – see Section 2.2); and a collection of measuring instruments, 'for the purpose of obtaining accurate quantitative results'.[56] The 28 March Council meeting quickly approved the proposal.[57] On 16 May a formal application was sent to the Prime Minister and just ten days later the government sent an official letter to the BAAS, to the effect that the Queen had given her permission for the association to take possession of the building.

The contrast between the response of the Royal Society and that of the BAAS to the Kew offer is dramatic: whereas the Royal Society's discussions took nine months, the BAAS made the decision at the same meeting at which the availability of the building was announced and took possession of the observatory just over two months later. This further strengthens the possibility that Sabine had given up on the Royal Society as a probable lost cause long before the formal rejection on 10 March – and even that he had prepared the ground with colleagues on the BAAS Council well before the meeting on 28 March. But without a record of what was actually said at the meetings we cannot know for sure. Certainly there is no record in the BAAS Council Minutes of anything being discussed about Kew Observatory in the months prior to 28 March 1842.

Decisions by the BAAS Council to take on new projects normally had to be sanctioned at an Annual Meeting of the Association. On this occasion, however, the Council resolved to take possession of Kew well before the 1842 Annual Meeting, held in Manchester in late June of that year. This may have been to avoid doubts creeping in if proceedings were delayed, as had happened at the Royal Society, or to

[56] BAAS 1842 'prospectus' for Kew Observatory, reprinted in Scott (1885), pp. 50-52.
[57] BAAS:CM, 28 March 1842.

pre-empt any dissent at the Annual Meeting. The acquisition of Kew was duly announced to the membership and wider public at the Annual Meeting on 22 June and it was approved with no recorded dissent. Even more telling was the vote of £200 to 'be placed at the disposal of the Council for upholding the establishment in the Kew Observatory'.[58] Not only was this a very different sum of money from the approximately £32 a year suggested by the Royal Society; the phrase 'upholding the establishment' is suggestive of a permanent, or at least long-term, institution. And indeed, the BAAS voted similar sums of money for Kew over the next few years: £200 in 1843[59] and £150 in 1844[60] and 1845.[61] Most importantly, this annual vote was not a government grant but was from the BAAS's own limited resources, which further underlines the commitment given to the project by Sabine, Wheatstone and the others on the BAAS Council. In the early to mid-1840s the BAAS made no proposals to apply for government funding for Kew; nor is there evidence of any such proposals being considered at this stage. It was purely a privately-funded project.

John Herschel seems to have played no part in the British Association's acquisition of Kew Observatory. In fact, the BAAS made more than one appeal to his authority during this time, not only to seek his advice, but also, one feels, to obtain the backing of someone who was seen as the leading figure in the physical sciences in this period, as noted in Section 2.4 above. This was certainly the tone of BAAS general secretary Roderick Murchison's letter to Herschel of June 1842, imploring him to attend that month's BAAS Annual Meeting: 'On this occasion your presence would be doubly useful in helping us to give birth to the child which you have so large a share in creating – the Kew Observatory of Physical Science'.[62] Herschel did attend this meeting, but he did not become personally involved in any BAAS committees on Kew. In reply to a letter from Wheatstone enclosing a draft of his prospectus for Kew Observatory, he expressed no particular disagreements with the project and thought that the observatory would be useful for experimental work, but he was rather cool towards the whole idea. It seemed to Herschel 'not very clear' that the British Association's plan for Kew as a physical observatory would

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[58] BAAS:AR, 1842, p. xxii.
[59] BAAS:CM, 25 September 1844.
[60] BAAS:CM, 17 June 1845.
[61] BAAS:AR, 1845, p. xviii.
[62] Murchison to Herschel, 16 June 1842, RS:HS 12.385.

work. He doubted whether the BAAS had adequate funds to support a physical observatory that did long-term, systematic observations for the production of data useful in theoretical work.[63] We should remember, though, that he might well have had the same doubts about the Royal Society wanting such a heavy annual budget commitment. Moreover, as in 1840 he now also questioned whether ‘the locality is fitted’ (Herschel’s emphasis) for such purposes.

But perhaps the main reason why Herschel did not want to become too closely associated with Kew was that by now he was reluctant to become heavily involved in the management of large scientific projects generally. Always preferring to do research in a private capacity without any obligation to larger organisations, or committing himself to regular, time-consuming work, Herschel was now fifty years old and anxious to settle down to the mammoth task of writing up the results of his astronomical observations at the Cape of Good Hope while he still had time and physical energy left. In the same June 1842 letter to Wheatstone, he expressed the wish to confine himself to ‘general advocacy’ of scientific projects except for those that he felt particularly passionate about, ‘now … that I can calculate on but very few years more of scientific efficiency’.[64] The BAAS was left to commence its programme of observational work at Kew without Herschel’s active involvement, as I shall describe in Section 2.6.

2.6 Francis Ronalds, meteorology and atmospheric electricity at Kew

The BAAS lost little time in preparing the newly acquired building for work. In July 1842 a committee was appointed ‘to superintend for the present the arrangements at the Kew Observatory’. This consisted of Wheatstone, the two general secretaries of the Association (Murchison and Sabine) and the treasurer.[65] In charge of the day-to-day work at the observatory for its first ten years under the BAAS, and the first individual to be known as the observatory’s ‘superintendent’ (the pre-1840 equivalents were known as ‘King’s Observers’) was Wheatstone’s fellow telegraphy pioneer, Francis Ronalds. Nothing is recorded in the papers of Ronalds or the BAAS as to how Ronalds, now in his fifties, was appointed to direct the Association’s

[63] Herschel to Wheatstone, 17 June 1842, TNA:BJ 3/26.
[64] Herschel to Wheatstone, 17 June 1842, TNA:BJ 3/26.
[65] BAAS:CM, 14 July 1842.

flagship institution, though by the early 1840s he was respected in scientific circles and had known Wheatstone for many years. It is possible that Wheatstone suggested Ronalds' appointment, for as early as November 1842 Ronalds wrote him a long letter, setting out his objectives for the Kew 'project', including electrical apparatus and meteorology.[66] According to an autobiographical letter dated 1860, Ronalds was indeed offered the post by the BAAS: keen to return to his interests in electricity and meteorology after a number of distractions, he 'accepted the honorary direction of the hardly more than projected Meteorological Kew Observatory under the auspices of the British Association'.[67] Ronalds was from a comfortably-off family of cheese merchants and appears to have funded his own researches[68]; it is an indication of the Association's limited budget that, unlike all the later superintendents at Kew, Ronalds' post had no salary attached. That Ronalds did not require a salary must have made his appointment attractive to the BAAS committee, with its very small initial budget of £200.

In January 1843, the BAAS Council announced that it had employed an assistant, John Galloway, at an annual salary of £27 7s 6d to take care of the observatory, to help the researchers 'and to obey to the best of his ability whatever instructions he may receive from time to time'. Galloway was initially paid a salary of £27 7s 6d and was arranged living accommodation in the building.[69] From the beginning he was much more than a caretaker. From 1 November 1842, he used instruments purchased by the BAAS to keep a 'meteorological register',[70] a traditional manual record of meteorological observations. We have no formal record of Galloway's background or what, if any, scientific training he possessed, but in his 1844 report to the BAAS Ronalds describes a new anemometer, attached to which is a 'sentry box', 'the invention of Sergeant Galloway, who made nearly the whole instrument'.[71] Given that Edward Sabine employed soldiers to perform the day-to-day instrument readings in his colonial magnetic observatories, it is quite possible that Galloway was a soldier or ex-soldier recruited by Sabine from among his subordinates in the Royal Artillery at Woolwich. This possibility is greatly

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[66] Ronalds to Wheatstone, 16 November 1842, IET S.C.Mss.1/4/17b.

[67] Ronalds to Carter (first name unknown), 21 February 1860, University College London Archives, GB 0103 MS ADD 206. I am grateful to Beverley Ronalds for this source.

[68] Symons (2004).

[69] BAAS:CM, 12 January 1843.

[70] BAAS:CM, 12 January 1843.

[71] Ronalds (1845), p. 129.

strengthened by Ronalds' earlier remark to Wheatstone that 'I suppose that the Artillery Sergeant could do some of the heavier work which might be wanted'.[72] This further strengthens the centrality of Sabine to the whole project. It is also an example of military personnel being used as low-cost labour to gather scientific data and even build their own equipment, as happened earlier in the 1830s when Coastguard officers were used to take data for William Whewell's tidal research.[73]

According to Ronalds' 1844 report, the meteorological record begun by Galloway measured temperature, pressure, humidity, rainfall, wind speed and wind direction. Observations were made at least twice a day, 'almost exclusively by Mr. Galloway'.[74] It is notable that from the beginning, high-quality instruments were used. When they could not be afforded, they were borrowed, as with a 'mountain' (portable) barometer 'lent by Colonel Sabine until we can afford the expense of a standard instrument'. Even more important, from the beginning of his reports Ronalds showed a critical attitude to both his instruments and his observations. Where possible, instruments of different types were used at the same time and results compared. Those whose accuracy was found to be wanting were dropped. With regard to the observations, Ronalds praised Galloway's efforts, but reflected that 'had our habits and qualifications been always adequate to the attainment of extreme accuracy, our instruments and other means would have been far from being so'.[75] This comment suggests that, according to Ronalds, the instruments were only as good as the less-than-perfect observers who used them. It is clear that Ronalds was trying to do meteorology to the highest possible standard of accuracy, perhaps higher than had hitherto been achieved anywhere else.

The second item in the 1842 prospectus suggested that Kew should become a centre for building and testing self-recording meteorological instruments. Automatic meteorological instruments were nothing new by 1842: self-recording barographs and thermographs, automatically recording observations on rolls of paper, had been in occasional use since the late seventeenth century.[76] However, automation of meteorological (and astronomical) observations was coming into vogue by the 1840s, as the new technologies of telegraphy and photography greatly extended the

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[72] Ronalds to Wheatstone, 16 November 1842, IET S.C.Mss.1/4/17b.
[73] Reidy (2008), pp. 169-172 and 281-293.
[74] Ronalds (1845), p. 131.
[75] Ronalds (1845), p. 131.
[76] Middleton (1966), pp. 41-42.

possibilities in this field. 1839, the year in which Louis Daguerre and William Henry Fox Talbot first announced their photographic processes, also saw the demonstration of a barograph that recorded a trace onto photographic paper. In the same year, Scottish astronomer John Pringle Nichol called for photographic registration to be used more widely in meteorological observations.[77] In 1844 the BAAS Council authorised the expenditure of £30 for the purchase of a top-quality self-recording barometer by Karl Kreil of Prague, and a further £25 was spent on transferring it to Kew[78] – a further sign of the Association's commitment to using the very best instruments at the observatory. Even more impressive was Wheatstone's 'Electro-magnetic Meteorological Register', which automatically recorded 1,008 observations per week. It contained instruments for recording temperature, pressure and humidity, each of which was activated in turn, when a wire connected to the top of the mercury in the instrument sent a signal to two type wheels, which printed the instrument reading in figures. Yet although Wheatstone's six-foot high device was pioneering and must have been a spectacular example of instrumental innovation and prestige at Kew,[79] it did not replace traditional meteorological observations and instruments. Rather, it was experimental in nature. Although experimentation was clearly on the agenda, Kew was becoming at least as much a central meteorological observatory as it was an experimental station.

From the summer of 1843, Ronalds and Galloway also began to make observations of atmospheric electricity, which had been stated as a clear objective in both the 1840 proposal and the 1842 prospectus. These electrical observations were recorded along with the traditional meteorological readings and take up about half of the columns of the meteorological register as reproduced in the 1844 *Annual Report*. The observations were made in the observatory dome; according to Ronalds' 1844 report, the instruments used to make the measurements were attached to the base of a conductor, a sixteen-foot long tube of copper placed vertically so that it protruded twelve feet above the dome's outer surface. Observations were made four times a day of the intensity of electric charge and whether this was positive or negative. In addition, a maximum and minimum charge was noted, based on hourly observations between 12 noon and 10 p.m., and an attempt was also made to relate the electric

[77] Middleton (1964), pp. 319-320.
[78] BAAS:CM, 17 June 1845.
[79] Anderson (2005), pp. 92-3.

charge to the type of weather.[80] These electrical observations must have made for a demanding routine, for in addition to the meteorological readings Galloway had to read the electrical instruments 'every day from half an hour before sunrise until night'. In return for this his salary was increased to one guinea per week, or almost double his original remuneration,[81] which demonstrates how seriously the BAAS, with its limited budget, was taking this work.

On a first reading, Wheatstone's 1842 prospectus – unlike the 1840 proposal – makes no provision for magnetic observations at Kew. It merely mentions that the observatory could be used as a place for the storage of magnetic instruments and training in their use. But the prospectus clearly did not preclude systematic observational work, for even the electrical observations are described therein only as 'experiments on atmospheric electricity'.[82] In any case, the electrical observations had an important connection with geomagnetism, for according to the 1843 *Annual Report*, the committee in charge of the observatory noted that atmospheric electricity had been given priority 'on account of its importance in connexion with the system of simultaneous magnetic and meteorological observations now making on various points of the earth's surface, in the recommendation of which the Association has taken so prominent a part.'[83] Thus from the very beginning, Kew Observatory was playing a direct part in the Magnetic Crusade. Moreover, as early as November 1842, in a list of meteorological instruments he said were needed at Kew, Ronalds had asked for 'Dipping & Variation needles'[84] and his 1844 report includes an as yet empty column in his meteorological register 'intended for the deviations of the electro-magnetic needle',[85] strongly suggesting that at least basic magnetic observations were being planned for the near future, perhaps when funding for instruments was forthcoming. Sabine may even have applied for a grant from the BAAS for magnetic work at Kew in 1842 – something not mentioned in the prospectus – for a private letter from Wheatstone mentions a 'proposition for the grant for the magnetic instruments'.[86] Magnetic observations were introduced to Kew gradually in the mid-1840s; not surprisingly, the instigator was Sabine. They

[80] Ronalds (1845), pp. 121-126 and 130-131.
[81] BAAS:CM, 1 December 1843.
[82] Scott (1885), p. 51.
[83] BAAS:AR (1843), p. xxxix.
[84] Ronalds to Wheatstone, 16 November 1842, IET S.C.Mss.1/4/17b.
[85] Ronalds (1845), pp. 130-131.
[86] Wheatstone to Sabine, 24 June 1842, RS:Sa.1779.

were initially made with self-recording instruments devised by Ronalds, contemporaneously with similar instruments built for Greenwich by Charles Brooke (see Chapter 3, Section 3.4). It seems, therefore, that the 1842 prospectus, with its emphasis on experimentation, did not prevent Sabine from slipping his beloved magnetic observations into Kew by the back door.

2.7 Conclusion

By the mid-1840s, the BAAS Council could claim to have established at Kew a 'physical observatory', dedicated to meteorological observation, work in atmospheric electricity and experiments with new types of self-recording instruments; indeed, as we have seen, Wheatstone used precisely this phrase in his 1842 prospectus for the observatory. Yet from the above we can see that only up to a point was it a physical observatory of the kind proposed by John Herschel. While aspects of it – meteorology, atmospheric electricity and experimental work – were certainly Herschelian, it was clearly not the central observatory that Herschel had in mind, which would also have incorporated fundamental work such as tides and sea levels and, in Herschel's view, would have been a government institution, not privately run by the BAAS (or the Royal Society). This goes a long way towards explaining why Herschel was equally lukewarm about Kew with both the Royal Society and the BAAS: the building at Kew was in entirely the wrong location for his idea of a physical observatory and both organisations, he felt, were incapable of supporting such an institution financially.

There is a strong case that the prime mover behind the whole Kew project, at every stage from June 1840 onwards, was not Herschel but Sabine. As we have seen, Sabine had a motive: to wrest control of the magnetic and meteorological observations from his arch-rival, Airy. The hand of Sabine is visible time and again throughout the story. That Sabine was behind the 1840 proposal is strongly suggested by the moves behind the scenes in the summer of that year. It was Sabine who, early in 1841, first let the Royal Society know of the availability of the Kew Observatory building and who then, seeing the Society's lack of enthusiasm, was one of those who took the project to the BAAS, perhaps deliberately steering it towards the latter organisation. At any rate, Kew in the mid-1840s was a permanent 'establishment' (the BAAS's own word) and was essentially a meteorological observatory, having as a central part of its programme observations of atmospheric electricity tied to the Magnetic Crusade – carried out, moreover, by a soldier from Sabine's own regiment. In other words, it pursued an agenda consistent with the 1840 proposal for a magnetic, meteorological and electrical observatory independent of Greenwich, as far as was possible in the absence of government funding. Indeed, some years later Sabine confessed privately to the meteorologist and astronomer William Radcliff Birt (who later became associated with Kew – see Chapter 3, Section 3.2) that the government, by means of 'observations at Greenwich', had 'undertaken to do, and in the most efficient manner what we wished to have done at Kew but what we have never been able to accomplish except in a degree very inferior to our wishes'.[87] Sabine, 'the artful dodger of the British scientific establishment',[88] again manipulated both the Royal Society and the BAAS towards his own agenda. While it is easy to see the establishment of an alleged 'physical observatory' at Kew as a straightforward realisation of Herschel's dream, in reality the story is more complex.

Although Sabine bemoaned the lack of government funding, this had an important bearing on the post-1845 history of Kew Observatory. Because Kew was privately funded, Sabine and others involved with the observatory had no obligations to the government and so were free to pursue their own agenda. As we will see in Chapter 3, later in the 1840s Kew was to suffer more than one threat to its existence. Yet the fact that Kew had to seek its own sources of income forced Sabine and his colleagues to broaden the range of observatory sciences practised there – with the result that, by the end of the 1850s, Kew would be an internationally famous institution of Victorian science.

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[87] Sabine to Birt, 25 May 1848, RS:Sa.1176.
[88] Reingold (1975), p. 51.

Chapter 3

Survival and expansion: Kew Observatory, the Government Grant and standardisation, 1845-1859

> Accept my best thanks for your kind attention in procuring for me that “sinew of Science” Cash.
>
> Francis Ronalds to Edward Sabine, 1846.[1]

> The Committee are glad to have an opportunity to testify to the increasing utility of the operations at the Kew Observatory, in the very laborious verifications, by Mr. Welsh, of the twenty sets of Meteorological Instruments intended by the East India Company for proposed meteorological observations in India.
>
> Report of the Kew Committee, read at BAAS Council Meeting, 31 January 1852[2]

3.1 Introduction

The phrase ‘sinew of science’, used by Francis Ronalds in the first epigraph above, nicely encapsulates a central problem of Kew Observatory (Fig. 3.1) in its early years: lack of money. As we saw in Chapter 2, in the 1840s the observatory was supported entirely by the BAAS’s limited funds. More widely, the phrase illuminates the first of the fundamental questions outlined in Chapter 1: the issue of how the physical sciences were organised in the nineteenth century, and, in particular, the question of who should foot the bill. In this chapter I hope to use Kew Observatory as a case study in the scholarly debate on the patronage of science in the mid-nineteenth century.[3] I show how the observatory, which in the mid-1840s had an annual budget of (at most) £200 and a restricted (albeit very definite) programme of work, was over the next decade transformed into an internationally-recognised institution whose budget had almost quadrupled. By the mid-1850s, moreover, part

[1] Ronalds to Sabine, 4 April 1846, IET S.C.Mss.1/4/17b.
[2] BAAS:CM, 31 January 1852.
[3] MacLeod (1971a) and Alter (1987) both deal with the patronage of science in the mid-nineteenth century. For a more general discussion of the scholarly literature in this field, see Chapter 1.

of its work was self-financing and on a commercial basis. The observatory was by then headed by a full-time, paid superintendent with scientific qualifications. In this chapter, I show how this transformation happened.

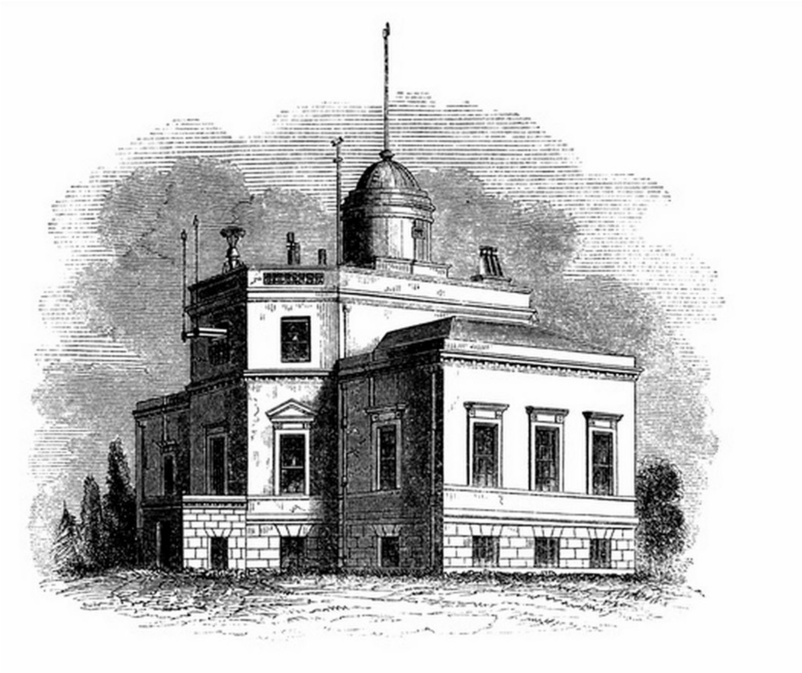

Figure 3.1 An engraving of Kew Observatory made in 1851. Image courtesy Royal Astronomical Society.

I have split my analysis into three broad thematic headings. In Section 3.2 I discuss how Kew Observatory survived several threats of closure in the 1845-1852 period. This was partly due to Edward Sabine's political astuteness: as during the moves to acquire Kew for the BAAS, described in Chapter 2, Sabine presented an official mission for the observatory that was politically acceptable while all the time pursuing his private agenda for a magnetic and meteorological observatory independent of Greenwich. The advent of the Government Grant in 1850 helped the observatory to survive – though not in the sense of the government supporting it with an annual grant. Rather, it will become clear that the BAAS Council may have delayed closing the observatory in anticipation of government support that had not yet been publicly announced. A second important factor in saving Kew from closure was the introduction of instrument standardisation on a commercial basis. In Section 3.3 I show how from the early 1850s Kew Observatory began standardising meteorological instruments on a very large scale, so that by the end of the decade, hundreds of instruments were being verified at Kew each year, which brought the observatory a substantial extra income. The main customers for standardisation were the London instrument-making trade, the Admiralty and the Board of Trade's Meteorological Department, under its innovating first director, Robert FitzRoy. Kew also did much standardisation work for foreign governments and researchers. This varied and prestigious client base brought Kew respect far beyond the Royal Society and BAAS, so that by the end of the 1850s there was no talk of closing it down. In this section I thus begin to address our fundamental question (Chapter 1, Section 1.1) of the development of standardisation at Kew in the context of the culture of the physical sciences.

Also during the 1846-1859 period, the range of observatory sciences practised at Kew notably expanded from the limited programme of work that was in progress during the mid-1840s. In Section 3.4 I show how Sabine finally established his cherished magnetic work at Kew, so that by the late 1850s Kew was a world centre for geomagnetic observations. This diversified programme of geomagnetic and meteorological observations itself increased the observatory's prestige – as was demonstrated, for example, by a government-funded display of the Kew instruments at the 1855 Universal Exposition in Paris. I also show how this growing programme of work required extra staff, so that by the end of the 1850s Kew had several staff, some of them with a scientific training. Thus I address our fundamental question (Chapter 1, Section 1.1) of the development of the observatory sciences, by showing how Kew mirrored the trend, identified by David Aubin, of diversification in the range of sciences practised in the observatory during the mid-nineteenth century. Indeed, it will become clear that Kew did not merely follow this trend: taken with its work in standardisation, Kew itself became a prominent landmark in the mid-nineteenth century observatory sciences.

3.2 The survival of Kew Observatory, 1845-1852

As noted in Chapter 2 (Section 2.5), at its annual meetings from 1842 to 1845 inclusive, the BAAS consistently voted grants of between £150 and £200 for the running of Kew Observatory, in addition to occasional one-off payments for specific projects there. But at the 1845 meeting the BAAS General Committee passed the motion: 'That it be referred to the Council to take into consideration previous to the next Meeting the expediency of discontinuing the Kew Observatory.'[4] As is typical of the BAAS *Annual Reports*, no reason was given as to why this recommendation was passed. However, a report in *The Times* the next day noted that:-

> A long discussion took place upon the propriety of the discontinuance of the Kew observatory, on the ground that it had been ascertained that the observations there being carried on formed part of the subjects of observation at Greenwich. It appeared that the expenses of this establishment were 150*l*. per year, which the reduced funds of the association would not allow.[5]

The article was anonymously authored and it appeared in a national newspaper that had a long history of being critical of the BAAS.[6] It therefore speaks more freely than any report from within the Association, and even though we have no idea as to whether the author was present at the meeting or working from second-hand reports it offers more insight into what might have happened. A similarly anonymous report in the *Athenaeum* notes that the Council was asked 'to consider whether the Electrical Experiments at the Kew Observatory should not be discontinued'. The *Athenaeum* claimed that the decision had nothing to do with money, but again said that it had been taken because 'similar observations were now being made at the Observatory at Greenwich, under the superintendence of Prof. Airy'.[7]

It is certainly true that by the 1840s the BAAS, still reliant on income from subscriptions and voluntary donations, was finding it increasingly difficult to meet its financial commitments. It had always been the Association's policy to fund one-off projects in preference to permanent institutions (see Chapter 1, Section 1.2) and in the competition for grant money Kew had many rivals from across the whole range of sciences. But regardless of any financial motive, both these independent sources cite the same primary reason for considering closure: that Kew was duplicating work being done at Greenwich. We have no documentary evidence as to who originated the motion to close down Kew, but it is reasonable to speculate that this may have been another move by George Airy to put an end once and for all to this source of competition from the other side of London, just as he had forestalled the Royal Society's ill-fated attempt in 1840 to establish an independent magnetic

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[4] BAAS:AR, 1845, p. xviii.
[5] Anon., 1845a.
[6] Orange (1981), pp. 58-59; Howarth (1931), pp. 35-36.
[7] Anon., 1845b.

and meteorological observatory (see Chapter 2, Section 2.3). The 1845 Annual Meeting was held at Cambridge, where Airy had found his intellectual feet in the world of reformed Cambridge mathematics in the 1810s and 1820s.[8] Many of his old friends from the Analytical Society were present at this meeting and played leading roles – notably John Herschel, who served as President. Airy had been observing atmospheric electricity at Greenwich since at least March 1842,[9] so he could quite reasonably have claimed that the work at Kew was duplicating that at Greenwich. Nevertheless, it is easy to imagine Airy being in a strong position at the 1845 meeting to argue against the continuance of Kew Observatory.

There is no evidence that the June 1845 motion raised any particular alarm bells with Sabine or the other advocates of the Kew project. The BAAS Council only came round to the issue at its January 1846 meeting, when it appointed a committee 'to collect information on the scientific purposes which the Kew Observatory has served, and on its general usefulness to science and to the Association'. Herschel was to chair the committee; its other members were Airy, Thomas Graham (Professor of Chemistry at University College London), George Peacock (Airy's former Cambridge tutor, now Dean of Ely Cathedral), Sabine and Wheatstone.[10] Of these, all except Airy attended the January 1846 Council meeting at which the committee was appointed, suggesting that Airy might have been co-opted on the initiative of his friends Herschel and Peacock. The committee's only recorded meeting took place on 7 May 1846, again suggesting little sense of urgency about the matter. The fact that Herschel had to ask Wheatstone for directions to the observatory, the venue for the meeting, emphasises how little interest he had in the entire Kew project.[11] As well as Herschel and Peacock, the presence of Airy on the committee would presumably have been a force against continuing the observatory, but the committee also had two of the observatory's staunchest advocates: Sabine and his ally Charles Wheatstone, who had strongly supported the BAAS taking on the observatory in 1842.

According to the committee's report, signed by Herschel, it was 'unanimously' agreed that the observatory at Kew should 'be maintained in its

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[8] Warwick (2005), pp. 72-75.
[9] Astronomer Royal's Journal, 11 March 1842, RGO 6.24.
[10] BAAS:CM, 16 January 1846.
[11] Wheatstone to Herschel, 30 April 1846, RS:HS 18.151.

present state of efficiency'.[12] The surviving correspondence suggests that a report was written in advance by Wheatstone and then deliberated on at the meeting.[13] Wheatstone had also drafted the BAAS's original 1842 prospectus for Kew, which had emphasised its use as an experimental station, so it may not be surprising that many of the reasons given in 1846 for keeping the observatory read almost like a repeat of those stated four years earlier for taking it on in the first place. The report emphasised the building's use as a convenient premises for the BAAS and as a repository for its instruments. The observatory was currently being used for 'inquiries into the working of self-registering apparatus', which were now bearing fruit. Similarly fruitful was Ronalds' ongoing study of atmospheric electricity: the report noted that this had 'in effect furnished the model of the processes conducted at the Royal Observatory'. More tellingly, the report noted that the BAAS's occupancy of the building was at the Queen's pleasure and a sign of her interest in and approval of scientific research and that if it were handed back now it might never again be available to science.[14] There is an echo here of the March 1842 BAAS Council meeting, at which the urgency of applying for use of the building was emphasised, lest the chance be missed (see Chapter 2, Section 2.5). The report was accepted, with no recorded debate, by the BAAS Council at its meeting in London the next day[15] and the decision to keep Kew Observatory running was ratified at the Annual Meeting in Southampton the following September. This meeting also duly renewed the observatory's annual £150 grant.[16]

That Airy, as a member of the committee, agreed to keep Kew running might seem inconsistent with the idea that the Astronomer Royal saw Kew as competition to Greenwich and so wanted to see it closed. But the committee's report, rather in the same way as the 1842 prospectus had emphasised the usefulness of Kew as a place for experimental inquiries rather than as a permanent establishment, only recommended that the electrical observations and experiments with self-recording instruments be kept going. Almost nothing was said about the magnetic and meteorological work that was central to Sabine's own agenda. In this light Airy

[12] Report, dated 'Kew Observatory, May 7, 1846' as reprinted in Scott (1885), pp. 54-5. The report is also printed verbatim in BAAS:CM, 8 May 1846.
[13] Herschel to Sabine, 20 April 1846, TNA:BJ 3/26. Wheatstone's report is also mentioned in Herschel to Airy, 29 April 1846, RGO 6/401/193.
[14] Report, dated 'Kew Observatory, May 7, 1846' as reprinted in Scott (1885), pp. 54-5.
[15] BAAS:CM, 8 May 1846.
[16] BAAS:AR, 1846, p. xx.

might have regarded Kew as a useful technical laboratory in support of Greenwich, with Ronalds giving invaluable advice on making and using apparatus for electrical observations. Indeed, two years later Ronalds claimed that Airy gave exactly this reason for agreeing to the continuation of the Kew observations in 1846: 'that they should serve as Tests for newly invented meteorological Instruments & Experiments'.[17] In any case, during 1845 and 1846, Airy had many other matters to worry about: he was heavily involved with work for the Railway Gauge Commission, set up to determine the standard gauge for Britain's rapidly-expanding railway network; at the time of the meeting at Kew on 7 May one of his Greenwich assistants was on trial at the Old Bailey for incest and murder; and in late September 1846 the Berlin astronomers Johann Galle and Heinrich D'Arrest announced the discovery of a new planet, Neptune, an announcement quickly followed by allegations of inaction on the part of Airy over predictions of the new planet's position sent to him by Cambridge mathematician John Couch Adams the previous year.[18] If Airy saw Kew as a problem at all at this stage, it would likely have been as but one problem among many.

Nothing further regarding the future of Kew Observatory appears on record for most of the next two years. Then, in April 1848 the Council asked the committee that had met in 1846 'to prepare a Report on what has since been done, and on the present state of the Observatory', in order to establish whether it was worth 'continuing the present expenditure' on the observatory. This time the initiative seems to have come from the Council and not the Annual Meeting, which was not held until August of that year. It is unlikely to have come from Airy, who was not present at the April meeting and was not a Council member. The minutes do, however, record the co-option to the committee of Leonard Horner (1785-1864).[19] Horner's main interests were geology and the improvement of working-class education; he had also served as the most energetic of the four commissioners appointed to enforce the 1833 Factory Act which attempted to limit the use of child labour in factories. Given the BAAS's limited budget and the £150 a year that it was

[17] Ronalds to Sabine, 30 June 1848, RS:Sa.1087.
[18] There is a very large literature on the 'Neptune scandal'. Of particular relevance to the pressures on Airy in 1846 is Chapman (1988a), pp. 124-126; and Smith (1989), pp. 401 and 410-411.
[19] BAAS:CM, 14 April 1848.

costing to run Kew Observatory, Horner might well have felt that the Association had more urgent priorities.

The 1848 motion caused much more consternation than that of 1846, triggering a vigorous correspondence between Ronalds, Sabine, Herschel and a meteorologist and astronomer who by 1848 was well-known in the physical sciences community but had had little direct involvement with Kew up to then: William Radcliff Birt. Self-taught in the sciences (as far as is known), Birt was an amateur astronomer eagerly looking for a paid job in the field of his hobby. In 1842, soon after the news had appeared of the BAAS's acquisition of Kew, Birt had sought a testimonial from Herschel in support of his application for the 'curatorship' of the observatory.[20] In the late 1830s Birt's work in both astronomy and meteorology had caught the eye of Herschel, especially his proposal for a long-term series of observations to detect 'atmospheric waves' – pressure waves which some, including Herschel, believed might help explain the circulation of the atmosphere, something that was poorly understood at the time. Between 1839 and 1843 Herschel supervised Birt in a project, supported by a £50 grant from the BAAS, to reduce meteorological observations with a view to verifying the existence of these waves. This resulted in several papers in the BAAS *Annual Reports* in the 1840s and beyond. Vladimir Jankovic has shown how the theory of atmospheric waves became discredited after the late 1840s, when it gradually became apparent that there was no real evidence for the waves and the emphasis of meteorology had changed from theory-driven research to practical, utilitarian work in support of the navy and merchant shipping.[21] But in the 1830s and 1840s Birt's work impressed Herschel because it resonated exactly with Herschel's own approach to research: that data should be gathered not for its own sake but for the purpose of putting theory to the test. Later, he was to praise Birt's analysis of the Kew observations of atmospheric electricity as an 'interesting and thoroughly <u>inductive</u> discussion of a mass of obsns.'[22] – words which might have been taken out of Herschel's *Preliminary Discourse*.

In May 1848, just six weeks after the future of Kew was again put under review, Birt wrote to Herschel to say that the possible impending closure of the observatory would terminate the five years' worth of electrical observations made

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[20] Herschel to Birt, 13 June 1842, RS:HS 19.96.
[21] Jankovic (1998), esp. pp. 34-39.
[22] Herschel to Birt, 1 August 1849, RS:HS19.138.

there so far and that the work might therefore be for nothing if the observations were not continued and discussed 'with the view of attempting the deduction of laws'. Birt offered his services in continuing the electrical observations and photographic registrations as well as work on the reduction of the electrical results, 'under the superintendence of Mr. Ronald [*sic*].'[23] Herschel agreed with Birt's rationale for keeping Kew Observatory going. He recommended to Sabine that in addition to continuing the observations there, 'those already accumulated should be discussed with scientific precision' (Herschel's emphasis) and that Birt's 'liberal offer' of undertaking the work should be accepted. He acknowledged that the financial situation was difficult for the BAAS, but that 'the Association ought not, except on very urgent grounds, to throw up the observatory'. It is a sign of the authority that Herschel commanded that the conclusion of his letter to Sabine reads almost like a military order: 'Should it not be in my power to attend at the Council ... you will oblige me by communicating this statement of my views ... and by reading the letter enclosed.'[24]

Sabine, however, was less sure about taking on Birt. For one thing, Sabine claimed that astronomy was Birt's real passion, much more than meteorology.[25] Moreover, at some point between 24 May and 17 June 1848, it became clear that Birt would require a salary of £100 per annum, thus putting an even greater strain on the observatory's tiny budget.[26] Ronalds hoped that Birt might take the place of the existing assistant, John Galloway, because Ronalds wanted a 'properly qualified' observer, who in addition to routine reading of the instruments could do the more complex work that now needed to be done, such as reducing the results.[27] But the proposed salary for Birt was nearly twice the £54 paid annually to Galloway. Little is known of Birt's personal life,[28] but he was clearly of a different class and career background from the ex-Artillery Sergeant Galloway. The latter was expected to clean and maintain the building, so if he were replaced by Birt, someone else would have to be employed 'to perform the menial duties of the house'.[29] Sabine, not

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[23] Birt to Herschel, 24 May 1848 (copy), RS:Sa.164.
[24] Herschel to Sabine, 1 June 1848, RS:Sa.656.
[25] Sabine to Herschel, 3 July 1848, RS:HS15.224.
[26] Sabine to Herschel, 17 June 1848, RS:HS15.222.
[27] Ronalds to Sabine, 30 June 1848, RS:Sa.1087.
[28] For short biographies of Birt, see: Hutchins (2004); Anon. (1882a); Anon. (1882b).
[29] Sabine to Herschel, 3 July 1848, RS:HS15.224.

surprisingly, preferred the existing arrangement of a ‘Servant’ living on the premises and doing some basic observing as well as ‘work of a menial nature’.[30]

The committee that had been reconvened in April 1848 met at Kew on 5 July and reported to the BAAS Council meeting two days later. The 5 July meeting was held in response to a lengthy report sent by Ronalds, apparently at Sabine’s request, on what had been achieved at Kew Observatory since 1846 and his views on its future, assuming that the committee and Council voted to continue it. Ronalds emphasised the differences in the work at Kew from that at Greenwich: in particular, the ‘unique’ observations of atmospheric electricity, which took a much wider variety of measurements than the Greenwich programme, and Kew’s far superior self-recording magnetic and meteorological instruments. If the observatory could not be kept running as it was (albeit with a better-qualified observer than Galloway), Ronalds asked that it at least be kept on as a depot for instruments. Failing this, he suggested, the Association could give up the building entirely, ‘recommending that it may be supported on a sufficient Basis for using it as a Proving House &c ..., by Her Majesty’s Government’.[31] By ‘Proving House’ Ronalds meant a place for testing and comparing meteorological instruments, something suggested in the original 1842 prospectus. We do not have the committee’s report this time, but the minutes of the Council meeting on 7 July suggest that the Council took up Ronalds’ recommendation for government support, for the committee was now asked to draw up a memorandum to the Treasury, asking ‘that means might be taken to preserve to the nation the benefit of the establishment of the Observatory at Kew’. The memorandum was to state that the observatory’s running costs, though not large, were beyond the means of the BAAS and that the immense value of the work at Kew meant that there was a duty to maintain it.[32]

The idea that Kew Observatory should be a central, government-supported ‘proving house’ may not originally have been Ronalds’. In late June Sabine had very strongly hinted at this to Herschel with his view that Kew could be turned into a ‘head quarter establishment’ for instrument trials and comparisons as well as for magnetism and meteorology.[33] Herschel dismissed this idea at the 5 July committee

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[30] Birt to Sabine, 4 July 1848, RS:Sa.168.
[31] Ronalds to Sabine, 30 June 1848, RS:Sa.1087.
[32] BAAS:CM, 7 July 1848.
[33] Sabine to Herschel, 23 June 1848, RS:HS15.223.

meeting, but two weeks afterwards he confessed to Sabine that he may have been too 'hasty', now that the proposal to apply to government had been taken up by the Council. He now asked Sabine to draw up a draft of the proposed memorandum.[34] In his reply, Sabine wrote of the need for a government 'establishment' for coordinating and reducing observations, due to a likely increase in the volume of meteorological and other observations coming in from the outposts of the British Empire.[35] Herschel's response began abruptly:-

> I cannot give my support to an application to Govt to take on itself the support of the Kew Observatory because I am not sufficiently impressed with the scientific necessity of such an establishment unconnected with the peculiar objects which made it desirable for the British Association as their private property.

Herschel declined to attend any meeting for the purpose of drawing up a memorandum to the government.[36] John Cawood has claimed that by the 1840s, Herschel had become exasperated with what he saw as Sabine's obsession with data gathering, which conflicted with Herschel's theory-driven approach to all scientific enquiry.[37] In Sabine's plan for a centre for coordinating observations, he might have seen another example of this.

Herschel's views were reflected in the next report of what had now become known as the 'Kew Observatory Committee'. This was presented to the BAAS Council in August 1848, at the start of that year's BAAS annual meeting in Swansea. The report – which was signed by Herschel – claimed that the Association could not continue the observatory even for another year on its current restricted budget, and that to pursue 'some of the most important objects which have all along been contemplated in its occupation' – including the standardisation work outlined in the 1842 prospectus – would be quite beyond the means of the Association. The report noted the possibility that the government would require some such central institution in the future, but concluded that the committee saw no option but to discontinue Kew as soon as possible and seek 'the most fitting mode of procedure for resigning it into the hands of Government'.[38] The decision to discontinue the observatory was duly

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[34] Herschel to Sabine, 21 July 1848, TNA:BJ 3/26.
[35] Sabine to Herschel, 25 July 1848, TxU: 32.20-23 (M0523.6).
[36] Herschel to Sabine, 31 July 1848, RS:Sa.657.
[37] Cawood (1979), pp. 514-515.
[38] Report of the Kew Observatory Committee, in BAAS:CM, 9 August 1848.

approved a week later at the Annual Meeting, when the Council was authorised to start closing it down. Birt was awarded a one-off grant of £50 for the reduction of the Kew electrical observations, but the observatory's annual grant was reduced to just £100, presumably for the purpose of winding it down.[39]

By January 1849 Galloway had been dismissed, presumably in anticipation of closing the observatory, but the Council made no move at this or any other meeting to hand the building back to the government. Instead, the Council resolved to continue the observatory 'in its present state' until the next annual meeting in September, when the question of its continuance would again come under the scrutiny of the wider British Association.[40] In the event, the 1849 annual meeting voted to continue Kew for another year, substantially increasing the grant to £250, though on the strict understanding that its continuation beyond the 1850 Annual Meeting was not guaranteed.[41] A letter from Lord Northampton reveals that the vote was passed with the intention of handing the observatory over to the government 'in a year or two',[42] so this was less of a change in policy from 1848 than at first appears. The decision to abandon Kew was not overturned in 1849: it was merely deferred. It is possible that the Council members, despite the decision at the previous annual meeting, did not *want* to part with the observatory that had done, and was doing, so much good work and had greatly added to the prestige of the Association. In addition, the government's award, in the spring of 1849, of £250 to Francis Ronalds for his improvements to self-registering magnetic and meteorological instruments (described in Section 3.4) must have further raised the observatory's prestige and made it more difficult to put the case for closing it down. However, the documentary evidence suggests that it was Herschel who took the final decision to defer: the reason given for continuing the observatory, and increasing the grant, was that Herschel believed the Kew electrical observations to be 'peculiarly valuable, and likely to produce important results'.[43]

In October 1849, the Council agreed to appoint Birt to carry out the observational work at Kew, at a salary of £100 per annum. Again, Herschel seems to

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[39] Resolutions passed by BAAS General Committee, 16 August 1848, in BAAS:CM, 12 January 1849.
[40] BAAS:CM, 12 January 1849.
[41] Resolutions passed by BAAS General Committee at Birmingham on 19 September 1849, in BAAS:CM, 25 October 1849.
[42] Northampton to Herschel, 18 September 1849, RS:HS.5.277.
[43] BAAS:CM, 25 October 1849.

have been instrumental in the decision to take him on. His letter to Sabine one month before the 1849 Annual Meeting again has the tone almost of a command: 'I should be very glad that anything should turn up by wh. Mr. B's … zeal for meteorl. obsn & reduction could be made available to Science. A continuance ... of the Kew Electrical observations would no doubt be a desirable object, ...'[44] Birt started work at Kew on 2 November. Yet almost from the start of his employment Birt seems to have taken on more than he had bargained for. Since the dismissal of Galloway, there had been nobody to do the basic readings of the meteorological instruments as well as the electrical observations. As explained in Chapter 2 (Section 2.6), this made for a laborious routine, requiring observations to be made at regular intervals from early morning until late evening. This now fell to Birt, much to his chagrin. As early as 15 November he was complaining that he had been led to believe 'that it was not at all contemplated to carry on a regular series of observations here but to attend more particularly to such objects as the [Kew] Committee ... from time to time might determine on'. From the start Birt also clashed with Ronalds, who, Birt claimed in the same letter, behaved in an 'ungentlemanly' manner towards him.[45] This may have been partly a conflict of personalities, but in addition Birt did not seem to recognise Ronalds' authority as superintendent at Kew – something evidenced by Birt's correspondence, which describes his clashes with Ronalds in minute and sometimes remarkably petty detail. For example, Birt wrote that he was not allowed to alter the positions of any meteorological instruments in the observatory, despite none of them – according to Birt – being suitably positioned.[46] By late December, Birt was feeling that he had been employed at Kew as a servant, 'in precisely the same capacity as Mr Galloway'. The way he was treated seems to have caused him to have a nervous breakdown and Birt was unable to continue with the electrical observations.[47]

The situation at Kew at the end of 1849 was made worse by Sabine being taken seriously ill in November of that year, possibly with some kind of fever, which made it necessary for all communications with Sabine to go via his wife. The Kew Observatory Committee did not meet until 22 March 1850, when Sabine had

[44] Herschel to Sabine, 16 August 1849, TNA:BJ 3/84 (iv).
[45] Birt to Professor [John?] Phillips, 15 November 1849, RS:Sa.169.
[46] Birt to Herschel, 15 January 1850, RS:HS4.137.
[47] Eliza Birt (Birt's daughter) to Elisabeth Sabine (Sabine's wife), 28 December 1849, RS:Sa.158; Ronalds to Sabine, 22 March 1850, RS:Sa.1091.

recovered sufficiently. The Committee directed that Birt was to make electrical observations three times a day for five days per week, together with meteorological observations at the same time.[48] Things did not improve for Birt, however, and on 5 June he wrote to Sabine to say that he would not be willing to work at Kew after the end of his first year there, 'under present arrangements'.[49] To Birt's horror, Sabine accepted this letter as Birt's resignation with immediate effect from 5 June. In desperation, he wrote to his old mentor John Herschel, that Sabine had misinterpreted his letter. Herschel replied that he was 'exceedingly sorry' about what had happened, but, true to form, did not wish to become further involved. Shortly afterwards, Birt wrote that he had been refused an interview with Sabine and now acknowledged that his resignation was final.[50] He found little sympathy with other leading BAAS figures, due at least in part to Ronalds having friends in high places: in September John Phillips reflected that 'Mr Birt rues as we say in Yorkshire of his unnecessary haste, but too late'; later that month he looked forward to going to Kew to 'see my friend Ronalds again'.[51]

Birt's disastrous time at Kew might well have stemmed from a notion he might have had that routine observing would be a secondary aspect of his work and that he would be able to devote most of his time at the observatory to research projects, such as his beloved atmospheric waves. Birt strongly suggested this in his letter to John Herschel: 'the Association had entrusted to me the investigation and discussion of two very important subjects [analysis of atmospheric waves and electricity] in which as you are well aware I have been successful'.[52] Not long after arriving at Kew, he had written to Herschel that he was thinking of applying to the Royal Society for a grant of £50 to support his research on atmospheric waves.[53] But perhaps the main reason why Birt was so unhappy at Kew was that he had hitherto done all his scientific work in his own time and – except for occasional payments from Herschel and the BAAS – his own money. He had thus been free to pursue his

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[48] Minutes of Kew Observatory Committee, 22 and 25 March 1850, in BAAS:CM, 9 April 1850.
[49] Birt to Sabine, 5 June 1850, RS:Sa.179.
[50] Birt to Herschel, 14 June 1850, TxU: 29.20 (M0103); Herschel to Birt, 16 June 1850, TxU: 24.6 (L0100)); Birt to Herschel, 19 June 1850; TxU: 29.20 (M0104). Jankovic (1998), pp. 37-38, briefly describes Birt's time at Kew.
[51] Phillips to [Forbes] Royle, 11 September 1850, RS:Sa.995; Phillips to Royle, 25 September 1850, RS:Sa.996.
[52] Birt to Herschel, 14 June 1850, TxU: 29.20 (M0103).
[53] Birt to Herschel, 21 December 1849, RS:HS4.135.

own interests and choose a pattern of work that suited him. But as a professional meteorologist, working at an observatory and reporting to a superintendent, Birt no longer had this freedom. His frustration in this regard is very apparent in his letter to Phillips on 15 November 1849, in which he complained about having to do 'a regular series of observations' rather than one-off projects.[54] Birt had been taken on at Kew at the urging of John Herschel, who admired Birt's research methods because they appealed to Herschel's theory-driven approach. But Herschel's approach was not what was required at Kew. Sabine required a loyal subordinate in his ranks, who would dutifully take the data that Sabine wanted. Birt was not such a person.

Sabine and the Kew Committee would have had fewer doubts about Birt's successor. John Welsh was born into a middle-class family in south-west Scotland and educated at Edinburgh University, in part under James Forbes, one of the instigators of the Royal Society's original 1840 attempt to establish a magnetic and meteorological observatory (see Chapter 2).[55] Unlike Birt, he was used to working as part of a team in a highly disciplined environment and he also had much experience of the type of observational work being done at Kew. Since 1842 he had worked at the magnetic and meteorological observatory at Makerstoun, Scotland, run by Sir Thomas Brisbane, a former soldier and governor of the penal colony of New South Wales, where he had founded the Paramatta Observatory. Brisbane was a patriarchal figure who ran observatories rather like the colony.[56] According to an anonymously-written obituary, Welsh's appointment to Kew owed much to the then Chairman of the Kew Committee, William Henry Sykes, to whom he had been recommended by Brisbane and John Allan Broun, Welsh's immediate superior at Makerstoun.[57] Sykes had spent most of his working life with the East India Company: like Brisbane and Sabine, he was an army officer who had had scientific roles, in Sykes's case compiling statistics on British India. The obituary's claim is believable: Brisbane's recommendation would have been received sympathetically by his fellow soldiers, Sabine and Sykes. In addition, the timing of Welsh's availability was convenient, for in 1850 the magnetic and meteorological work at Makerstoun was closed down and Welsh made redundant. On 5 July 1850, less than

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[54] Birt to Professor [John?] Phillips, 15 November 1849, RS:Sa.169.
[55] Hartog and McConnell (2008).
[56] Schaffer (2010) esp. pp. 120-125; Sweetman and McConnell (2004).
[57] Anon. (1859), p. xxxiv.

a month after Sabine took Birt's expression of dissatisfaction as his resignation from his post, the Kew Committee decided to employ Welsh at Kew.[58]

Aged just 25 at the time of his appointment, Welsh immediately settled into his new job. By late 1850 he had commenced a series of daily experiments on atmospheric electricity – work of the sort that had so troubled Birt. Subsequent Kew Committee reports are almost gushing in their praise of Welsh, as in: 'The zeal and intelligence with which Mr. Welsh has continued to execute his duties has given the Committee unmixed satisfaction'.[59] Ronalds remained as honorary superintendent at Kew, though he resigned in late 1852, after which Welsh took over the running of the observatory. Neither the BAAS Council minutes nor the minutes of the Kew Committee contain any record of Ronalds' resignation or his reasons for leaving, though it may well be connected with the death of his mother (Ronalds never married) and his acceptance of a Civil List pension in honour of his scientific work.[60] Also, in his autobiographical letter Ronalds claimed to have been 'annoyed & oppressed at Kew' by 1852, perhaps because by then, as we shall see below, the emphasis and extent of the work at Kew was very different to that when Ronalds had arrived in 1842.[61]

Although the observatory's long-term future was by no means secure, in October 1849 the committee originally appointed in 1846 now effectively became permanent. The committee's brief was now 'visiting and exercising a general superintendence' over the activities at Kew.[62] Known in the Council Minutes since August 1848 as the 'Kew Observatory Committee', in May 1850 its name was shortened to 'Kew Committee', by which title it was known for the rest of the BAAS's tenure of the observatory – and also after the Royal Society took it over in 1871. Welsh was appointed as the 'Observer at Kew',[63] a title reminiscent of that of 'King's Observer' used to describe the director of the observatory when it was George III's private establishment. Such language, like the phrase 'Kew

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[58] KCM, 5 July 1850.
[59] BAAS:CM, 29 November 1852.
[60] In August 1852 he expressed great anxiety to wind up his financial transactions in connection with Kew and 'great need of relief from matters of this kind' due to illness and family matters. Ronalds to Sabine, 9 August 1852, RS:Sa.1093.
[61] Ronalds Autobiography Letter, 21 February 1860, University College London Archives, GB 0103 MS ADD 206. Courtesy Beverly Ronalds.
[62] BAAS:CM, 25 October 1849.
[63] BAAS:CM, 31 July 1850.

Committee', is indicative of the observatory's increasing prestige within the BAAS. More and more it was being thought of as a permanent institution, even though funding was not guaranteed beyond the 1850 Annual Meeting. In fact, the documentary evidence suggests that from mid-1850 onwards, Kew Observatory started to assume some of the characteristics of a business. From June 1850, formal minutes were kept of Kew Committee meetings. Starting on 27 August, Ronalds and Welsh kept a diary of all activities at Kew, including visitors and administrative changes. The diary was maintained until 31 October 1851.[64] On 5 July the Kew Committee decided that the observatory's complement of staff 'should consist of an Observer and a Mechanic'; at the same meeting, Ronalds reported that he had engaged Mr [R B] Nicklin, whom he described as a 'photographic mechanic'.[65] Thus from mid-1850, Kew had a scientifically-qualified 'Observer' (Welsh), with Nicklin assisting him with the mechanical work.

It is possible that this new business-like nature of Kew Observatory was connected with John Herschel's appointment, in December 1850, to the post of Master of the Royal Mint.[66] The position left Herschel with little time for scientific pursuits and from then on his direct involvement with Kew Observatory ceased. As we have seen, the authority commanded by Herschel had led to the appointment of Birt, against the wishes of Sabine. Now, with Herschel no longer playing a leading role, Sabine had a free hand to appoint loyal subordinates and direct his own programme of work at Kew. However, a more immediate reason is likely to have been the appointment of John Peter Gassiot to the Kew Committee in October 1849. A Fellow of the Royal Society since 1840, Gassiot was respected as a chemist and became renowned for his spectacular electrical experiments at his London home. Most importantly for the subsequent history of Kew Observatory, Gassiot was a businessman through and through, who had made his fortune as an importer of port wine. The new regime at Kew, with its division of labour into 'Observer' and 'Mechanic', directed by a permanent committee that kept regular minutes of its meetings, shared several characteristics with those of a business concern. Gassiot's future correspondence would emphasise this change of regime, as would his role in

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[64] KCM, 16 September 1850; 'Kew Diary', 27 August 1850 – 31 October 1851, hereafter cited as 'KD'.
[65] KCM, 5 July 1850.
[66] Buttmann (1974), p. 178.

the introduction of instrument standardisation at Kew (see Section 3.3). The new pattern of work also fitted in perfectly with Sabine's wish for disciplined observers. Such a business-like way of working may also be a reason why Ronalds, a self-funded inventor and gentleman scientist, became 'annoyed & oppressed' and left Kew in 1852.

At the 1850 annual meeting of the BAAS, Welsh's salary was still only guaranteed for the following year. At the same meeting, the BAAS General Committee asked the Council to contact the Royal Society – and, if need be, the government – as to 'the possibility of relieving the Association from the expense of maintaining the establishment at Kew'.[67] But this was to be the last grumble about the cost of maintaining Kew to appear in the BAAS Council Minutes for some years, for by the time of the 1850 annual meeting, the observatory's finances were improving. At this meeting, the BAAS annual grant to Kew was increased to £300; according to Ronalds, this was again due mostly to unrecorded behind-the-scenes actions by John Gassiot.[68]

That there was any difficulty at all about the grant may have been due to an older enemy, George Airy, who at this meeting became BAAS President for the 1850-1851 session. Just days after taking office he wrote to Kew Committee chairman William Sykes, expressing his view that the observations now in progress at Kew with self-recording instruments (see Section 3.4) should be terminated, because Airy believed that the original purpose of Kew was the testing of newly-invented instruments, not continuous observations. Airy also remarked that Kew would not obtain any government support for such continuous observations.[69] As in 1840, Airy seems to have been concerned that Kew was duplicating the regular magnetic and meteorological observations that were already receiving government support at Greenwich. In his reply, sent with the approval of the Kew Committee, Sykes assured Airy that the observatory's primary purpose, that of experiment, was always kept in view and that such long-term observations as were in progress were all for specific purposes, in that the barometers, magnetometers and other instruments all required long periods of observational testing to be verified.[70] Airy

[67] BAAS:CM, 29 November 1850.
[68] Ronalds to Sabine, 23 August 1850, RS:Sa.1092.
[69] Airy to Sykes, 16 August 1850, RGO 6.403.26.
[70] Sykes to Airy, 25 November 1850, RGO 6.403.76.

seems to have made no further move against Kew for the rest of his presidency of the BAAS. We do not know whether he really believed Sykes's response that the data-gathering at Kew was secondary to its main purpose of instrument testing, but he must have realised that there was no moving the Kew Committee.

The 1850 grant increase shortly followed another turn of events which, together with the enhanced BAAS money, would 'render "poor Kew" rich', as Ronalds put it in a letter to Sabine.[71] In late 1849 there came the announcement that the Whig government of Lord John Russell intended to provide an annual grant of £1,000 to the Royal Society for scientific purposes. Roy MacLeod has noted that although there was no guarantee that the new Government Grant would be permanent – indeed, it was nearly terminated when Lord Palmerston became Prime Minister in 1855 – from the beginning the Royal Society worked on the principle that it would last indefinitely.[72] As noted in Chapter 1 (Section 1.2), active members of the Royal Society Council often played prominent roles in the BAAS as well. Therefore it was not long before some leading BAAS figures saw the potential of the Government Grant for supporting Kew Observatory. Sabine became secretary of the Royal Society's new Government Grant Committee, while Murchison, an enthusiast for Kew Observatory ever since 1842 and ever keen to seek influence with the aristocracy and government,[73] became its chairman. Murchison, in particular, was ecstatic about the prospect of government money for scientific research, dubbing it in March 1850 'the California of the Government thousand'[74] – a reference to the California Gold Rush of the previous year.

Soon after the Government Grant was publicly announced, Murchison, wanting to keep the observatory running 'coute qu'il coute', suggested to Herschel that now that this new source of government money was available, the Royal Society might take responsibility for Kew Observatory if the BAAS had to give it up. Also, he agreed with Sabine 'that a good national Physical Observatory should be sustained at Kew'.[75] Once again, Sabine was advocating a state-supported national physical observatory but once again, Herschel refused to give his backing. Herschel

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[71] Ronalds to Sabine, 23 August 1850, RS:Sa.1092.
[72] MacLeod (1971), pp. 330-331. See also Hall (1984), pp. 147-151 and pp. 163-164.
[73] Orange (1981), pp. 53-57.
[74] Murchison to Herschel, 2 March 1850, RS:MM 16.128.
[75] Murchison to Sabine, 9 February 1850, RS:Sa.911; Murchison to Herschel, 11 February 1850, RS:MM 16.126.

believed that for the Royal Society to commit itself to the maintenance of any observatory or to spending any portion of a grant for an indefinite period of years 'should most earnestly deprecate the RS'. This does not contradict Herschel's earlier advocacy of state-funded physical observatories, for he had always believed that these should be run directly by the government and not scientific societies. For Herschel, the permanent maintenance of observatories and laboratories was not the Royal Society's mission. Herschel was no less enthusiastic than Murchison about the new grant, which he saw 'as a Godsend to British Science'.[76] But Herschel believed that it should be used, firstly, to assist 'Private individual Experimental Research' (Herschel's emphasis); secondly, for analysis and reduction of observations already made; and also for occasional, undefined, special scientific projects of fixed duration.[77] Herschel therefore saw the grant very much as an extension of the existing culture in which scientific research was funded primarily by private individuals of independent means.

Murchison, when he presented the report of the Government Grant Committee to the Royal Society Council, deferred to Herschel's views on how the grant should be distributed,[78] and so once again Herschel punctured the idea of Kew Observatory being funded by the state. However, a major success for Kew came with the announcement of the very first round of awards out of the Government Grant: £100 was awarded to Sabine for new instruments at Kew Observatory. The news may not have been a great surprise, given that the committee making the awards had two of the observatory's loudest advocates as its chairman and secretary, while a third advocate, Wheatstone, was on the sub-committee recommending the award. The money was spent on a new vertical force magnetograph – which helped put the Kew magnetic observations on a well-funded, permanent footing (see Section 3.4 below) – as well as modifications to a Daniell hygrometer, and also a 'standard thermometer' with which other thermometers could be compared (discussed in Section 3.3).[79] Although no proposal was ever put forward in these years for the Royal Society to maintain Kew Observatory out of the Government Grant, the Kew

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[76] Herschel to Murchison, 15 February 1850, TxU: 26.11 (L0269).
[77] Herschel to Murchison, 15 February 1850, TxU: 26.11 (L0269). These views are remarkably similar to the recommendations presented in the Government Grant Committee's report of 7 March 1850, suggesting that Herschel may have had a major influence on them. See Hall (1984), pp. 147-148.
[78] Murchison to Herschel, 2 March 1850, RS:MM 16.128.
[79] BAAS:CM, 29 November 1850.

Committee continued to be successful in attracting substantial grant income from the Royal Society. Out of the 1851 Government Grant, £150 was awarded for the construction and verification of standard meteorological instruments at Kew, as well as the purchase of an apparatus for graduating thermometer tubes. An additional award of £175 was made to George Gabriel Stokes, Lucasian Professor of Mathematics at Cambridge, for experiments to be carried out at Kew to determine the indices of friction of various gases.[80]

That members of the Kew Committee so quickly, and successfully, applied for money from the Government Grant also raises the possibility that they might have been anticipating some announcement like this. It is interesting that despite a very firm statement in August 1848 that the BAAS Council would close the observatory and give the building back to the government, in fact it never quite got round to doing so: as we have seen, in January 1849 the Council deferred the issue until that year's annual meeting, when the observatory was reprieved for another year until 1850. The origins of the Government Grant are somewhat obscure, Prime Minister Lord Russell's initial letter to Lord Rosse, allegedly dated 24 October 1849, having long since disappeared.[81] It is known, however, that John Herschel was a friend of Lord Russell, which leaves open the possibility that the grant may have been the result of unrecorded, informal talks between these two. The possibility that Herschel might have been anticipating the announcement of the grant is strengthened by the fact that he was chairman of the Kew Committee in 1849 when it agreed to defer closing the observatory. More particularly, as noted above, the resolution at the 1849 BAAS annual meeting, to keep Kew Observatory running and to increase its annual grant from the BAAS, was cited as being in response to John Herschel's favourable opinion of the ongoing electrical observations at Kew. This resolution is dated 19 September 1849 – barely more than a month before the date of Lord Russell's alleged letter and less than two months before the earliest recorded minutes of the Royal Society's Government Grant Committee.[82]

Despite the presence of Sabine and Murchison on the Government Grant Committee, Kew had to compete with a substantial, and growing, body of applicants from other sciences. Not all of the money awarded to Kew from the Royal Society

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[80] BAAS:CM, 2 July 1851.
[81] MacLeod (1971a), p. 325.
[82] BAAS:CM, 25 October 1849; MacLeod (1971a), p. 325.

was out of the Government Grant – for example, the £261 awarded in 1852 for meteorological balloon ascents (described in Section 3.4) was from the Society's Wollaston Donation Fund – an older, private source of funding.[83] In an environment in which government support for science remained very limited – in addition to the BAAS grant to Kew remaining very modest – the Kew Committee had to look for other sources of income. It was in this context that, in the early 1850s, the Kew Committee began pursuing an enterprise that would soon be self-financing and would bring the observatory to the notice of a far wider circle than hitherto: that of instrument standardisation.

3.3 The origins of standardisation at Kew Observatory

Apart from one very brief description,[84] there has been no discussion as to how and why instrument standardisation began at Kew in the early 1850s. In this section I will show that the standardisation work partly owes its origins to two influential members of the Kew Committee – Gassiot and Sabine – seeing an opportunity that this work presented to earn some extra income that the Kew Committee wanted to keep the observatory running. It was also driven by a perceived need in British government and scientific circles for standardised meteorological instruments to serve the requirements of the Royal Navy and merchant marine. Yet it will also become clear in this section that the standardisation work at Kew itself became an essential service that would be sought after by instrument makers and government departments – including foreign governments. Through standardisation alone, Kew would enormously increase its prestige by the end of the 1850s.

The origins and early development of standardisation at Kew Observatory need to be seen in the context of an ongoing move by the government to redefine the national standards of weight and measurement in the years after the Napoleonic Wars, for commercial and legal as well as scientific purposes. Government and business alike wanted reliable standards of length and weight to maintain Britain's pre-eminent position in global trade and also to reduce the widespread fraud that was allegedly encouraged by long-standing regional variations in British weights and

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[83] BAAS:CM, 29 November 1852.
[84] Barrell (1969), pp. 171-174.

measures.[85] In 1824 an Imperial Weights and Measures Act had finally established a system of standards of length and weight, enshrined in law, after centuries of failed legislation. This 'Imperial' system of weights and measures was based on a standard yard and pound kept in the Houses of Parliament. These standards were destroyed in the October 1834 fire that burned down both the parliament buildings. Re-establishing the standards proved to be a long process. The job of redefining the length standard was first taken on by Francis Baily; when Baily died in 1844, the work was completed by Richard Sheepshanks, Airy's long-standing friend (who in 1840 had tipped him off about Sabine's plans for an observatory independent of Greenwich – see Chapter 2, Section 2.3). Sheepshanks's painstaking measurements, only completed in 1854, had to be done in a temperature-controlled environment; they were carried out in the basement of Somerset House in London (then the headquarters of both the Royal Society and the Royal Astronomical Society) and to monitor the temperature Sheepshanks made his own standard thermometers.

By the early 1850s, demand for standard thermometers (and other meteorological instruments) was also coming from other sources. In 1851 army officer William Reid, who had long been interested in the causes of tropical storms,[86] established a network of meteorological observers on land outposts across the British Empire, the observations to be made by soldiers in the Royal Engineers. Then, in 1853, United States Naval Observatory superintendent Matthew Fontaine Maury convened an 'International Meteorological Conference' in Brussels. Maury had become renowned for his accurate system of ocean weather charts and wanted to extend this to all oceans around the globe. For this to become a reality, it was necessary to institute an internationally-agreed system for recording weather observations aboard ships. Such a system was agreed upon at the Brussels conference, held in August and early September 1853 and was signed up to by ten nations, including Britain. To issue naval and merchant shipping with standard meteorological instruments, as well as to administer the collation of the weather data obtained, the British government set up a new department, known initially as the Meteorological Department of the Board of Trade and then, after 1867, the Meteorological Office.[87]

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[85] Schaffer (1997), pp. 440 and 443; Crease (2011), p. 103.
[86] Fleming (1990), p. 37.
[87] Burton (1986); Burton (1988), pp. 24-27; Walker (2012), pp. 20-22.

As noted in Chapter 2 (Section 2.5), and as acknowledged by Barrell, one of the objectives listed in the BAAS's 1842 prospectus was 'a station to which persons … may bring their instruments for the purpose of comparison with the standard instruments there deposited.[88] That the BAAS did not implement the standardisation part of its Kew prospectus immediately in 1842 may have been due partly to the observatory's very restricted budget for most of the 1840s, in addition to Sabine's first priority being to establish Kew as an independent magnetic and meteorological observatory.

The introduction of instrument standardisation at Kew was part of the new business-like regime implemented on the observatory by Gassiot and Sabine after the arrival of John Welsh in August 1850 (described in Section 3.2). The following month, Welsh began experiments to compare hygrometers made by John Frederic Daniell and the well-known French chemist and instrument maker Henri Victor Regnault.[89] By 1850 Regnault was well-known for his work on the physical properties of the steam engine and he was also a leader in the field of precision measurement, who had greatly improved the accuracy of thermometers. One of his hallmarks was his careful elimination of errors during the measurement process itself, rather than simply correcting them afterwards. He was highly respected by men of science across Europe, including James Forbes and the youthful William Thomson.[90] In November, the Kew Committee used the first Royal Society Government Grant to purchase from Regnault, 'a standard thermometer ... every degree of which shall have been examined and shall be guaranteed by M. Regnault himself', in order to verify or correct thermometers made by British instrument makers.[91] By early 1851, it was clear that the Kew Committee's ambitions went further: in addition to verifying thermometers, the Committee now also proposed to use the Regnault thermometer as a standard for making thermometers, using a graduation apparatus by French engineer and inventor Louis-Guillaume Perreaux. The machine was initially paid for by Gassiot, and arrived at Kew in February 1851.[92] The BAAS Council minutes claimed that it was obtained via Gassiot's actions, 'in anticipation' of money being received from the 1851 Government

[88] Quoted in Scott (1885), p. 51.
[89] Gassiot to Sykes, 19 September 1850, RS:Sa.591.
[90] Middleton (1966), p. 108; Chang (2004), pp. 75-6 and 83-4.
[91] BAAS:CM, 29 November 1850.
[92] KD, 22 February 1851; KCM, 25 March 1851.

Grant.[93] In July, Regnault himself visited Kew and advised both on the use of the Perreaux dividing engine and on his method of calibrating, graduating and testing thermometers. On Regnault's suggestion, the Kew Committee invited Perreaux to Kew to iron out some technical problems with the machine; Perreaux visited Kew in October 1851.[94]

It is clear that Sabine also took a leading part in this initiative. Just days after the Perreaux machine had been put into operation, Sabine 'suggested the desireability [*sic*] of dividing thermometers at once with Fahrenheits degrees instead of an arbitrary scale'.[95] Further evidence of Sabine's leading role can be found in his friendly correspondence with John Welsh, who rapidly took charge of the verification programme at Kew: as early as April 1851 the Kew Committee claimed him to be a 'master' in the use of the graduation machine.[96] Sabine came to treat Welsh as a personal friend, as is evidenced by his letter offering him 'a card for Lord Rosse's Soirées'.[97] Welsh duly complied with Sabine's call for Fahrenheit-scale thermometers: a letter to Sabine dated December 1851 encloses a step-by-step account of a process he invented for graduating a thermometer in degrees Fahrenheit.[98] In January 1852 the Kew Committee reported that the thermometers made by Welsh, when compared with each other and with the Regnault standard, had been found to be 'highly satisfactory' by the Royal Society's Government Grant Committee and that 'standard instruments bearing the mark of having been constructed and verified at the Kew Observatory' had been supplied to the imperial observatory at the Cape of Good Hope. Further thermometers had been ordered by the Hobarton observatory (part of the Magnetic Crusade) and by James Forbes for his experiments on heat.[99]

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93 BAAS:CM, 11 April 1851.
94 KD, 29 July 1851; 20 October 1851.
95 KD, 22 March 1851.
96 BAAS:CM, 11 April 1851.
97 Sabine to Welsh, 5 April 1852, TNA:BJ 1/11. Lord Rosse was then the President of the Royal Society and a traditional duty of that office was to host soirées for Fellows after Royal Society meetings.
98 Welsh to Sabine, 17 December 1851, TNA:BJ 3/32/38-40.
99 BAAS:CM, 31 January 1852.

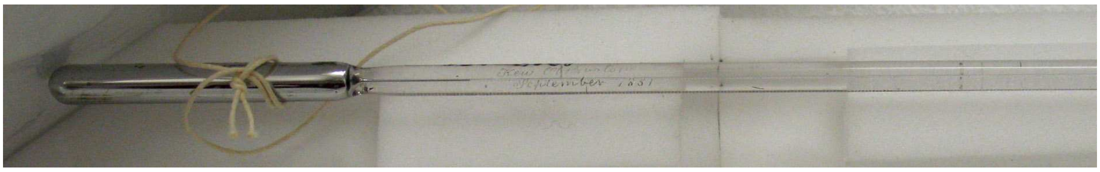

Figure 3.2 An early Kew standard mercury thermometer, inscribed 'Kew Observatory / September 1851'. Science Museum Object No. 1915-156; photograph by Lee Macdonald.

Sabine's fellow scientific servicemen also played an important role in instrument standardisation. In January 1852 the Kew Committee reported that John Welsh had begun some 'very laborious verifications' of twenty sets of meteorological instruments to be used by the East India Company for meteorological observations in India.[100] Until 1858, the East India Company managed Britain's imperial possessions in India, including the military regiments. The demand for instruments is likely to have been in response to William Reid's 1851 initiative, calling on the military to start a programme of meteorological observations across the British Empire. This possibility is much strengthened by the fact that Reid briefly served on the Kew Committee and BAAS Council in the early 1850s.[101] But the person most likely to have put this thermometer initiative into effect was the Kew Committee Chairman, William Sykes, who was now a director of the East India Company, based at East India House in London. The verification of large numbers of thermometers soon became an ongoing practice. On 5 March 1852 the Kew Committee was authorised 'to supply Standard Thermometers, on official application, to any department of Her Majesty's Government or the East India Company'. Many thermometers were not made at Kew: they were made by London instrument makers and then verified at Kew. That Sabine was fully behind the mass-production of thermometers for the East India Company and other bodies is attested in his letter to Welsh one day before the 5 March meeting: 'It is extremely desirable that we should meet the applications from Government as far as we may be able to do so'.[102] By late September 1854, some 40 thermometers, 20 hygrometers and four barometers for the East India Company had been tested at Kew, as had several more meteorological instruments for other institutions. By the same date a total of 94 thermometers had been made at Kew for 'institutions and individuals'.[103] Thus by

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[100] BAAS:CM, 31 January 1852.
[101] KCM, 16 September 1850; BAAS:CM, 2 July 1851.
[102] Sabine to Welsh, 4 March 1852. TNA:BJ1/11.
[103] BAAS:CM, 20 September 1854.

the mid-1850s, Kew had become an imperial capital of meteorological instruments, a place that the empire relied on for the manufacture and testing of thermometers. Alex Soojung-Kim Pang has shown how technology, components and observation methods developed in the mother country were necessarily 'hard-wired into' astronomical instruments used at imperial observatories and on eclipse expeditions.[104] In the same way, the technologies developed at Kew were becoming essential to the British Empire's meteorological instruments.

The standardisation work at Kew soon assumed a commercial aspect. Soon after the Kew Committee began making and testing thermometers for the East India Company, it also began doing regular work for government departments and other bodies in return for fees. In March 1852, the Committee was authorised to sell thermometers to individual BAAS members or Fellows of the Royal Society at £1 per instrument and also to make them for 'certain of the Philosophical Instrument Makers'.[105] Then, the 1853 International Meteorological Conference, and the consequent establishment of the Meteorological Department of the Board of Trade, had the effect of further expanding the role of Kew Observatory as a standardisation centre, as it obliged British ships to provide weather reports to an internationally-agreed standard, using standardised instruments. By the end of the conference, in early September 1853, the Kew Committee had agreed to provide Admiralty Hydrographer Francis Beaufort with a specimen of a thermometer specially adapted for meteorological observations at sea and Welsh was set to work on constructing one.[106] Welsh must have completed the task very quickly, for on 3 December Beaufort was informed that samples of the Kew marine thermometer had been sent to various London instrument makers, with requests for the prices at which they could supply such thermometers in bulk. Two well-known firms, Casella and Negretti and Zambra, were selected as having quoted the lowest prices and Beaufort was informed that either of these companies could supply the Admiralty with thermometers for just 5s 6d (five shillings sixpence) apiece. In April 1854 Kew entered into a similar agreement with the Board of Trade to provide meteorological instruments for merchant shipping.[107] By mid-1855 the observatory had tested the

[104] Pang (2002), p. 142.
[105] BAAS:CM, 5 March 1852.
[106] BAAS:CM, 7 September 1853.
[107] BAAS:CM, 20 September 1854.

accuracy of more than 2,000 thermometers; of these, 400 were for the Admiralty and 480 for the Board of Trade.[108] These mass-production thermometers were all made by the instrument makers and then tested at Kew. Both Casella and Negretti and Zambra had been founded earlier in the nineteenth century by Italian immigrants and both already enjoyed a fine reputation.[109] In an 1860 advertisement, Casella proudly listed Kew as one of the 'Royal Observatories' that it supplied its wares to.[110] In the sense of the instruments being verified at Kew Observatory before being sent on to the Admiralty and Board of Trade, Kew Observatory can be considered as the customer for as well as the inventor of the marine thermometers made by these firms, anticipating a tradition of partnerships between maker and customer-inventor identified by Mari Williams as beginning much later in the nineteenth century.[111]

One-half of these 2,000 thermometer verifications were, in fact, for the United States government, not the British. In August 1853 Maury, while in Europe for the meteorological conference, met with Sabine and informed him that he was not satisfied with the marine barometer then being used by the US Navy. He obtained the agreement of the Kew Committee, via Sabine, to make a better one.[112] Kew had been verifying barometers – and also hygrometers, for measuring atmospheric humidity – since late 1852 for the East India Company,[113] but a special problem with making a barometer for use aboard ship was the errors in the level of the mercury in the tube caused by the motions of the ship. Welsh and London instrument maker Patrick Adie corrected the problem by suspending the barometer freely on an arm attached to the wall of a ship's cabin and by constricting the lower part of the tube. Welsh and Adie's design proved successful in sea trials and the barometer adopted by the Kew Committee in March 1854 became known as the 'Kew pattern' or 'Kew type' barometer; Negretti and Zambra referred to it as the 'Kew Marine' barometer.[114] This model of barometer was selected to be supplied to the US Navy.[115] By mid-1855 some fifty marine barometers on this model had been

[108] BAAS:CM, 27 June 1855.
[109] Williams (1994), pp. 24-26; Read (1985), p. 8.
[110] Williams (1994), p. 24.
[111] Williams (1994), p. 21.
[112] Sabine to Welsh, 14 August 1853, TNA:BJ 1/11; BAAS:CM, 7 September 1853.
[113] BAAS:CM, 29 November 1852.
[114] BAAS:CM, 20 September 1854; Middleton (1964), pp. 164-165; Negretti & Zambra, 1864.
[115] BAAS:CM, 20 September 1854.

dispatched from Kew to the United States. At the same time, Kew also sent 1,000 verified thermometers to the US Navy.[116] The US Naval Observatory, of which Maury was superintendent, was keen to catch up with its European counterparts and had by now established a practice of touring Europe for the best instruments. Already in the 1840s its astronomer James Melville Gillis had visited some leading European observatories and instrument makers to procure the best astronomical equipment for the new establishment on the other side of the Atlantic.[117] These visits by Maury and Gillis also fitted in well with the improving diplomatic relations between Britain and the United States in the period from the conclusion of the war of 1812 (in which Sabine had served) and the start of the American Civil War in 1861.[118] Yet instrument verifications at Kew for foreign governments did not stop with the United States: for example, twelve barometers were verified at Kew for the Portuguese government in the 1855-56 period.[119]

Also during 1855, Welsh completed setting up a standard barometer at Kew, with which other barometers could be compared. The Kew Committee soon felt confident enough to arrange with instrument makers to make Kew-verified barometers and thermometers available to the public at prices of £4 4 shillings per barometer and £2 2 shillings for a set of six thermometers, with advertisements to be placed in newspapers to this effect.[120] The statistics for meteorological instruments verified at Kew in the 1850s are remarkable: between mid-1854 and mid-1859, the observatory tested more than 9,000 instruments for British and foreign government departments, instrument makers and private individuals (see Table 3.1). Importantly, this standardisation work was profitable. The income from verifications was such that once they had covered the cost of the barometer verification apparatus, the Kew Committee felt able to reduce the charge for verifying barometers from ten to five shillings per instrument.[121] By the late 1850s, verifications were bringing the observatory around £100 per year.[122]

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[116] BAAS:CM, 27 June 1855.
[117] Dick (2003), pp. 62-67.
[118] Woodward (1962), p. 205.
[119] BAAS:CM, 6 August 1856.
[120] BAAS:CM, 6 August 1856 and 1 December 1856.
[121] BAAS:CM, 6 August 1856.
[122] Receipts for verifications were: £141 5s for 1856-1857; £110 for 1857-1858; and £69 12s 9d for 1858-1859 (BAAS:CM, 26 August 1857, 22 September 1858 and 14 September 1859).

	1854-55	1855-56	1856-57	1857-58	1858-59	Total
Thermometers	2520	530	1524	268	911	5753
Barometers	257	137	278	221	187	1080
Hygrometers	1269	100	751	150	92	2362
Total	4046	767	2553	639	1190	9195

Table 3.1 Total numbers of instruments tested at Kew Observatory, 1854-1859. Data from BAAS:CM, 12 September 1855, 6 August 1856, 26 August 1857, 22 September 1858, 14 September 1859.

These revenues made a noticeable difference to the observatory's annual income, as its annual grant from the BAAS Council was still only £350 for the year ending August 1857.[123] Thus a major – and publicly-visible – part of the observatory's work was effectively self-financing. Moreover, it was also an essential government service, which made it much harder to make any case for closing down the observatory. This adds further weight to the idea that the introduction of standardisation in 1850 was an astute long-term move by Gassiot and Sabine. Gassiot, ever the entrepreneur, likely saw the commercial potential of the standardisation work and worked with Sabine to instigate it – even to the extent of paying for the dividing engine out of his own considerable pocket. Gassiot succeeded Sykes as Chairman of the Kew Committee in May 1853 and remained in this office for the rest of the 1850s.[124] But perhaps even more importantly, Kew Observatory had gained considerable public authority as a centre for top-quality meteorological instruments – overseas as well as within Britain. This is attested by Casella mentioning Kew in its advertisement, in addition to the Kew Committee being consulted by government departments. Although it may be going too far to claim that by the early 1850s Kew was 'the acknowledged source of thermometers and barometers for expert observation',[125] Kew was well on the way to being able to make this claim by the end of that decade.

It may be asked why all this large-scale standardisation work went to Kew and not to Airy's Greenwich, which at the time had an established programme of

[123] BAAS:CM, 26 August 1857.
[124] KCM, 30 May 1853.
[125] Anderson (2005), p. 92.

rating chronometers for the Admiralty and so might have been a natural first choice for further verification work, when the need came. Some thermometers used by volunteers in the British Meteorological Society and some barometers destined for ports were, indeed, verified at Greenwich under James Glaisher,[126] but these were an exception to the general rule, as in the 1850s the great expansion of weather recording initiated by the Brussels conference applied only to marine meteorology, not land stations. There are several possible reasons for the dominance of Kew in this field. First, it is evident that two key members of the Kew Committee – Sabine and Sykes – had close connections with, respectively, the Admiralty and the East India Company, two major customers for the standardisation work. Although an army officer, Sabine's connections with the Admiralty went back to the 1820s, when he had been an original member of a Royal Society committee set up to advise the Admiralty. Perhaps more important was that with the instigation of the thermometry programme in 1850, standardisation was established at Kew independently of government, before the demand came from the East India Company, the Admiralty and the Board of Trade, thus leaving Airy and Greenwich out of the loop. Indeed, Airy was an early customer for one of the Kew thermometers.[127] In any case, Airy may not have been interested in entering this field for himself. Jim Bennett has described how Airy, despite having a lifelong interest in the science of horology and the improvement of chronometers, took objection to staff time at Greenwich being taken up with routine work on chronometers.[128] This suggests that there were limits as to what Airy regarded as his territory.

Yet, as we have seen, Airy *did* still feel that geomagnetic and meteorological observation firmly belonged to Greenwich and not Kew. Both fields also underwent great development and expansion between 1845 and 1859, as did the general working of Kew Observatory. This will be discussed in the following section.

3.4 Meteorology and Geomagnetism at Kew, 1845-1859

Alongside the new, high-profile work in standardisation, during the 1845-1859 period meteorological observation at Kew developed enormously from the basic

[126] Anderson (2005), p. 95; Walker (2012), pp. 36-7.
[127] BAAS:CM, 29 November 1852.
[128] Bennett (1980), pp. 269-270.

programme of observations with manually-read instruments that had been established in the mid-1840s (Chapter 2, Section 2.6). In particular, these years saw the development of new types of meteorological instruments. At the same time, Sabine succeeded in establishing his cherished programme of geomagnetic observations at Kew, again using innovative self-recording instruments. Funding for the Magnetic Crusade finally ran out in 1848, yet long-term magnetic observations continued to be carried out under Sabine's direction, at several colonial observatories as well as at Kew. It is possible to argue that through Kew Observatory, Sabine managed to keep a Magnetic Crusade of sorts going throughout the 1850s and beyond. In this section I show how both the magnetic and meteorological work at Kew did at least as much as standardisation to raise the observatory's national and international prestige, so that by the end of the 1850s Kew was renowned as a world centre for research in both branches of science.

Observations of atmospheric electricity continued after the appointment of John Welsh in 1850, though thereafter they were mentioned less in BAAS reports, suggesting that the programme had become a watching brief rather than front-line research.[129] In 1856 the electrometer assembly was removed from the observatory dome to make way for the solar telescope (see Chapter 4) and a smaller electrical apparatus was built on the side of the dome.[130] Yet Ronalds' original apparatus remained a prototype for other observatories: copies were built at Kew for the East India Company in 1847 and the Madrid Observatory in 1852, suggesting that Kew was respected as an international standard in this field.[131] A new type of instrument for observing atmospheric electricity, devised by William Thomson, would be installed at Kew in the 1860s (see Chapter 6, Section 6.3).

Work on geomagnetism *per se* came to Kew in the mid-1840s with a project by Ronalds to build a self-recording instrument for measuring magnetic declination – the difference between true north and magnetic north. This 'declination magnetograph' was an extension of the 1840s trend towards instrument automation, which made use of the new technologies of photography and telegraphy (see Chapter 2, Section 2.6). The device worked using a magnet with a mirror that reflected light

[129] This reduced priority was mirrored at Greenwich: in his annual reports, Airy mentions the Greenwich electrical apparatus only briefly after the mid-1840s and not at all as of the 1851 report. See, e.g. Airy (1851), p. 9.
[130] BAAS:CM, 6 August 1856.
[131] Ronalds to Sabine, 30 June 1848, RS:Sa.1087; BAAS:CM, 29 November 1852.

through condensing lenses to form a concentrated spot of light on a moving strip of photographic paper, thus making a trace of the variations in the magnetic field over time. The magnetograph required a vibration-free support. This was achieved by suspending it between two masonry pillars that had originally supported the transit instrument that had been used to determine time for King George III's clocks – further evidence that in the Kew building the BAAS had a ready-made environment for precision measurement (see Chapter 1, Section 1.5). Ronalds published the details of his invention in the Royal Society's *Philosophical Transactions*.[132] But the same volume contains a description of a very similar device built by Charles Brooke, a surgeon who invented a number of scientific instruments in his spare time. By mid-1847 Brooke was automating the magnetic and meteorological instruments at Greenwich; a year later these were up and running.[133] The Admiralty awarded Brooke a prize of £500 for this invention, perhaps on the recommendation of George Airy. Nothing, however, was awarded to Ronalds, even though Ronalds published his work at the same time and Airy must have been aware of it, which suggests a further example of Airy's antipathy to Kew. Lord Northampton (formerly President of the Royal Society, now President of the BAAS) and John Herschel then applied to the government for some recognition for Ronalds. In April 1849 Ronalds was awarded £250; the money was apparently forwarded directly from the Prime Minister, Lord Russell.[134] This successful joint application by Northampton and Herschel must have brought the work at Kew to the notice of Lord Russell's government and may possibly have made that government more receptive to the idea that it could or even should reward scientific research with public money. Therefore it may have been more than a coincidence that just six months later Russell, according to later accounts, wrote to the Royal Society's President, Lord Rosse, with the original offer of an annual £1,000 government grant for scientific research. This, together with the friendship between Russell and Herschel, also strengthens the possibility that, as discussed above in Section 3.2, the Kew Committee deferred closing the observatory in anticipation of government funding.

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[132] Ronalds (1847).

[133] Airy (1847), p. 5; Airy (1848), pp. 9-10.

[134] BAAS:CM, 20 April 1849 and 12 September 1849; Northampton to Sabine, 27 April 1849, RS:Sa.947.

In April 1851, Ronalds began a six-month trial of two further magnetographs, along with the original declination magnetograph, forming a suite of instruments that recorded the three essential elements of the Earth's magnetic field: declination, intensity and dip (deviation from the horizontal).[135] The trial was completed and the results reported, but these instruments do not seem to have been used on a permanent basis during the early 1850s. The Kew Committee claimed as reasons limited funds and the priority of experiment over long-term observation at Kew. Moreover, the work was funded by a one-off grant of £100 from the Royal Society's Donation Fund.[136] Certainly the funding situation was not generous in the early 1850s, but the introduction of standardisation must also have consumed much of the limited time and resources available, especially as Welsh had only one assistant at this time (see below). Yet there is evidence that some magnetic observations were being carried on quietly at Kew. In March 1850 Sabine obtained authorisation from the Council to commence a modest programme of magnetic observations at Kew, to be made one day per week using manually-read instruments in a portable wooden observatory set up in the Kew Observatory grounds (to isolate the instruments from iron).[137] Both the instruments and the hut were 'lent' by Sabine, suggesting that they were hardware left over from the Magnetic Crusade. Correspondence between Welsh and Sabine further demonstrates that some magnetic work was being kept going – as in a comparison by Welsh of the magnetic dip at Kew with that at Woolwich.[138]

During these years equipment for other observatories and expeditions was also made at Kew: in 1850 Ronalds completed for the Toronto observatory (one of the stations that had participated in the Magnetic Crusade) an instrument for measuring magnetic dip. In early 1858, magnetic instruments were made at Kew for David Livingstone's upcoming expedition to Africa and members of Livingstone's party came to Kew to be trained in their use – an example of the observatory acting as an imperial capital of magnetic instruments as well as the meteorological ones described in Section 3.3.[139] Indeed, through this system of supplying instrumentation and training to overseas observatories and expeditions, in addition to

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[135] KD, 1 April 1851; BAAS:CM, 11 April 1851.
[136] BAAS:CM, 31 January 1852; BAAS:CM, 31 July 1850; BAAS:CM, 11 April 1851.
[137] BAAS:CM, 9 April 1850.
[138] Welsh to Sabine, 19 November 1854. RS:Sa.1734.
[139] BAAS:CM, 9 April 1850; KCM, 24 April 1858. The government paid for the Toronto instrument.

quietly carrying on a low-level programme of geomagnetic observations, some of the work of the Magnetic Crusade continued at Kew even after government funding for it had officially ended. A permanent programme of magnetic observations with self-recording equipment began in January 1858 with improved versions of Ronalds' instruments, built with the aid of £250 from the Royal Society Government Grant. This programme of observations was in response to the 1852 discovery by Sabine and others of a correlation between sunspot activity and variations in the Earth's magnetic field and was designed to run in parallel with a programme of solar photography at Kew (see Chapter 4).[140] With this new set of self-recording instruments, Sabine at last had a magnetic observatory that could rival Greenwich.

In 1855, Kew Observatory was given international promotion when a selection of Kew magnetic and meteorological instruments was displayed at that year's Universal Exposition in Paris. This international exhibition, which ran from May to November 1855, was a deliberate attempt by Napoleon III to outshine Britain's 1851 Great Exhibition and flaunt the glory of the new second French Empire, Napoleon III having become Emperor only in 1852 after several years of political turbulence in France.[141] As in 1851, a major aim of the Paris exhibition was to display the finest examples of scientific progress from around the world. The Paris exhibition would be viewed by a huge audience, so it was a great coup for Kew to have instruments exhibited there. The involvement of Kew Observatory with the Paris exhibition originated with a letter sent in December 1854 from the Board of Trade to Lord Wrottesley, Lord Rosse's successor as President of the Royal Society. The letter claimed that the manufacturers of some scientific instruments, including 'those for conducting researches into the laws of magnetism, heat, light, electricity, and other physical forces' were under-represented in the list of British manufacturers proposing to send displays to the exhibition. The Board of Trade asked whether the Royal Society could appoint a committee to cooperate with them in filling this deficiency. The committee appointed by the Royal Society included three important members of the Kew Committee: De La Rue, Sabine (now Treasurer of the Royal Society) and Wheatstone.[142] It may not be surprising, therefore, that at the next meeting of the Kew Committee, Sabine announced that the Royal Society would be

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[140] BAAS:CM, 26 August 1857 and 26 April 1858.
[141] Tombs (1996), pp. 188-189; Baguley (2000), pp. 194-195.
[142] RS:CM, 14 December 1854.

happy to accept the help of the Kew Committee in sending a display of magnetic and meteorological instruments to Paris. The Kew Committee appointed John Welsh and mechanical assistant Robert Beckley (see below) to accompany the instruments to Paris.[143]

One might have expected Greenwich, Britain's premier government observatory, to have a display at this exhibition. Yet it was Kew and not Greenwich that took the 25-foot long exhibition space in Paris, alongside another 25 feet of counter space for smaller instruments. Both spaces were largely taken up by Kew apparatus, such as a self-recording magnetograph by Francis Ronalds, and the thermometer verification apparatus.[144] Some Greenwich instruments were exhibited, but they were only brought to Paris as a small part of the Kew display.[145] The Board of Trade refunded the expenses, totalling just over £200, incurred in transporting the instruments to Paris.[146] The Board of Trade might have had good reason to be grateful to the Kew Committee and to promote the work of the observatory, given that in the year to September 1855 over 2,800 meteorological instruments had been verified at Kew for British government departments.[147] The Paris exhibition symbolises how, by the mid-1850s, Kew was becoming nationally and internationally recognised as an important centre for designing, building and testing magnetic and meteorological instruments.

The regular meteorological observations with manually-read instruments were continued at Kew throughout the 1845-1859 period, mostly without interruption. At the same time as his invention of a self-recording declination magnetograph (see above), Ronalds also developed instruments that automatically recorded temperature, barometric pressure and atmospheric electricity at Kew.[148] In 1854, John Welsh designed and built a new type of screen for shading thermometers from direct sunlight; this was an early form of 'louvered' thermometer screen, that allowed air to circulate freely around the thermometers while keeping them shaded.[149] One enterprise which might have brought Kew to wider public notice was a series of four balloon ascents in 1852 to make meteorological observations at high

[143] KCM, 23 January 1855.
[144] BAAS:CM, 27 June 1855.
[145] Welsh to Sabine, 7 January 1856, RS:Sa.1737.
[146] BAAS:CM, 27 June 1855 and 6 August 1856.
[147] BAAS:CM, 12 September 1855.
[148] Ronalds (1847).
[149] BAAS:CM, 20 September 1854; Middleton (1966), pp. 219-221.

altitude. These ascents were spectacular public events: they took place in the large 'Nassau' balloon owned and operated by Charles Green, the best-known balloon pilot, or 'aeronaut' of the time, and the choice of London's Vauxhall pleasure gardens as a launch site meant that they would have been noticed by many people. Yet the very appeal to the public of balloon launches as a spectacle and social event meant that ballooning was not seen as a serious activity,[150] which may explain why Welsh's ascents were the first serious scientific balloon flights in the UK. The BAAS Council first asked the Kew Committee to arrange to make balloon observations in March 1852; the Committee's main object was to determine the temperature and humidity of the atmosphere at different heights and also to see whether the chemical composition of the air at high altitudes differed from that at sea level. Arrangements were quickly made to hire Green and his Nassau balloon, a special set of instruments was made by Patrick Adie and verified by Welsh, and prior to each ascent circulars were sent out to volunteer meteorological observers across the south of England, asking them to make detailed observations on an hourly basis for the duration of each flight. The ascents were funded by the Royal Society through a £261 grant from its Wollaston Donation Fund, a private fund bequeathed by former President William Hyde Wollaston.[151]

A total of four ascents were made, between August and November 1852. Welsh accompanied Green on the balloon on each occasion and on the first two flights R. B. Nicklin (first name unknown), an assistant at Kew, helped with the instrument readings. The highest altitude, 22,930 feet, was attained on the fourth ascent; on this occasion, the effects of high altitude were enough to cause difficulty in breathing and tiredness after any exertion. All four ascents were a scientific success, however. In a substantial paper published in the Royal Society's *Philosophical Transactions*, Welsh reported that the air temperature steadily declined with altitude, except for a hiatus where for 2,000 feet the temperature remained static, the height of this zone varying between 4,000 and 8,000 feet depending on the weather. An analysis of air samples by the chemist William Allen Miller (a member of the Kew Committee, who had helped in the early stages of the

150 Tucker (1996), esp. pp. 146-148; Rolt (1966), pp. 190-192.
151 BAAS:CM, 5 March 1852 and 29 November 1852. Examples of the BAAS circulars can be found in the papers of George Airy – see, for example, RGO 6.402.457.

thermometer standardisation work) demonstrated that the composition of the air at the highest altitudes reached was the same as that at sea level.[152]

The ascents gained some publicity outside scientific circles, as in a short article in the *Illustrated London News* with an illustration showing Welsh, Green, Nicklin and Adie just before the first flight.[153] Yet they generated nothing like the public excitement that arose when the BAAS revived meteorological balloon flights the early 1860s, this time under a special 'Balloon Committee' appointed at the 1858 Annual Meeting.[154] By the time the flights were recommenced, Welsh was dead and the meteorologist on board was Greenwich Observatory's James Glaisher, who had taken great interest in the 1852 flights as one of the ground observers. When the opportunity arose again, Glaisher volunteered his services.[155] Glaisher's ascents became a symbol of Victorian scientific exploration in a way that Welsh's pioneering work never did. This was no doubt partly because of the September 1862 ascent, in which Glaisher and his aeronaut Henry Coxwell had a narrow escape with their lives: the balloon went out of control and ascended to a record-breaking height of approximately 37,000 feet, causing Glaisher to temporarily pass out before Coxwell managed to stop the balloon ascending. The incident led to Glaisher and Coxwell being lionised as brave, heroic explorers living up to the best Victorian values.[156] But the main reason why Welsh's work remained less well known is more likely to have been the difference in temperament between the two men. By the early 1860s, Glaisher had already become a well-known public figure: since the mid-1840s he had been writing for various newspapers about the Greenwich meteorological observations and he frequently gave public lectures on meteorology and his own scientific exploits, occasionally to the annoyance of his superior, George Airy. Some of his scientific contemporaries frowned upon him as a self-publicist: in 1865 the botanist Joseph Hooker described him as an example of 'those cattle, who live by self-glorification'.[157] Welsh, by contrast, published only in scientific journals; moreover, his Royal Society obituary noted his diffident personality.[158] As

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[152] Welsh (1853), esp. pp. 338-340.
[153] Anon. (1852a). The picture is briefly mentioned in Tucker (1996), p. 150. The 17 August ascent is also briefly described in Anon. (1852b).
[154] BAAS *Annual Report* 1858, p. xxxix.
[155] Rolt (1966), pp. 192-194.
[156] Tucker (1996), pp. 169-171.
[157] Quoted in Anderson (2005), p. 99.
[158] Anon. (1859-1860), p. xxxvii.

noted in Section 3.2 above, Welsh was happy to work quietly in the disciplined environment of a Victorian observatory.

As the narrative of the balloon flights suggests, even the dynamic John Welsh could not have done all the many types of work carried out at Kew in the 1850s – magnetic and meteorological observations, standardisation, instrument development, balloon experiments and more – on his own. From 1850 at least one assistant was employed at the observatory; as noted in Section 3.2, labour at Kew was divided between an observer and a mechanic. Nicklin, who accompanied Welsh on the first two balloon flights, was working at Kew by July 1850 at the latest and left at some point in 1852. He helped John Welsh with reading instruments and photographing the Sun.[159] Robert Beckley started work at Kew in November 1853, on the recommendation of the renowned inventor, chemist and astronomer Warren De La Rue, who was soon to become an important figure on the Kew Committee (see Chapter 4).[160] Beckley was much more than an assistant: he was actively involved in instrument design and construction, in 1856 building an anemometer to a design by Thomas Romney Robinson and constructing a recording device for it. His £91 annual salary put him at the low end of the professional classes at the time and was not far below the £100 earned by Welsh when he joined the observatory.[161]

This trend towards employing more technically-qualified assistants continued from the mid-1850s. March 1855 saw the arrival of Dr Hermann Halleur, on William Sykes's recommendation. He seems to have originally trained as a medical doctor before serving as director of the Royal Technical School in Bochum a few years before coming to Kew. He assisted with the standardisation work, but left in September 1855; the following year he took the post of Professor of Natural Science at Calcutta University, for a salary of £840, a figure that must have been galling for John Welsh.[162] Halleur was replaced in March 1856 by Balfour Stewart. Like Welsh, Stewart was one of James Forbes's Edinburgh graduates in Natural Philosophy. He was employed by the Kew Committee as an 'Assistant Observer', suggesting an increasingly formal structure to the observatory's personnel. Stewart

[159] KCM, 5 July 1850; KD, 1 April 1851 and 21 June 1851; Welsh to Sabine, 3 March 1852, RS:BJ 3/32.
[160] KCM, 12 November 1853 and 3 December 1853.
[161] Beckley (1858); BAAS:CM, 27 June 1855.
[162] KCM, 11 June 1855; Panwitz and Schwarz (2011), p. 472; Welsh to Sabine, 7 January 1856, RS:Sa.1737.

also remained at Kew for just a short period. In October he returned to Edinburgh to work as an assistant to Forbes – though not before he had invented a thermometer for measuring the sum total of temperature fluctuations, which he wrote up as a paper for the Royal Society.[163] Stewart was succeeded in October 1856 by Charles Chambers, who was recommended by the Council of the Society of Arts. The Society of Arts examinations had been newly introduced that year and Donald Cardwell cites the employment of Chambers at Kew as an example of the Society using its influence to help students who had passed the examinations gain scientific employment.[164] In January 1858, fifteen-year-old George Whipple began work at Kew; initially, he was employed 'to assist in the general work of the Observatory', establishing a precedent of employing boys as junior assistants in the observatory (see Chapter 6, Section 6.2).[165]

Welsh himself was still earning only £200 per annum at the time of his early death in May 1859; this income was modest even when compared with the £240 paid to the Astronomer Royal's deputy at Greenwich.[166] We have no record of Welsh ever complaining to his superiors on the Kew Committee about his situation. However, when Balfour Stewart gave notice of his resignation, Welsh confided in a letter to his old tutor, James Forbes that Stewart had 'put up very good naturedly with the inconveniences of this awkward place and with the uninteresting sort of work we have so often to do'.[167] Yet although Welsh had to do much 'uninteresting' work for relatively little, in 1857, when he was still only 32 years old, he was recognised by being elected a Fellow of the Royal Society – ten years after the 1847 reforms that had restricted the annual intake of new Fellows to fifteen, to be elected on scientific eminence alone. The citation mentioned his balloon ascents, his work on verification of barometers and that he was 'eminent as a meteorologist'.[168] That the observatory was headed by an FRS from 1857 only increased its scientific prestige.

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[163] BAAS:CM, 6 August 1856.
[164] BAAS:CM, 26 August 1857; Cardwell (1972), pp. 84-85.
[165] KCM, 24 April 1858; BAAS:CM, 22 September 1858.
[166] Chapman (1988b), p. 52.
[167] Welsh to Forbes, 6 September 1856, St Andrews msdep / 7 / Incoming / 1856 / 85a and b.
[168] Election certificate, John Welsh (1824-1859), RS:EC/1857/14.

3.5 Conclusion

'I should like you to see Kew. It is a nice place now.'[169] So Sabine concluded a letter to John Herschel in April 1857. Certainly, much had changed at Kew since 1845. In the late 1840s Kew Observatory had an annual budget of £150 and faced several serious threats to its continued existence. By the end of the 1850s, its BAAS grant had increased to £500 per annum. The observatory sciences practised at Kew had grown to encompass a full range of cutting-edge geomagnetic and meteorological research, in addition to a large-scale programme of instrument standardisation that brought in significant extra money. Whereas in 1845 the only paid member of staff at Kew was an army sergeant on £54 per year, by 1859 the observatory had five paid staff, giving a total salary bill of nearly £500.[170] By the late 1850s, too, the observatory's fame and prestige had increased enormously: its name was attached to a well-known marine barometer and its work for expeditions and overseas observatories had given it international prominence.

We have seen how the introduction of the Royal Society Government Grant in 1849 was less of a dramatic change for Kew Observatory than it might seem. The rescue of Kew Observatory from closure at the end of the 1840s owes more to the astuteness of Sabine and the businessman Gassiot, who together introduced a business-like regime at Kew. In particular, they likely saw the potential of standardisation to become self-funding and, even more importantly, that it could be an essential service to government, thus fatally weakening the case for closing Kew. The real importance of the Government Grant in saving Kew, was that Sabine and Gassiot introduced the standardisation programme in the early 1850s, buying a dividing engine in anticipation of grant money, which ensured that the work of verifying instruments for the Admiralty, the Board of Trade and the London instrument makers went to Kew and not to Greenwich. It is also possible that John Herschel deferred the closure of the observatory because he may have known about the Government Grant before it was officially announced – though he certainly did not believe that it should ever be used to support institutions like Kew on an ongoing basis. We can see from the experience at Kew, then, that the Government Grant was not a change from *laissez-faire*. If anything, it enhanced the *laissez-faire* environment in which the Kew Committee had to work, in that it gave the

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[169] Sabine to Herschel, 6 April 1857, RS:HS 15.242.
[170] BAAS:AR, 1859, p. 7.

Committee one-off sums of money that they could use to start up the standardisation service, which they operated on a commercial basis. In any case, only a minority of the observatory's income before 1859 came from the Government Grant. Its largest source of income was still the annual BAAS grant. Even one-off projects – from Ronalds' pioneering experiments in self-recording magnetic and meteorological apparatus to the spectacular balloon flights in 1852 – were as often funded from private sources as they were by government. Kew Observatory in 1859 was still an independent institution controlled by Morrell and Thackray's 'gentlemen of science'.

Yet Kew Observatory in the late 1850s was more than just 'a nice place'. It was also an important place in the landscape of the physical sciences. Sabine and Gassiot, aided by the technical ingenuity of Francis Ronalds, John Welsh and their assistants, had established at Kew a world-class magnetic and meteorological observatory with self-recording instruments like those at Greenwich. Even when he was president of the BAAS, Airy was unable to stop the Kew magnetic and meteorological observations. When the British government sponsored a display of magnetic and meteorological instruments to the 1855 Paris Exposition, the display was dominated by instruments from Kew and not from Greenwich. The Paris Exposition was an instance of how the work of Kew was becoming internationally known. During the 1850s, Welsh and his colleagues built and tested instruments for foreign observatories, and they provided training in their use to expeditionary parties. A number of distinguished foreign visitors inspected the instruments and observational work at Kew, such as Berlin Meteorological Institute director Heinrich Wilhelm Dove, who had become famous for his global temperature maps.[171] Foreign institutions, as well as British government departments, were turning to Kew for standardised instruments. By 1859, the range of observatory sciences practised at Kew had increased further, with the introduction of another new project, again privately funded: the photographic investigation of the mysterious dark spots seen on the disc of the Sun, to be discussed in Chapter 4.

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[171] KCM, 13 September 1854; Anderson (2005), pp. 88-89.

Chapter 4

‘Solar spot mania’, ‘cosmical physics’ and meteorology, 1852-1870

> I believe I have been writing a great deal of nonsense – but I must confess that a solar spot mania has fairly seized me!
>
> John Welsh to Edward Sabine, 23 April 1852[1]

> There is a class of observations which may be called Cosmo-Physical observations, of immense importance at the present moment; and there is, moreover, a sort of preparatory scientific conviction gradually arising that we are on the eve of some grand generalization, which may coordinate many things which seem at present strangely diverse and unconnected. … Among these phenomena we have the physics of sun-spots, magnetic and electric disturbances, and meteorological phenomena generally.
>
> (Anon.), *Athenaeum*, 3 October 1868[2]

4.1 Introduction

Chapter 3 discussed how between the late 1840s and the late 1850s Kew Observatory not only survived, but also diversified its activities and became nationally, indeed internationally famous as a centre for instrument standardisation as well as for geomagnetic and meteorological observations. Yet as suggested by the first epigraph above, the latter part of this period also saw the beginnings of the work for which, at least among historians of science, the observatory is now best remembered: the first systematic programme to photograph the Sun and its then mysterious dark spots. According to the standard histories, this project was started with the word of the great Sir John Herschel; then, the Kew solar camera or ‘photoheliograph’ was designed by Warren De La Rue and under the direction of Balfour Stewart, John Welsh’s successor, it began pushing the boundaries of the

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[1] Welsh to Sabine, 23 April 1852, TNA:BJ 3/32.
[2] Anon. (1868a), p. 436.

emerging discipline of astrophysics.[3] The results of the Kew photographic programme were used by Kew Observatory superintendent Balfour Stewart to derive controversial theories relating the formation of sunspots to planetary alignments and they inspired studies into possible relations between sunspots and weather that assumed importance in late nineteenth-century imperial governance. The results remain of interest to astronomers today working on models of the solar cycle.[4]

This chapter aims to address three broad questions: first, how and why solar astronomy came to Kew in the 1850s; second, how the photoheliograph was used in practice; and finally, the subject of the second epigraph, what was the true nature of the complex relationship between solar, magnetic and meteorological research at Kew under the directorship of Balfour Stewart from 1859 to 1870 – and, indeed, Stewart's own tortuous connections with Edward Sabine, the Kew Committee and the Meteorological Department of the Board of Trade. All three questions are related to two overall themes of this thesis: the organisation of science and the observatory sciences in practice.

Neither of the first two questions – on the origins of the photoheliograph and its use in practice – are addressed satisfactorily in the existing literature. As noted in Chapter 1 (Section 1.5), there is as yet no detailed history of the origins and practice of solar photography at Kew. None of the existing articles and books are specifically about Kew and so they inevitably treat Kew only briefly.[5] The third question, on Balfour Stewart's theories of solar-terrestrial relationships and his wider 'cosmical physics', has been tackled more effectively. Paul Charbonneau has presented a solar physicist's overview of nineteenth-century attempts to establish planetary influences as the cause of the sunspot cycle and how these were later debunked by statistical analyses and the discovery of the magnetic nature of sunspots.[6] Graeme Gooday has shown how Stewart used the Kew sunspot data to support various theories linking sunspots with terrestrial meteorology and magnetism – all in the context of Victorian energy physics and Stewart's religious convictions which led him to argue against materialist cosmologies – and that his advocacy of such theory-driven research led

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[3] This is approximately the story told in Hufbauer (1991), pp. 46-67 and King (1955), p. 226.
[4] Charbonneau (2002); Gooday (2004); Anderson (2005), pp. 250-276; Meadows (2008).
[5] Hufbauer (1991); Rothermel (1993); Schaffer (1995), esp. p. 259 and pp. 276-283. See Chapter 1 (Section 1.5) for some discussion of the literature on nineteenth-century observatories and solar astronomy.
[6] Charbonneau (2002).

him into conflict with Sabine and his eventual resignation from Kew.[7] All this is certainly true, but as we shall see, archival evidence suggests that the story is more complex.

Before I start to address these three questions, I briefly set the narrative in the historical context of what had been discovered about sunspots and their supposed influences on the Earth by the mid-nineteenth century (Section 4.2). In Section 4.3 I examine how and why solar photography came to Kew and argue that John Herschel's well-publicised rallying-cries for systematic solar observation were only part of a much more complex story. In Section 4.4 I discuss how the photoheliograph was used to make its most famous observations, the photographs of the 1860 total solar eclipse; I show that the expedition to photograph this eclipse was largely directed and financed by a self-funded man of science. In Section 4.5 I argue that Stewart's clash with Sabine was due not only to the latter's impatience with Stewart's theory-driven usage of the photoheliograph results but also to the reorganisation of the Board of Trade's Meteorological Department after Robert FitzRoy's suicide in 1865. The reorganisation had a huge importance in changing the work regime at Kew Observatory – perhaps more so than has hitherto been appreciated by historians. Overall, in this chapter I address two of the great questions outlined in Chapter 1 (Section 1.1) of this thesis. In critically reassessing the story of the photoheliograph's origins and its use in practice, I challenge and revise the notion that solar photography at Kew was the work of a 'public observatory' and so help to address our fundamental question as to how the physical sciences were organised in the Victorian era. Secondly, in discussing the story of the photoheliograph and especially Balfour Stewart's work with the solar photographs after 1859, I argue that the observatory sciences both diversified and increased their importance in the 1860s.

4.2 Sunspots and Sun-Earth connections

Sunspots were studied seriously by Galileo and others in the early seventeenth century with the newly-invented telescope, because the presence of dark spots on the solar surface seemed to contradict the Aristotelian notion that the Sun was pure and

[7] Gooday (1989); Gooday (2004); Gooday (2007).

incorruptible. Interest in the spots thereafter waned – perhaps in part because in the mid-seventeenth and early eighteenth centuries there were very few spots on the Sun, a period later termed the 'Maunder Minimum' – and does not seem to have revived until well into the eighteenth century. From the 1770s onwards William Herschel began observing the Sun closely as part of his new approach to astronomy that emphasised the 'natural history' of the heavens. Herschel believed that the Sun's luminous surface was a veneer covering a dark, solid body beneath, and that the sunspots were small openings in the brilliant surface. By the mid-1790s he was also thinking seriously about the Sun's effect on the Earth's climate and for how long the Sun would continue to shine with the same 'lustre'. These speculations became important to Herschel after his discovery in 1800 of invisible heat rays – infra-red radiation – from the Sun. He believed that sunspots enhanced the Sun's total heat output and so that more sunspots would give warmer weather on Earth. Herschel went back over historical sunspot observations and claimed to have detected a correlation between the numbers of sunspots and the price of wheat: higher sunspot activity, according to Herschel, had coincided with periods of cheaper food and therefore good harvests and warmer weather. Herschel's theories met with considerable controversy, but they set a precedent for speculation as to whether solar activity affected terrestrial weather.[8]

Neither Herschel nor any other early observer detected any regularity in these fluctuations in sunspot activity. In the 1820s, German amateur astronomer Heinrich Schwabe began making daily drawings of the Sun's disc in an attempt to detect a proposed planet close to the Sun that some astronomers thought might be the cause of mysterious perturbations in the orbit of Mercury. He found no planet, but in 1843 he claimed that the number of spots was rising and falling in a regular, ten-year cycle. He first published these findings in the *Astronomische Nachrichten*, a respected journal, but nevertheless his work does not seem to have been read in the English-speaking world at the time. The discovery was, however, noted by the polymath Alexander von Humboldt, who had been influential in stimulating interest in terrestrial magnetism in the 1820s and 1830s (see Chapter 2, Section 2.2). Humboldt wrote about Schwabe's sunspot cycle in *Cosmos*, the great summation of Humboldt's life's work in the Earth sciences. When *Cosmos* was translated into

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[8] Hufbauer (1991), pp. 35-40; Hoskin (2011), pp. 148-149.

English in 1852, the discovery would have dramatic consequences, described below.[9]

John Herschel shared many of his father's beliefs as to the nature of the Sun – such as it being a solid body underneath a luminous envelope – and while at the Cape of Good Hope he was eager to investigate its properties further. He invented a device which he called an 'actinometer' to measure variations in the amount of heat received by the Earth from the Sun and by January 1837 had begun a regular programme of sunspot drawings. He used a small refracting telescope to project the Sun's image onto a white screen for safe viewing.[10] By March he had obtained an interesting result: he noticed that the spots seemed to traverse the Sun's disc in a pair of parallel bands on either side of the solar equator, which he likened to the Earth's trade winds. He was unable to find any correlation between 'the more or less spotty state of the surface of the Sun' and the radiation readings of his actinometer, but he did suggest it as worth investigating whether episodes of high sunspot activity coincided with increases in the frequency of the aurora, as 'both phaenomena are now in full vigour and both have had a long period of repose'.[11]

In his 1847 *Results of Astronomical Observations* (here abbreviated to *Cape Results*), Herschel speculated carefully on the nature and cause of sunspots, suggesting that the Sun's luminous outer envelope might be a fluid that flowed between the Sun's poles and equator in a manner analogous to the global circulation of the Earth's atmosphere. The currents approaching the equator might, according to Herschel, displace the luminous matter beneath, exposing patches of the dark solar interior, which we see as sunspots, and the rotation of the Sun would deflect these currents longitudinally, causing the spots to appear in 'trade wind' bands. Herschel urged those who observed the Sun to make their drawings available so that the state of the Sun on any given day could be determined. He emphasised that 'a systematic and continuous series of observations of the solar spots cannot be too strongly insisted on' and that observers should pool their results 'to secure an *unbroken*

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[9] Hufbauer (1991), p. 46; Charbonneau (2002), p. 351.
[10] John and Lady Herschel to Caroline Herschel, 10 January 1837, in Evans et al. (1969), pp. 280-282; Herschel (1847a), p. 431.
[11] Herschel to Francis Baily, 1 March 1837, RS:HS 3.138. Meadows and Kennedy (1982), p. 424, briefly note Herschel's 1837 speculation on a possible link between sunspots and aurorae.

history' of the Sun's aspect. He also suggested that the new technology of photography might be used in this collaborative solar work:-

> And now that clock-movements have been applied to our equatorials, and that photographic delineation can supply, in the utmost perfection, the talent of the draftsman, it were much to be wished that the subject were seriously taken up as part of the regular business of observatories. An interchange of copies might perhaps take place, without recourse to the engraver, by the aid of *the Kalotype* process of Mr. Talbot, to any moderate and useful extent.[12]

It may have been the process of writing up these observations for publication that revived Herschel's interest in solar studies, for in the second half of the 1840s he began to call more widely for a programme of systematic solar observation. In addition to the *Cape Results*, he also published his idea in the Royal Astronomical Society's *Monthly Notices*. Herschel proposed that the RAS begin collecting 'an unbroken series of such drawings' made by astronomers around the world in order to gain 'a knowledge of the laws which govern these mysterious phenomena, and the periods, if any, which they observe in their formation, and thence of elucidating the nature of the sun itself'. Near the end of this letter, Herschel again briefly noted that 'the exceeding facility with which photographic processes are executed, and especially the short time which the *Talbotype* process occupies, makes their execution on a given scale, and with every requisite degree of precision, easily attainable'.[13]

In fact, Herschel had realised the potential of the new science of photography in accurately recording the Sun's appearance as early as 1839, almost as soon as his friend (and fellow Cambridge Wrangler) William Henry Fox Talbot had communicated to him his invention of the negative-positive calotype or 'Talbotype' process. After successfully making a photographic image of his own using a similar process, Herschel commented that it would be 'a beautiful mode of making the sun represent its own spots n times a day or of mapping the moon.'[14] But although he briefly mentioned photography in both the *Cape Results* and his 1847 *Monthly Notices* letter, Herschel's emphasis in his proposed collaborative effort was on drawings to be made every clear day, as he himself had pioneered at the Cape.

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[12] Herschel (1847a), pp. 432-435. 'Kalotype' or 'calotype' was the name given to William Henry Fox Talbot's early photographic process.
[13] Herschel (1847b).
[14] Draft of Herschel to Talbot, 30 January 1839, quoted in Schaaf (1992), p. 50.

Herschel's main aim was for continuous coverage (note the repeated use of the word 'unbroken') of the ever-changing spots, regardless of the method employed. It is likely that he regarded photography, although full of exciting possibilities, as a new and untested technique that not every potential solar observer had access to. Having worked closely with Fox Talbot on the development of the photographic process in the years immediately after 1839, Herschel had no illusions as to the technical challenges posed by this new medium.[15]

But this time his plan, although published in what had become one of the world's premier journals dedicated to astronomy, was not taken up. By the late 1840s Herschel had retired from systematic astronomical observation and from 1850 he would be immersed in his highly stressful job as Master of the Royal Mint. Only in 1854 would he repeat his call for a systematic programme to observe the sunspots. This, it has hitherto been assumed, initiated the setting-up of a solar photographic telescope at Kew Observatory. Yet the story of how solar photography came to Kew is much more complicated than this, as I will discuss in Section 4.3.

4.3 'Solar spot mania': the origins of the Kew sunspot programme

In the spring of 1852, Sabine obtained an important result from the large volume of data generated by the Magnetic Crusade: he found that the frequency and intensity of magnetic disturbances and the mean monthly range of magnetic variations rose and fell in a ten-year cycle, with a minimum in 1843 and a maximum in 1848. A similar period had been derived slightly earlier by Johann Lamont of Munich from continental European observations, but in March 1852 Sabine noticed something else. His wife Elisabeth had recently translated Humboldt's *Cosmos* from the German, including the reference to Schwabe's discovery of a ten-year sunspot cycle. Sabine immediately saw that Schwabe's cycle coincided with the magnetic cycle that he had just discovered. He wrote excitedly to Herschel about his finding.[16] Herschel, busy at the Royal Mint, may not have replied, for almost a month later Sabine wrote to him again, urging him 'to look at the remarkable coincidence' between the sunspot and magnetic cycles, which Sabine thought was 'much too

[15] Buttmann (1974), pp. 136-152; Schaaf (1992), pp. 45-102.
[16] Sabine to Herschel, 16 March 1852, RS:HS 15.235. This is quoted in Meadows and Kennedy (1982), p. 420.

remarkable & consistent … to be passed as a mere accident'.[17] Herschel did, though, reply to Michael Faraday in November 1852, in response to Faraday forwarding him a letter from Swiss astronomer Rudolf Wolf, who had used a historical analysis of solar observations going back to the eighteenth century to refine Schwabe's period to 11.1 years. From his response we know that Herschel acknowledged the importance of Sabine's discovery of the correlation between the sunspot and magnetic cycles: 'If all this be not premature we stand on the verge of a vast cosmical discovery such as nothing hitherto imagined can compare with'. He saw the discovery as a vindication of his view that a connection existed between sunspots and the aurora, suggesting that electric currents in space were 'auroralized' by the Sun's upper atmosphere and that the 'red clouds' seen during a solar eclipse (now known as solar prominences) might be 'reposing auroral masses'.[18]

Secondary sources suggest that Herschel was the central driving force in initiating the Kew sunspot photography programme, by writing to the Kew Committee with a plea for a continuous photographic record of the Sun, whereupon the Kew Committee followed his word.[19] Yet they do not explain why he only wrote to the Committee in the spring of 1854, two years after Sabine's discovery of the sunspot-terrestrial magnetism relation, nor why he recommended that Kew and not Greenwich or some private observatory take on the work. The latter is especially surprising given that in the 1840s, as we have seen, he had encouraged private individuals to observe the Sun.

In fact, Sabine also sent his original 1852 paper on the sunspot-magnetism connection to John Welsh, the superintendent at Kew who, as noted in Chapter 3, was on friendly terms with Sabine. On 23 April Welsh replied enthusiastically, agreeing with Sabine about the coincidence between the sunspot and magnetic disturbance periods. Welsh suggested that if we suppose 'that the Sun is a magnet – an electro magnet – (a great electric light perhaps) it will undoubtedly have some influence upon the magnetic condition of the planet' – and any irregularities in the Sun's magnetic field would show up in the Earth's. He suggested, as an initial experiment, that Schwabe's solar observations could be compared with past records

[17] Sabine to Herschel, 12 April 1852, RS:HS 15.236.
[18] Herschel to Faraday, 10 November 1852, RS:HS 23.127.
[19] Charbonneau (2002), p. 355; Le Conte (2011), p. 23; Rothermel (1993), p. 152.

of magnetic disturbances to see if outbreaks of sunspots coincided with disturbances. Then, if a further regular series of solar data were needed:-

> the best way by far would be to take photographic pictures of the Sun every day at a few stations where clouds are least plentiful. These pictures are very easily obtained and require no apparatus beyond a good telescope of perhaps 10 or 12 feet focus or an object glass alone mounted on any rough thing which could be directed to the sun.

Welsh went on to remark that the previous summer he had taken some images 'with a very wretched little reflector which quite convinced me of the practicability of the operation'. He apologised for writing what may have been nonsense, but confessed 'that a solar spot mania has fairly seized me!'.[20] Although Welsh was not the first to advocate photography as a means of recording sunspots – as we have seen, Herschel did so in 1839 – his April 1852 letter to Sabine is the first recorded suggestion that photography be used as the *main* method in a regular, multi-observatory photographic patrol of solar activity. He was also the first to suggest that it could be done with a small and simple, and so inexpensive, telescope – an attractive proposition to the ever budget-conscious Kew Committee. More importantly, it was Welsh who was the first to argue for a photographic sunspot observing effort in response to Sabine's discovery of the sunspot-geomagnetism relationship.

If Sabine replied to Welsh, we have no record of it. Nor do we have any evidence of contact between Welsh and Herschel, who did not make any move until two years later when he wrote his well-known letter to the Chairman of the Kew Committee, John Peter Gassiot. This was published in two prominent places: the 1854 *Annual Report* of the BAAS and the *Monthly Notices* of the RAS for March 1855. The *Monthly Notices* version, although concerned solely with his proposal for the sunspot observations, bears the generic title: 'On the Application of Photography to Astronomical Observations'. This, together with its author's name and reputation, would have ensured the article a wide audience. Herschel emphasised the importance of a system of daily solar photographs (no mention of drawings now), in order to maintain 'a consecutive and perfectly faithful record of the history of the

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[20] Welsh to Sabine, 23 April 1852, TNA: BJ 3/32. The 'Kew Diary' for 1850-1851 confirms that on 21 June 1851 Welsh and an assistant (Nicklin) 'procured some Daguerreotype pictures of the sun with the help of a small reflecting telescope'. (KD, under entry for 1851 June 27th.)

Spots'. Like Welsh, he sketched out how it could be done in practice using a small telescope (he suggested a 3-inch refractor), a magnified image of the Sun being formed on the photographic paper or glass with an eyepiece equipped with wires that would enable the positions and sizes of the spots on the photographs to be measured. He also suggested, as did Welsh, that it should be done at multiple observatories in order to obtain continuous coverage, though he went further in thinking that these stations should be spread evenly in longitude around the globe.[21]

Although the letter suggests that Herschel independently took the initiative of urging the Kew Committee to take up the systematic study of sunspots using photography, secondary sources seem to have overlooked a claim in the Committee's 1854 report just before the start of Herschel's letter, to the effect that Sabine had reported Herschel suggesting to him the importance of daily solar photographs and that Herschel's letter was in response to one from Gassiot asking Herschel for a statement of his views on the matter.[22] The minutes of the Kew Committee for 15 March 1854 bear this out: having heard Sabine's report of Herschel's suggestion, the Committee requested Gassiot to ask Herschel for 'his views as to the importance of the object and the best mode of carrying it into effect'.[23] No copy of Gassiot's letter seems to have survived in Herschel's files, but in the original manuscript of his reply Herschel writes: 'I am ashamed to have allowed your letter to remain so long unanswered but I hope you will not attribute the delay to wilful negligence'.[24] This apology is omitted from both published versions, perhaps to save Herschel the embarrassment of advertising his tardiness.

That the initiative seems to have come from Sabine and the Kew Committee helps to explain why the solar photography went to Kew. It is also possible that Sabine originally owed the idea of a photographic programme to Welsh and not Herschel, and that he merely used the latter's imprimatur to gain support for the idea – a possibility strengthened by Sabine's patchy track record of reporting the truth, as discussed in Chapter 2. Furthermore, given that Herschel was overworked at the Royal Mint, it is even possible that Sabine had been informally lobbying Herschel

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[21] Herschel to Gassiot, 24 April 1854, printed in BAAS:AR 1854, pp. xxxiv-xxxv; Herschel (1855), pp. 158-159. The RAS version is addressed to 'Colonel Sabine', but both the BAAS version and the original manuscript (see below) are clearly addressed to Gassiot.
[22] BAAS:AR, 1854, p. xxxiv.
[23] KCM, 15 March 1854.
[24] Herschel to Gassiot, 24 April 1854, RS:MC.5.164.

for his support ever since 1852, but that the latter had never written and so Sabine now asked Gassiot to write a formal letter on behalf of the Kew Committee.[25] The 1998 *Calendar* of Herschel's correspondence records very few letters on scientific subjects in the early 1850s; most of them are about Royal Mint business.[26] It is possible, then, that the original initiative came from Sabine and Welsh in 1852, not from Herschel in 1854.

Events moved quickly after the Kew Committee received Herschel's letter. Within just over two weeks, the Committee had requested estimates of the costs of an instrument along the lines suggested by Herschel, from the instrument makers Thomas Cooke of York and Andrew Ross of London.[27] By the Annual Meeting in September 1854, Ross had won the contract and the instrument was under construction. Meanwhile, a grant of £150 to cover the cost of construction was rapidly secured from the Royal Society's Donation Fund.[28] The Donation Fund was from private money, so although the Kew sunspot programme is sometimes referred to as being the work of a public observatory,[29] the solar telescope was in fact funded from private sources.

The detailed design of the telescope was also worked out by a private individual, Warren De La Rue, a wealthy printer and stationer who had invented an innovative machine for making envelopes and was also renowned as a chemist and a pioneer of astronomical photography. De La Rue had taken up astronomical photography seriously as recently as 1851: a fine photograph of the Moon on display at that year's Great Exhibition encouraged him to try his own hand at lunar photography. Astronomical photography was not new in the 1850s: photographs of the Moon had been taken in the United States as early as 1840 and images of the Sun, showing spots, had been produced in the mid-1840s using the French 'Daguerreotype' process, which recorded photographic images onto sensitised metal plates.[30] But in the early 1850s De La Rue was among the first to exploit a new photographic technology, the wet collodion process invented by Frederick Scott Archer. This new process greatly increased the possibilities for photographing

[25] Accounts of Herschel's life emphasise how he was overworked in these years, to the point of a nervous breakdown later in 1854 (Buttmann (1974), pp. 176-183).
[26] Crowe et al. (1998).
[27] Gassiot to Herschel, 9 May 1854, RS:HS 8.59.
[28] BAAS:AR, 1854, p. xxxv.
[29] Schaffer (1995), p. 259.
[30] Tobin (2003), pp. 52-54.

celestial objects, because plates coated with wet collodion were much more sensitive to light than those prepared with Daguerreotype or Talbotype surfaces. Whereas with the older processes even a bright object like the Moon required an exposure of many minutes or even hours, a good image of the Moon could be secured after just a few seconds' exposure with collodion. De La Rue quickly brought himself up to speed with the new process and began taking outstanding pictures of the Moon with his private 13-inch reflector. By the mid-1850s he was widely acknowledged as Britain's leading expert on astronomical photography.[31] He was elected a member of the Kew Committee in March 1854 and it was to him that the Kew Committee turned for a detailed costing and design of a telescope dedicated to photographing the Sun.[32]

Under De La Rue's direction, the telescope for photographing the Sun, or 'photoheliograph', as it became known, was built fairly quickly.[33] The photoheliograph was a refracting telescope with an object glass 3.4 inches in diameter and 50 inches in focal length, which used eyepieces to project magnified images of the Sun onto a photographic plate.[34] In October 1856 De La Rue reported to Herschel that the instrument was complete and erected in the dome at Kew Observatory formerly used for Francis Ronalds' atmospheric electricity observations (Chapter 2, Section 2.6).[35] Yet the telescope did not become operational until mid-March 1858 and it would not be used continuously at Kew to take daily solar photographs, as suggested by Welsh and Herschel, until five years after that date. It is likely that, although Sabine discovered the correlation between solar activity and terrestrial magnetic variations and so had an interest in seeing his results vindicated by the photographic programme, the observatory had more urgent priorities in these years. In 1857 and 1858 Welsh was doing double duty: in addition to superintending the observatory he was busy with Sabine's magnetic survey of Scotland described in Chapter 3 – indeed, De La Rue mentioned the survey as a likely cause of delay in

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[31] Hartog, rev. Meadows (2004); E B K[nobel] (1890), pp. 157-160; Le Conte (2011), p. 16.
[32] KCM, 15 March 1854; BAAS:AR, 1854, p. xxxv.
[33] The term 'photoheliograph' – 'writing with the light of the Sun' – first appears in BAAS:CM, 26 August 1857. The word sounds Herschelian, especially as Herschel claimed to be the author of a letter to *The Times*, signed 'Helioscopus', urging people to observe the Sun (Herschel to Sabine, 3 April 1857, RS:HS 15.241; 'Solar Spots', *The Times*, 6 April 1857, p. 12). Yet 'Helioscope' was the word used to describe a small solar telescope built by Christoph Scheiner in the early seventeenth century: see King (1955), pp. 41-42.
[34] De La Rue (1860), pp. 149-153.
[35] BAAS:CM, 27 June 1855; De La Rue to Herschel, 12 October 1856, RS:HS 6.137.

starting the solar work at Kew.[36] At the same time, Welsh had the complex additional task of setting up the new self-recording magnetic instruments designed to work in tandem with the photoheliograph (Chapter 3, Section 3.4).

John Welsh's final illness that led to his early death in May 1859 (see Section 4.4) further delayed the project by at least six months, but even after Balfour Stewart succeeded him in July 1859 the photoheliograph was only being used intermittently. Some of the problems were of a technical nature: for example, the Sun's intense radiation was causing stains to appear on the plates.[37] Then, for several months in 1860 the instrument was away from Kew for an expedition to Spain to photograph a total solar eclipse (to be discussed in Section 4.4). A more fundamental problem, though, seems to have been a lack of available labour at the observatory to make regular use of the instrument. In November 1859 the Kew Committee reported that 'occasional' solar photographs were being taken as opportunities arose, but that the work was 'necessarily much retarded for the want of a Photographer'.[38] The wet collodion process, though it enabled much shorter exposures than older photographic methods, had a disadvantage in that it was very labour-intensive: the plates had to be prepared immediately prior to exposure and then exposed and developed while still wet. Therefore two people were needed to produce solar images: one to take the pictures at the telescope, the other to prepare and develop the plates. But the Kew Committee did not have sufficient funds to hire an extra assistant to help with the work. On the eve of the 1860 eclipse the Committee's report lamented that 'unless a special grant be obtained, the Photoheliograph will remain very little used'.[39] In 1861, after the instrument was back from the eclipse expedition, it was decided that operating the photoheliograph interfered too much with the observatory's already very busy schedule and therefore De La Rue was asked by the Kew Committee, and agreed, to set up and run the instrument at his private observatory at Cranford, to the west of London.[40]

For a whole year, starting in February 1862, De La Rue used the photoheliograph at Cranford to take regular photographs of the Sun's disc, showing spots. By this time the technical problems had been ironed out and the instrument

[36] De La Rue to Herschel, 28 September 1857, RS:HS 6.140.
[37] BAAS:CM, 14 September 1859.
[38] BAAS:CM, 17 November 1859.
[39] BAAS:CM, 27 June 1860.
[40] BAAS:CM, 4 September 1861.

was working to De La Rue's immense satisfaction: he considered that it could take images 'so perfect that much light would be thrown on the physical constitution of the Sun if the instrument were worked "with a will" for a few years'.[41] De La Rue was assisted in the photography by a Mr Reynolds, who had also assisted him at the July 1860 eclipse and who was presumably the recipient of the £40 grant that the BAAS Council had by then agreed to pay for a photographic assistant.[42] Unlike the various salaried assistants at Kew, Reynolds is not itemised in the accounts included with the annual reports of the Kew Committee in the early 1860s, suggesting that the money was paid privately to De La Rue rather than via the Kew Committee.

De La Rue had no intention of keeping the photoheliograph permanently at Cranford: in September 1862 he expressed the hope that by the time it had completed a year's work there, steps would have been taken to have it working at Kew or somewhere else.[43] Solar photography at Cranford was duly terminated in February 1863 and by early May the instrument had duly begun work back at Kew. Soon after then, the labour shortage problem was solved by employing 'a qualified assistant' to help with the photographic work. This assistant is not named in the Council minutes or Kew Committee reports, nor is any salary included in the accounts, but in 1866 De La Rue revealed that the photographs were being taken by a 'Miss Beckly' [*sic*]. Elizabeth Beckley was the daughter of Robert Beckley, the mechanical assistant at Kew who, among other things, had built the anemometer mounted on top of the dome. In 1871 Elizabeth would marry one of the other assistants at Kew, George Mathews Whipple (see Chapter 5). De La Rue claimed that the photography

> seems to be a work peculiarly fitting to a lady. During the day she watches for opportunities for photographing the Sun with that patience for which the sex is distinguished, and she never lets an opportunity escape her. It is extraordinary that even on very cloudy days, between gaps of cloud, when it would be imagined that it was almost impossible to get a photograph, yet there is always a record at Kew.[44]

Robert Beckley lived with his family in the observatory, with his wife acting as the building's housekeeper.[45] It is likely that Sabine had some part in the idea of

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[41] De La Rue to Herschel, 14 September 1862, RS:HS 6.150.
[42] BAAS:AR, 1862; BAAS:CM, 22 November 1861.
[43] De La Rue to Herschel, 14 September 1862, RS:HS 6.150.
[44] De La Rue (1866), p. 77. The employment of Elizabeth Beckley is briefly mentioned by Schaffer (1995), p. 271 and Le Conte (2011), p. 33.
[45] KCM, 12 November 1853.

employing Elizabeth Beckley, for in 1861 he suggested 'that Mr. Beckley should have an assistant in his department of working in wood and metals, and in photographic work: *to be found, if possible, by Mr Beckley himself*' (my emphasis).[46] Significantly, Elizabeth Beckley's name does not appear on the salary list in the observatory's annual accounts, nor is there any mention after 1863 of a grant to employ a photographic assistant. Yet a diary kept at Kew in the 1860s reveals occasional payments of £5 to 'Miss Beckley', suggesting that she was paid piecemeal.[47] Sabine, with his customary political adroitness, had devolved responsibility for the labour shortage problem on to Beckley, who had solved it using casual labour from within his own family.

While woodwork and metalwork would doubtless not have been thought 'fitting to a lady', it is not difficult to imagine a father-daughter partnership at work in photographing the Sun. The daughter might have watched for precious intervals of clear sky and operated the photoheliograph, while her father prepared the plates and developed them after exposure. This is not, of course, the first time that a woman had been employed as a scientific assistant. Indeed, going back to at least the seventeenth century, women were sometimes far more than assistants: Elisabetha Hevelius in the seventeenth century actively made and analysed astronomical observations with her husband Johannes Hevelius, as did Caroline Herschel with her brother William a century later.[48] Moreover, in the early 1870s Elizabeth Beckley would also help with analysing the results from the sunspot photographs (Chapter 5, Section 5.5). However, this seems to be the earliest case of a woman being employed in the day-to-day work of astronomical *photography*. Yet although women did not have a recognised role in scientific photography in the 1860s, they were by no means excluded from the burgeoning field of *commercial* photography. Some prominent portrait photographers in the mid nineteenth century were women and one contemporary source notes that by 1873 women accounted for one-third of all photographic assistants.[49] In 1880s colonial India, a labour shortage problem would again be solved when meteorological observations in Madras came to be reported to the government by Elizabeth Iris Pogson, daughter of Madras astronomer

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[46] Sabine to [Balfour Stewart], 6 July 1861, TNA: BJ 1/29.
[47] 'Sun diary', 1863-1865, RGO 57/11.
[48] Fara (2004), pp. 130-144 (on Elisabetha Hevelius) and pp. 145-166 (on Caroline Herschel).
[49] Cited in Becker (2011), p. 182.

Norman Pogson, who had insufficient staff to cope with the extra burden of meteorological work.[50] It is plausible, then, that the unofficial employment of Miss Beckley as 'a qualified Assistant, under the immediate supervision of Mr. Beckley'[51] reflected a contemporary trend.

We can see, therefore, that the establishment of solar photography at Kew was a much more complex story than the triumphant realisation of Herschel's vision of a continuous record of the Sun's changing spots with a view to understanding nature of the Sun that had so intrigued him and his father. Most importantly, the instrument was paid for out of a private donation fund of the Royal Society. The design and early operation of the 'Kew' photoheliograph was largely in the hands of the self-funded man of science Warren De La Rue. The staff at Kew were preoccupied with other work and the Sun was photographed by Beckley and his daughter. The Kew solar photography programme was not part of any public observatory, but very much a privately-funded initiative. This would also be a characteristic of the best-known scientific work done with the photoheliograph, to be discussed in the next section.

4.4 The Kew Photoheliograph in Practice: the 1860 solar eclipse and beyond

The most important single scientific result ever obtained with the Kew photoheliograph was derived from photographs of the total solar eclipse of 18 July 1860, which was visible over southern Europe. Total eclipses of the Sun are rare events, visible only from narrow strips of the Earth's surface. Very often, they can only be seen from remote locations. In the mid-nineteenth century, therefore, expeditions to observe eclipses were difficult and costly to organise. Interest in eclipses had increased slowly but steadily among astronomers since the early nineteenth century. Francis Baily's discovery of strange 'beads' of light at the edge of the Moon during an eclipse in 1836 led the Astronomer Royal George Airy to become interested in eclipses. Airy personally observed the total eclipses of 1842 in Italy and 1851 in Sweden. During both events, Airy and others had been particularly intrigued by the mysterious red flames, known as 'prominences', seen around the edge of the Moon's silhouette when the eclipse was total. It was not then known

[50] Anderson (2005), pp. 280-281.
[51] BAAS:AR, 1863, p. xxxviii.

whether they were part of the Sun or fires on the surface of the Moon, or even caused by the Earth's atmosphere.[52]

The impetus to photograph the 1860 eclipse with the photoheliograph came from Warren De La Rue, who was one of those intrigued by the prominences. To photograph the prominences in sufficient detail, an ordinary telescope would not do, because it gave too small an image scale. This led him to decide to use the Kew photoheliograph, whose high magnification, combined with the sensitive collodion plates, might render images of sufficient quality to solve the mystery of the prominences.[53] De La Rue obtained the Kew Committee's permission to use the photoheliograph which was then, as noted in Section 4.3, insufficiently used at Kew due to the shortage of labour.[54] According to De La Rue, Airy offered, on his own initiative, to apply to the Admiralty for the use of a ship to convey the party of astronomers (including Airy) to northern Spain, where the total eclipse would be visible. Airy later confirmed that he had a successful interview with the First Lord of the Admiralty, which led to the astronomers being offered the HMS *Himalaya* for this purpose.[55]

In a classic example of the complexity of Victorian eclipse expeditions,[56] a special hut had to be built to house not only the photoheliograph but also a small darkroom immediately adjacent to the instrument, so that the wet collodion plates could be prepared just before exposure and developed immediately afterwards (Figure 4.1). This portable 'photographic observatory' was assembled from prefabricated parts made in England. Several sets of photographic chemicals had to be taken, to guard against the failure of one set in the remote observing location.[57] As Pang has emphasised, Britain's imperial infrastructure was important to the success of eclipse expeditions, but the 1860 observing effort was further complicated by its location outside the British Empire, which meant the Foreign Office negotiating customs barriers and De La Rue's party relying on a network of local geographical knowledge, at the centre of which was engineer Charles Vignoles, who

[52] Rothermel (1993), pp. 147-150; Hufbauer (1991), p. 44.
[53] De La Rue (1862b), pp. 333-334.
[54] BAAS:CM, 27 June 1860.
[55] De La Rue (1862b), p. 355; Airy (1860), p.2.
[56] Pang (2002), pp. 11-48.
[57] Gassiot (1861), p. xxxv.

at the time was helping to build the Spanish railway network.[58] The expedition was nevertheless an outstanding success. De La Rue and his assistants duly set up the photoheliograph and hut at the village of Rivabellosa in northern Spain and the total phase of the eclipse was seen in a clear sky. Two photographs taken at different stages of totality successfully showed the prominences. The movement of the Moon over the prominences during the course of the eclipse, plus the perfect coincidence of the positions of the prominences on both photographs, confirmed for De La Rue the solar origin of these features. Further corroboration was provided by photographs taken nearby by Vatican astronomer Angelo Secchi and others.[59]

Figure 4.1 The Kew photoheliograph, observing hut and observers at the 1860 total solar eclipse in Spain. Image courtesy Royal Astronomical Society.

The harmonious involvement of Airy with the Kew expedition might seem to sit uncomfortably with the story told so far of Airy's hostility to the (to him) upstart

[58] Pang (2002), pp. 121-143; Airy (1860), pp. 2-3.
[59] De La Rue (1862b), pp. 407-415.

observatory on the other side of London from Greenwich. However, it could be argued that the 1860 eclipse expedition was not really a Kew expedition at all. Of the four men who assisted De La Rue with his eclipse photographs only one, Robert Beckley, appears on the Kew Observatory salary lists. Two of the assistants gave of their services for free and the other, Reynolds, was privately employed by De La Rue.[60] Balfour Stewart has no recorded involvement with the eclipse. Neither does Sabine, quite likely because the eclipse was not a direct part of his magnetic and meteorological work. On 7 July, the day the *Himalaya* set sail for Spain, Sabine was writing to Stewart about the need to start continuous photographic recording with Francis Ronalds' self-recording barometer – a thoroughly routine aspect of the work at Kew.[61] The expedition was partly funded by £150 from the Royal Society Government Grant; apart from the loan of a ship, this was the extent of the government's involvement. In the event, the total cost of the expedition amounted to £512, the balance of £362 being paid by De La Rue.[62] The 1860 eclipse expedition can therefore be seen not as the work of Kew Observatory, but as an old-fashioned partnership between government and wealthy amateurs, in which the government provided sea transport and diplomatic support, but the science was funded largely by the practitioners themselves. In this respect it bore some similarity to the transit of Venus expedition of 1769, to which the wealthy Joseph Banks contributed much financial support, and to Herschel's self-funded expedition to the Cape in the 1830s, in which he carried out work for the government on matters such as education in the colony.[63]

The Kew photoheliograph did, nevertheless, have a great influence on solar astronomy throughout the rest of the nineteenth century and beyond, in that it set a precedent for solar photography at other observatories. By the mid-1870s, 'photoheliograph' would be the name for a number of telescopes dedicated to solar photography, of which many would be based closely on the original Kew design. The earliest of these was set up at the observatory in Wilna, Russia (now Vilnius, Lithuania). The Wilna photoheliograph may have had its origins in an 1858 visit by De La Rue to Russia, where he had learned about the upcoming 1860 eclipse. By the

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[60] Gassiot (1861), p. xxxv.
[61] Sabine to Stewart, 7 July 1860, TNA:BJ 1/29.
[62] Gassiot (1861), p. xxxv.
[63] Ratcliff (2008), p. 17; Ashworth (1998).

summer of 1862 Dallmeyer – the successor to Andrew Ross, who had built the Kew photoheliograph – was building a similar instrument for Wilna, under De La Rue's direction; at the same time the Wilna observatory's director, Dr Sabler, visited De La Rue to receive training on the Kew instrument.[64] The Wilna photoheliograph was working two years later and, with a brief interruption caused by the illness and death of Sabler and his assistant, remained in operation throughout the rest of the 1860s.[65] In 1872 Airy rated the photoheliograph highly enough that he acquired it in order to take daily solar photographs at Greenwich after the solar observation programme at Kew was terminated. The Kew photoheliograph was superseded in 1875 by a new telescope closely modelled on the Kew instrument (see Chapter 5, Section 5.3). In the same way in which it had become prestigious for instrument standardisation, geomagnetic observations and meteorology, by the mid-1870s the name 'Kew' had become associated with solar photography.

But the main object for which the photoheliograph was used in the 1860s – the study of sunspots – would provide a mass of data that would be used by Balfour Stewart, superintendent of Kew Observatory from 1859, in support of theories linking solar activity with terrestrial weather and magnetism. Stewart's work on the postulated causes and terrestrial effects of solar activity, and the resulting controversy that would be partly responsible for Stewart's resignation from Kew in 1869, is the subject of Section 4.5.

4.5 Balfour Stewart and Sun-Earth connections

For all John Welsh's unrecognised role in the origins of the Kew sunspot programme, he did not have the chance to direct it in practice. By 1858 he was suffering from serious health problems that prevented him from completing the magnetic survey of Scotland and also from attending that year's BAAS annual meeting at Leeds, Welsh being 'only fit to be handed over to the Doctor'.[66] In late November, in the hope of improving his condition, he left Kew to stay in Falmouth, Cornwall with Samuel Fox, a friend and magnetic colleague of Sabine – a further indication of Welsh's closeness to the latter. A letter to his doctor indicated possible

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[64] De La Rue to Herschel, 14 September 1862, RS:HS 6.150; BAAS:AR, 1862, p. xxxvii.
[65] BAAS:AR, 1870, p. xlviii.
[66] Welsh to Sabine, 27 September 1858, RS:Sa.1764.

tuberculosis, in several places as well as the lungs.[67] He remained active through his illness, but he did not recover. He died on 11 May 1859, aged thirty-four.[68]

Balfour Stewart began work at Kew on 1 July; a month later the Kew Committee officially appointed him as John Welsh's successor.[69] As noted in Chapter 3 (Section 3.4), Stewart had worked at Kew as an Assistant Observer from March to October 1856 and during his brief stay he had made a name for himself by inventing a new type of thermometer. This experience at Kew made him, according to the Kew Committee, 'peculiarly fitted' to be the new superintendent.[70] In some ways he had a similar background to Welsh: he was just four years younger, born into a middle-class family of Scottish merchants and studied natural philosophy at Edinburgh under James Forbes. He might therefore seem to be Welsh's 'natural successor' at Kew,[71] but in fact the Committee reported that Stewart was one of six applicants for the post. One of the other applicants was James Breen, who for eleven years had worked as an assistant astronomer to James Challis, Plumian Professor of Astronomy at Cambridge University; Breen's application had come with Challis's recommendation.[72] That it attracted an applicant – and a referee – of such distinction is a sign that the most senior paid position at Kew was becoming highly sought after. In addition, back in 1855 James Forbes had not been unreservedly enthusiastic about Balfour Stewart when Welsh had asked about hiring him as an assistant; he wrote that Stewart was scientifically competent and hoped he would be hired, but that 'his manner is at first a little dry.' This was after Forbes had earlier written that he wanted to see more of Stewart's capabilities before committing himself to judgement.[73] However, the Committee selected Stewart for the position on the grounds that Welsh had 'repeatedly expressed to the Chairman his desire to have the assistance of Mr Stewart' and that all the others on the Kew staff wanted Stewart to be appointed.[74]

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[67] Welsh to Sabine, 6 December 1858, RS:Sa.1767; Samuel J Fox to [headed 'Copy; to Dr Bence Jones'], 27 December 1858, RS:Sa.1768.
[68] Anon. (1859-1860), pp. xxxiv-xxxviii.
[69] KCM, 1 August 1859.
[70] BAAS:CM, 14 September 1859.
[71] Anderson (2005), p. 145.
[72] KCM, 1 August 1859; Clerke and Gross (2004); Hutchins (2008), pp. 70-71 and 126.
[73] Forbes to Welsh, 18 December 1855, TNA:BJ 1/9; Forbes to Welsh, 20 October 1855, TNA:BJ 1/9.
[74] KCM, 1 August 1859.

In fact, Stewart was different from Welsh in some important ways. Since leaving university as a very young man, Welsh had worked under the patriarchal Sir Thomas Brisbane at the Makerstoun Observatory before moving on to become Sabine's faithful subordinate at Kew. Stewart, by contrast, had spent his first ten years after university outside science altogether, in a business career that culminated with a short spell in Australia. After his short first period at Kew, he returned to Edinburgh to work as an assistant to Forbes in teaching and laboratory work. He was able to do some research of his own; during this period he published what turned out to be his most important work, in which he showed that radiation did not emanate just from the surface of a body but worked throughout that body – rather like absorption, to which, as Stewart showed, radiation was equivalent, anticipating Kirchhoff and Bunsen's ground-breaking 1859 radiation laws and triggering a priority dispute with Kirchhoff. This and other papers by Stewart showed a strong theoretical bent as well as considerable grounding in experiment.[75] Therefore by the time he returned to Kew in 1859, Stewart was a mature man who had established a firm reputation as an independent scientific researcher. In addition, he was used to working on his own initiative in a university environment that concentrated on teaching and research – very different from the highly utilitarian work such as instrument standardisation that formed the backbone of the regime at Kew. He was less likely to be comfortable in the humble position that Welsh had accepted, for all the latter's originality as an experimentalist. This needs to be taken into account when we try to understand Stewart's actions as superintendent at Kew over the next decade.

Stewart's career at Kew began, almost literally, with a bang. On the morning of 1 September 1859 Richard Carrington, scion of a wealthy brewing family with the means to practice astronomy full-time, was routinely observing the Sun from his observatory at Redhill, Surrey, when he noticed a pair of intensely bright points of light appear in front of a large sunspot group. Over the next five minutes these moved perceptibly across the sunspot before fading from view. At the time, Carrington was one of Britain's most respected observational astronomers, with a reputation as a meticulous cataloguer of star positions as well as a solar observer.

[75] The dispute between Stewart and Kirchhoff and their respective supporters is described in Siegel (1976). The most detailed biography of Stewart is by Schuster (1888). Other biographies can be found in T[ait] (1887), Schuster (1932), and Hartog and Gooday (2004).

His September 1859 observation was part of a long-term programme of visual sunspot recordings in the manner of John Herschel, carefully plotting sunspots on a projected image. Carrington carefully noted the start and finish times of this ‘singular appearance’, as he called it. His observation of the brilliant points of light was confirmed by another British astronomer, Richard Hodgson, who had been observing the Sun at the same time, and both later presented accounts of their observations at a meeting of the Royal Astronomical Society. One or more days after 1 September, Carrington visited Kew Observatory, presumably to see whether any photographs had been taken of the event with the photoheliograph. According to a later account by Charles Chambers, by then the chief magnetic observer at Kew, Stewart was away when Carrington called, so Chambers himself received him. The photoheliograph was still used only intermittently (see Section 4.3), and no pictures of the Sun had been taken on 1 September. However, for several days before and afterwards the self-recording magnetometers had registered wild variations, an event known as a ‘magnetic storm’, and great displays of the aurora were seen from many parts of the world, including London. When Carrington and Chambers examined the magnetometer traces for 1 September they immediately noticed a pronounced jump at the exact time when Carrington had seen the points of light on the Sun.[76]

The phenomenon witnessed by Carrington and Hodgson,[77] as well as the magnetic disturbances in the days around it, seems to have sparked Stewart’s interest in the Sun and its relationship with terrestrial magnetism, as Stewart’s published work and correspondence after 1859 shows a distinct turning towards this topic. In a paper published in the Royal Society’s *Proceedings* in 1861, Stewart described the 1859 disturbances as recorded at Kew and proposed a possible explanation, that the longer-term disturbances lasting hours were caused by a large ‘primary’ electric current emanating from the Sun, while shorter and more sudden disturbances were due to slight variations in this current that induced secondary currents on the earth’s surface and atmosphere, the latter causing aurorae.[78] Sabine, in a powerful position from 1861 as President of the Royal Society, took great interest in the Carrington event and initially showed broad agreement with many of Stewart’s views on the magnetic disturbances. Sabine was happy to speculate with Stewart about the 1859

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[76] Carrington (1859); Hodgson (1859); Stewart to Sabine, 14 November 1859, RS:Sa.1380.
[77] This is now known to be a powerful and extremely rare type of solar flare.
[78] Stewart (1861).

event. He himself wrote to Stewart about a ‘curious theory’ advanced by Emmanuel Liais, chief meteorologist at Paris Observatory, which proposed that the Sun’s heat was being continually replenished by ‘aerolites’ (meteors) falling into it; the friction of these bodies falling through the solar atmosphere caused electricity and hence sunspots and magnetic disturbances. Moreover, the incidence of these aerolites, and hence sunspots, was ‘regulated by the attractions of the planets near the Sun, and to have then nearly a decennial period, (due to the great influence of Jupiter)’. In the same letter Sabine wrote approvingly of Stewart’s analysis of the 1859 event.[79] Similarly, when Stewart thought that he had found a correlation between sunspot activity in the Sun’s southern hemisphere and magnetic disturbances on Earth, Sabine thought his enquiry ‘well worthy of being followed up’.[80]

More dramatic was Stewart and Sabine’s agreement on a relation between the Sun and displays of the aurora. In August 1862 Stewart revived (without acknowledgement) Herschel’s 1852 assertion that the red flames seen during eclipses were aurorae on the Sun (Section 4.3). Sabine responded enthusiastically and took the speculation further, suggesting that the solar ‘aurorae’ triggered aurorae on Earth and wondered whether ‘all the planets participate in such appearances, though we may never attain to their observation’. Stewart expressed himself ‘delighted’ at Sabine’s agreement and suggested a variety of observational evidence in favour of the red flames on the Sun being aurorae, including their red colour, their possibly changeable appearance and their greatest frequency coinciding with periods of magnetic disturbance on Earth. As to Sabine’s suggestion that aurorae might occur on all the planets, Stewart wondered whether ‘perhaps Mr De La Rue could photograph one [of the planets] during an Aurora and ascertain this’.[81] Stewart publicised his views on the red solar ‘protuberances’ in the *Philosophical Magazine*, a scientific periodical which, as Crosbie Smith has noted, had a large readership and was receptive to articles with a speculative element. Stewart gave full

[79] Sabine to Stewart, 26 November 1860, TNA:BJ 1/29.
[80] Stewart to Sabine, 18 October 1861, RS:Sa.1459; Sabine to Stewart, 21 October 1861, TNA:BJ 1/29.
[81] Stewart to Sabine, 27 August 1862, RS:Sa.1479; Sabine to Stewart, 31 August 1862, TNA:BJ 1/30; Stewart to Sabine, 1 September 1862, RS:Sa.1481. Photographic technology was not then capable of photographing aurorae on other planets, but in 1997 the Hubble Space Telescope photographed aurorae around the poles of Saturn, believed to be caused by particles from the Sun – over a century after this initial prediction by Sabine and Stewart (Van Allen and Bagenal (1999), p. 50).

acknowledgement to Sabine for the idea that the Sun could trigger aurorae on other planets.[82]

It was partly for his work on relations between aurorae, magnetic disturbances and earth currents that Stewart was elected a Fellow of the Royal Society in June 1862, thus putting him on an equal scientific rank with John Welsh, his deceased predecessor at Kew.[83] Yet his election certificate and his 1 September 1862 letter to Sabine both indicate another preoccupation of Stewart's: fundamental physics. Stewart's work on radiation formed part of the citation for him being elected FRS and, as noted above, had been the most significant achievement of his scientific career before he became superintendent at Kew. Now, in his reply to Sabine, Stewart envisioned the electric current emitted by the Sun as being in two components, one moving towards and the other away from the Earth, and that the total magnetic action experienced on Earth was the difference between the two components. He suggested that sunspots could be breaks in one of these currents and that such a break represented a small change in the value of one of these components which could, in his words, 'produce very powerful effects'.[84] This idea that small changes in the Sun's output could produce powerful effects elsewhere in the universe would shortly become important in Stewart's scientific writings, as we shall see below.

Stewart soon went much further in his explorations into the causes and effects of sunspots. From 1864 he collaborated in a series of papers for the Royal Society that carefully described the changing positions of the spots and levels of solar activity, the latter being estimated by measuring the total area of the Sun's surface covered by sunspots as shown on the photoheliograph images. Stewart's co-investigators were De La Rue, who designed a special machine for measuring the sunspot areas, and Benjamin Loewy, an assistant responsible for reducing the measurements to a publishable form. Stewart claims to have taken on Loewy in early 1864 at a salary of £60 per annum,[85] yet he does not appear on any of the Kew salary lists published in the BAAS reports. It is likely that his salary was paid by the wealthy De La Rue, especially as some of Loewy's correspondence with Stewart

[82] Smith (1998), p. 63; Stewart (1862), esp. p. 304.
[83] Balfour Stewart, Royal Society Election Certificate, 1862, RS:EC/1862/12.
[84] Stewart to Sabine, 1 September 1862, RS:Sa.1481.
[85] Stewart to Sabine, 17 February 1864, RS:Sa.1512.

bears the letterhead of De La Rue's Cranford observatory. Little is known of Loewy's life, though we do know that before coming to Kew he worked as an assistant at the Flagstaff Observatory in Melbourne, Australia, a magnetic and meteorological observatory whose regime seems to have been similar to that at Kew in its early years.[86] According to Arthur Schuster, Loewy had come to Kew on the recommendation of the Flagstaff Observatory's director, Georg Balthasar von Neumayer.[87]

From the early 1860s, Stewart also began using the Kew sunspot results in support of his theoretical researches. In April 1864 he read a paper to the Royal Society of Edinburgh in which he claimed to have found, using data from photoheliograph images, a correlation between outbreaks of sunspots at certain longitudes of the Sun's surface and the drawing-away of planets from above those longitudes. Later in this paper it becomes clear that Stewart had much broader aims: he explained that spot production is suppressed when a planet approaches the Sun due to 'the preferential radiation' of the smaller body towards the larger one. This radiation, according to Stewart, is caused by the smaller body's motion through the ether – the invisible, all-pervading medium which by the mid-nineteenth century had become important in theories of light and heat propagation, thanks to the widespread acceptance of the wave theory of light and the application of analytical mathematics to the science of optics.[88] In the vanguard of this mathematical ether physics were Stewart's fellow 'North British' natural philosophers James Clerk Maxwell and Peter Guthrie Tait. Stewart gave Tait partial credit for the idea of bodies radiating due to their motion. In his paper he likened the radiative effects of moving bodies in space to those of atoms.[89] Three months later, in a letter to Sabine about magnetic disturbances, he expressed the belief that an understanding of motions and their effects on the interplanetary scale might in fact help us to understand motions at a molecular level:-

> I feel it difficult to conceive how we can ever thoroughly ascertain the real nature of molecular forces unless we have some natural [analysis?] to guide us such as that which supposes the planetary & solar systems – to be on a large scale what the

[86] BAAS:CM, 14 September 1864; 'Flagstaff Observatory, 1858-1863', http://museumvictoria.com.au/collections/themes/1630/flagstaff-observatory-1858-1863.
[87] Schuster (1932), pp. 213-214.
[88] Stewart (1864); Cantor and Hodge (1981), pp. 49-50.
[89] Stewart (1864).

> atomic systems are on a small. If this be true it is of the utmost importance to study those cosmical forces [?]led on a large scale which we have the opportunity of doing in order perhaps to arrive at the nature of those which act on so small a scale that we cannot directly investigate them[90]

This is the earliest recorded instance in which Stewart used the word 'cosmical' when referring to fundamental physical theory. In the years to come he would return to this 'cosmical' theme when attempting to explain relations between the Sun, geomagnetism and meteorology, notably in his inaugural lecture when he took up the Professorship of Natural Philosophy at Owen's College, Manchester in 1870.[91]

For Stewart, the ether was crucial to understanding these 'cosmical forces'. Stewart and Tait believed that moving bodies dissipated their energy via friction with the ether: in December 1863 Stewart informed Sabine of an experiment that appeared to show that a rapidly-rotating disc had a slightly higher temperature than a stationary one, due to its motion 'through etherial [*sic*] space'. He now proposed using part of a £50 Royal Society Donation Fund grant to construct an apparatus to test the heating of a rotating disc in a vacuum, thus eliminating friction with the air as a source of heating.[92] The results were published in two papers in *Proceedings of the Royal Society* in 1865: again the rotating disc produced a small, yet detectable heating effect.[93] In a letter to Sabine – though not in either paper – Stewart asserted that: 'If we thoroughly prove these results they will I fancy be connected with celestial appearances and sun spots…', again making a link between the sunspot measurements and Stewart's wider physical theory. He also asked if it were possible to have another £25 in order to complete the investigation.[94] Two months later Stewart was again asking for money ('I do not think that more than £100 would be necessary') for another experiment to test the idea that a small body radiated more heat (via the ether) when close to a large body than when further away.[95]

Crosbie Smith and Graeme Gooday have argued that the driving influence behind all these ideas was the strong religious convictions of Stewart and others in the North British group, who saw a need to defend a Christian cosmology against

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[90] Stewart to Sabine, 12 July 1864, RS:Sa.1515.
[91] Gooday (2004), p. 130.
[92] Stewart to Sabine, 29 December 1863, RS:Sa.1510.
[93] Stewart and Tait (1865a); Stewart and Tait (1865b).
[94] Stewart to Sabine, 17 February 1865, RS:Sa.1538.
[95] Stewart to Sabine, 27 April 1865, RS:Sa.1540; Stewart to Sabine, 13 May 1865, RS:Sa.1544.

natural philosophers of a materialist persuasion, most notably John Tyndall, who exploited the now fashionable principle of the conservation of energy to argue for a purely deterministic universe. The North British group believed, in accordance with the Scriptures, that the universe had a finite lifetime and so that all the energy contained therein would eventually have to be dissipated. The ether offered a medium through which energy could be dissipated without violating the principle of the conservation of energy. Stewart's best-known defence of his Christian cosmology was the 1875 popular book *The Unseen Universe*, co-authored with Tait, which became a widely-read statement of the case for the compatibility of science and religion.[96] Yet Stewart was arguing the same case while he was still superintendent at Kew. In the second of two articles for the semi-popular literary and scientific *Macmillan's Magazine*, published in July and August 1868, Stewart argued for a 'principle of delicacy', in which the Sun had an extremely sensitive molecular structure which could easily be affected by the changing positions of the planets Venus and Jupiter, thus causing sunspots to form. He likened this principle to a similar one that he believed existed in human beings: human thought, he believed, required a minuscule input of energy, yet could cause huge change, in the same way as that the tiny amount of energy involved in pulling a trigger could have a lethal effect. From this he inferred that a 'Supreme Intelligence' might have a massive influence through exerting tiny amounts of energy through the 'delicate' universe.[97] Something like this 'principle of delicacy' can be discerned in Stewart's 1 September 1862 letter discussed above, in which he suggested that a small change in the Sun's electrical output could 'produce very powerful effects'.[98]

Stewart co-authored both *Macmillan's Magazine* articles with J. Norman Lockyer, an astronomer and science writer who in 1868 was soon to shoot to fame for co-discovering (with French astronomer Pierre Janssen) that the Sun's 'red flames' could be studied outside an eclipse by means of the spectroscope, and also for the discovery of a new chemical element in the solar spectrum, which he named 'helium'.[99] By 1868 Lockyer was a close friend of Stewart and they would remain collaborators long after Lockyer founded *Nature* the following year. While it is

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[96] Smith (1998), pp. 253-255; Gooday (2004), esp. p. 128.
[97] Stewart and Lockyer (1868), esp. p. 327.
[98] Stewart to Sabine, 1 September 1862, RS:Sa.1481.
[99] Meadows (2008), pp. 51-60.

reasonable to suppose that these two came to know each other at meetings of the Royal Astronomical Society in the early 1860s,[100] archival evidence suggests that Lockyer also visited Kew in this period. On 6 January 1863 Sabine informed Stewart that he had 'had an application for a Mr. Lockyer of Wimbledon to be allowed to see the Observatory. I do not know what may be the amount of his instrumental knowledge or interest.' Stewart replied that he would be happy to show Lockyer around.[101] Sabine's reference to 'a Mr. Lockyer' demonstrates how little-known Lockyer was in the early 1860s, when he was working full-time at the War Office and his astronomical activities were often restricted to evening observations from his garden in Wimbledon. If Lockyer visited Stewart at Kew sometime in January 1863, the two of them would have had the opportunity to exchange ideas in private, away from the hubbub of London scientific meetings, at precisely the time when Stewart was developing his ideas on the aurora, 'delicacy' and 'cosmical' forces and Lockyer was open to new ideas at the beginning of his career.

Exactly what Sabine thought about all this theorising by Stewart and his friends is not known, because he does not refer to it directly in published reports and some of his letters from the mid-1860s are missing from Stewart's papers in the Kew Observatory archives. But from the defensive tone of some of Stewart's replies we can tell that Sabine had at least some reservations. For example, his theory of planetary influences on sunspot formation must have been too much for Sabine, for in January 1865 Stewart wrote, regarding a paper on this subject that he had sent to the Royal Society: 'I do not think that sun spots are the work of venus [*sic*]'; he thought merely that Venus had 'the effect of <u>regulating</u> the phenomena the <u>predisposing</u> cause of which is to be looked for elsewhere'.[102] His 27 April proposal to spend £100 on an experiment to test the radiation of heat from a small body at varying distances from a large one could not have been well received either – and not only by Sabine, for it seems from Stewart's 13 May response that George Gabriel Stokes, Lucasian Professor of Mathematics at Cambridge and Secretary of the Royal Society, found the idea 'speculative'. Stewart responded with a strident reminder to Sabine that:-

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[100] Gooday (2004), p. 119.

[101] Sabine to Stewart, 6 January 1863, TNA:BJ 1/30; Stewart to Sabine, 8 January 1863, RS:Sa.1496.

[102] Stewart to Sabine, 16 January 1865, RS:Sa.1535.

> there is no doubt from your own observations that there is a connexion between the sun & the earth different from a mere gravity influence I need only allude to the connexion between sun spots & magnetic disturbances.

Stewart conceded 'that we tried to push the thing on too fast' and proposed to just carry on with the rotating disc experiment.[103] Stewart was still defensive about his rotating disc experiments in December 1866: referring to a less than enthusiastic response to his latest paper on this subject read to the Royal Society the previous evening, he emphasised to Sabine that the heating effect observed in the rotating disc 'is a new result – both [William] Thomson and Maxwell consider that a new fact has come to light' – strategically deploying two of the most prestigious names in 1860s physics.[104]

Gooday has argued that Stewart, as a theory-driven natural philosopher, sought to understand the big picture of meteorology, geomagnetism and solar activity as part of his 'cosmical' view of physics. To this end he insisted, against the wishes of the Kew Committee, on recording levels of atmospheric water vapour as part of an attempt to understand large-scale atmospheric dynamics, and he also unsuccessfully asked Sabine for a full ten years' worth of magnetic results with a view to understanding the relationship between the Sun and terrestrial magnetism over an entire sunspot cycle. Both requests brought him into conflict with Sabine and Gassiot: their aims took the form of 'a gentlemanly "natural history" of meteorological observations' that involved collecting and presenting large amounts of data as an end in itself, with no need for any theoretical extrapolation from the results. The conflict led ultimately to Stewart's resignation from the observatory.[105] It is certainly true that Stewart conflicted with Sabine over both requests: he was only able to complete the ten-year magnetic tabulations with a donation of £400 from Gassiot's personal fortune,[106] and, as we shall see below, he made water vapour recordings a condition of withdrawing his resignation in 1869. A further reason for personal animosity between Sabine and Stewart should be noted: as Smith has pointed out, Sabine was a good friend of Tyndall, Stewart's arch-opponent in the

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[103] Stewart to Sabine, 13 May 1865, RS:Sa.1544.
[104] Stewart to Sabine, 7 December 1866, RS:Sa.1580.
[105] Gooday (1989), pp. 32-40, esp. p. 32.
[106] BAAS:AR 1870, p. lvi.

'unseen universe' debate;[107] in addition, Sabine and Tyndall were both from Irish Protestant backgrounds and so might have felt a kinship in terms of religious background.

But in 1865, the situation at Kew was complicated by a personal tragedy. On 30 April Robert FitzRoy, head of the Meteorological Department of the Board of Trade, committed suicide. It was widely believed by contemporaries that FitzRoy took his own life partly due to a highly-strung temperament but also because he had become demoralised by increasing criticism from scientific colleagues of the accuracy of his weather 'forecasts' (FitzRoy's own term). Within days of FitzRoy's death, the Board of Trade asked the Royal Society for advice as to how the Meteorological Department should be run in the future. Sabine, as President of the Royal Society, took the initiative at once. He joined the chorus of those criticising the 'unscientific' methods of the Department under FitzRoy and as early as 15 June 1865 wrote a letter to the Board of Trade, calling for a larger number of meteorological observations to be made. Hitherto the Department had only collected observations made at sea, but now, to bring Britain into line with other nations, Sabine called for observations to be made on land in the British Isles as well as at sea, and that these land observations should be collated and published at a 'central office'. Most importantly, in the same letter he recommended that Kew Observatory could be used 'as the central meteorological station' to standardise and supply self-recording instruments to a string of land observatories distributed in a north-south line across the British Isles, and to receive the resulting observations.[108] The Board of Trade appointed a committee, with representatives from the Admiralty and the Royal Society as well as the Board, to report on the Meteorological Department's current activities and draw up recommendations for its future.

The Royal Society's representative on this committee was Francis Galton, who was then best-known as a meteorologist and a geographer. A leading member of the Royal Geographical Society, in 1863 he had published *Meteorographica*, a book on mapping the weather. Because Galton chaired the committee, the report that it presented to parliament on 13 April 1866 has become known to historians as the 'Galton Report'.[109] It criticised the Department's data gathering methods under

[107] Smith (1998), pp. 178 and 179.
[108] Sabine to T H Farrer (Board of Trade), 15 June 1865, in Board of Trade (1866), pp. iii-v.
[109] Burton (1988), pp. 59 and 255; Walker (2012), p. 60.

FitzRoy and, especially, the weather forecasts. To much controversy among sailors, members of Parliament and the wider public, it recommended that both the forecasts and FitzRoy's system of storm warnings (the latter especially popular with sailors) should be suspended until such time as they could be placed on a scientific basis. The collection of data, the report stipulated, should now be supervised by 'a scientific body'; alternatively, Kew Observatory could be adapted for this purpose. As in Sabine's June 1865 letter, the report recommended a series of six meteorological observatories, each with an identical set of self-recording instruments and that Kew become the nerve centre to which data from these outstations should be sent.[110]

Galton has received credit for writing the report. In support of this assertion, Katharine Anderson has noted that he was the only member of the committee who (like his cousin, Charles Darwin) had ample independent means with which to pursue his scientific interests and so had time to draw up the report.[111] But the report's recommendations for the land meteorological observations clearly bear a suspicious similarity to Sabine's June 1865 letter to the Board, especially the idea that Kew should become the central observatory. Galton was a good friend of Sabine's and shared the latter's predilection for gathering large quantities of statistics. He had also been a member of the Kew Committee since 1860 and had begun supervising the testing of sextants at Kew in connection with his Royal Geographical Society work; he seems to have commanded enough authority to have had some stone posts erected in the observatory grounds in connection with this.[112] A letter from Galton to Sabine, written just after the report was published and explaining his reasoning behind it, is particularly revealing. Galton's suggestions for 'putting the whole of the meteorology into the hands of Kew' and that the reconstructed Meteorological Department would act as 'a branch office in London' reporting to Kew would have been music to Sabine's ears.[113] That Galton probably colluded with Sabine in the so-called 'Galton Report' is consistent with Sabine's

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[110] Board of Trade, (1866).
[111] Anderson (2005), pp. 123-124.
[112] BAAS:CM, 28 June 1861; Galton to Stewart, 5 July 1860, TNA:BJ 1/24. In his autobiography, Galton notes Sabine's influence in bringing him onto the Kew Committee. (Galton (1909), p. 225) The minutes of the Kew Committee confirm that Galton was elected to the Kew Committee 'on the proposition of Genl. Sabine' (KCM, 28 May 1860).
[113] Galton to Sabine, 16 March 1866, RS:Sa.586; also cited in Anderson (2005), p. 140 and Burton (1988), p. 58.

track record of manoeuvring behind the scenes to achieve his aims. In the sense that it gave Sabine control over British land meteorology, via Kew Observatory, the report is an echo of Sabine's machinations, described in Chapter 2 (Section 2.3), for a meteorological and magnetic observatory independent of Greenwich. Indeed, Sabine's and Galton's proposals did not include any role for the Magnetic and Meteorological Department at Greenwich. Predictably, this angered George Airy, who began a heated correspondence with the Royal Society Council, asserting that even Kew's 'very respectable position' did not justify the Council 'in absolutely setting aside all notice of the Government Observatory'. The Council took no action on this letter.[114] This was not long after a separate dispute, earlier in the 1860s, in which Airy had challenged Sabine as to the necessity of continuing the magnetic observations at Kew while the same observations were being carried out at Greenwich. Airy believed that this work was best done at Greenwich. He gave his reasons for this view in an address to the Greenwich Board of Visitors, in which Airy claimed that he saw it as his duty 'as National Observer' to measure and print the figures shown by the Greenwich instruments.[115] Now, the new proposals by Sabine and Galton once again challenged Airy's prestige as the 'National Observer'.

Making Kew the central meteorological observatory, with responsibility for reducing, tabulating and publishing the results from the six proposed outstations as well as standardising and inspecting the instruments for these observatories, would dramatically increase its workload – and that of its superintendent. Stewart gave his reactions to the Galton Report's proposals in a series of three letters to Gassiot, the first written a month after the report was published. Stewart said that he would decline to remain as superintendent if Kew were to be dedicated entirely to meteorology, or if his job were to be divided into two posts, one running the current work being done under the BAAS and the other working for the Board of Trade. But if both branches of work were to be placed under one director, Stewart said he would be happy to remain in the position.[116] His only reservation was about the reductions of the land observations. He asked if these could be done elsewhere, as the Board

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[114] Airy to George Gabriel Stokes, 31 March 1866, RS:MC.7.317; RS:CM, 19 April 1866. Airy's letters to the Council are briefly referred to in Anderson (2005), p. 143 and Walker (2012), pp. 59-60.
[115] Address to the Visitors of the Royal Observatory, Greenwich, by the Astronomer Royal' (confidential), January 1863, RGO 55.
[116] Stewart to Gassiot, 17 May 1866, RS:Sa.1571.

was planning to do with the marine observations.[117] But the Kew Committee does not seem to have entertained this possibility, as well they might not, given Sabine's desire for control over the observations: 'the Superintendent of Kew Observatory should also be responsible reducer of all the observations.' Stewart nevertheless agreed to put his name forward to continue in the role and agreed to 'make every possible arrangement to devote my whole time to the duties of this office'. He also solemnly agreed to cease work on the experiments he was doing in collaboration with Tait (presumably those connected with ether) and also to stop spending any time on the sunspot investigations after he had finished the paper he was currently writing with De La Rue and Loewy.[118]

Stewart also expressed the belief, apparently on his own initiative, that the Kew Committee's duties under the proposed new regime would be eased if they had the services of a secretary who would 'make himself acquainted with the whole concern & who might be always at hand'. Stewart then volunteered himself for this position: 'I think that, if not at the very first at least ultimately the Supt. of the Kew Obsy might undertake this office'.[119] In October 1866 the Kew Committee and the Council of the Royal Society held a joint meeting, at which it was agreed that the system of meteorological observatories would be run by a 'Superintending Scientific Committee' whose members would be unpaid but which would need 'a competent paid Secretary' – five months after Stewart had volunteered his services.[120] Stewart's putting himself forward and, indeed, suggesting the creation of the Secretary's position, may have been because he saw it as an opportunity to increase his salary, which was still just £200 per annum, well short of that earned by James Glaisher, head of the Magnetic and Meteorological Department at Greenwich. It was with the aim in mind of increasing his annual income to £400 that in 1861 he had written to Sabine to explore the possibility of his also taking on the position of Secretary to the BAAS.[121] By the mid-1860s, Stewart was married with a young family, so he would have had an additional motive to increase his income.

Stewart's hopes of a pay increase were rewarded when in January 1867 his salary was increased to £400, on the understanding that he served both as

[117] Stewart to Gassiot, 28 May 1866, RS:Sa.1572.
[118] Stewart to Gassiot, 7 June 1866, RS:Sa.1573.
[119] Stewart to Gassiot, 28 May 1866, RS:Sa.1572.
[120] BAAS:CM, 4 September 1867.
[121] Stewart to Sabine, 7 October 1861, RS:Sa.1458.

superintendent of Kew Observatory and as Secretary to the Board of Trade's Scientific Committee, by now renamed the Meteorological Committee. This new committee, chaired by Sabine, had eight members, five of whom were either on the Kew Committee or had served on it recently.[122] Robert Henry Scott was appointed as FitzRoy's successor at the head of the Meteorological Department, very likely through his friendship with Sabine[123] – another indication of Sabine's desire for control over the meteorological observations. By the summer of 1868 self-recording instruments had all been verified at Kew and sent to the observatories which were established at Falmouth, Stonyhurst (Lancashire), Glasgow, Aberdeen, Armagh and also Valencia on the west coast of Ireland.[124]

Stewart's fears about the increased workload at Kew soon proved to be justified, as the new observatories were soon sending a flood of data to the central station. In January 1867 his request for some extra money to pay Loewy to help with the reductions went nowhere.[125] Stewart's further complaints six months later brought some stern admonition from Gassiot, who explained to Stewart that his requests for assistance had always been treated with 'the most liberal spirit', but that he had to 'bear in mind that in addition to your duties of Superintendent you have also undertaken those of Secretary and … you are the [certain?] & responsible officer of the Meteorological Committee'. Gassiot ended the letter with a warning that Stewart would now have little time for experiments requiring his 'personal investigation'.[126] Stewart did manage to hire a junior assistant, but Sabine's letter of 31 July, setting out how this assistant should be employed, again has the tone of a schoolteacher disciplining a wayward pupil: while waiting for the meteorological data to come in, said Sabine, the 'youth' should be employed in tabulating the magnetic results, as Stewart would find the resulting experience very valuable 'when ere long, you will have to state the pecuniary aid you will require as a central meteorological Observatory'. In the same letter Sabine assured Stewart that it was not the aim of the BAAS or the Kew Committee 'to view the ultimate purpose of the photograms [the traces from the self-recording instruments] as accomplished by their

[122] BAAS:CM, 4 September 1867.
[123] Burton (1988), pp. 70-72.
[124] BAAS:AR, 1868, pp. xliii and xliv.
[125] Stewart to Sabine, 5 January 1867, RS:Sa.1586.
[126] Gassiot to Stewart, 23 July 1867, TNA:BJ 1/24.

being merely put away in drawers for safe keeping'.[127] In 1876, some years after leaving Kew, in an article for Lockyer's journal *Nature*, Stewart used an identical phraseology in criticising the meteorology of the past, as having been conducted by 'Royal Societies and Astronomical Institutions' (such as the Royal Society and the former King's Observatory at Kew), and whose results 'were reduced after a mechanical and strictly statistical method, and then put aside in a drawer'.[128] That Sabine's words should rankle with Stewart such that he could throw them back in his face some nine years after they were written demonstrates the strength of Stewart's feelings about the regime at Kew.

As if all this were not enough, the standardisation work begun at Kew in the early 1850s (Chapter 3, Section 3.3) continued throughout the 1860s. Until the mid-1860s around 100 barometers and 400 thermometers were being verified and issued with certificates at Kew each year; by 1869 the number of thermometers tested each year had increased to over 1,100.[129] The construction of self-recording instruments for foreign observatories – such as the Coimbra Observatory in Portugal, to which instruments were sent in 1867 – also remained central to the work at Kew.[130] A request from a brewery in 1869 for a standard thermometer suggests that Kew was also becoming recognised in the commercial sector as a source of high-quality instruments.[131] Indeed, Kew had become so well-known that, as John Davis has persuasively argued, French scientists began lobbying for a dedicated magnetic and meteorological observatory along the lines of Kew; by 1870 such an institution, partly modelled on Kew had been established at Montsouris, a mile from Paris Observatory.[132] Even before the workload increased after the Meteorological Department reorganisation, the modest two-storey Georgian building must have been a cramped space in which to work. By now the BAAS had the use of the entire building, but with the magnetic instruments in the basement, the photoheliograph and accompanying apparatus in the dome, plus the meteorological and magnetic reductions and instrument standardisation taking place in the middle floors, there was no room to spare. This lack of space was recognised in the Galton Report and

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[127] Sabine to Stewart, 31 July 1867, TNA:BJ 1/30.
[128] Quoted in Gooday (1989), p. 7-36.
[129] BAAS:AR 1869, p. xlv.
[130] BAAS:CM, 6 September 1865.
[131] Jackson & Co. (brewery) to Kew Observatory Secretary, 17 August 1869, TNA:BJ 1/26.
[132] Davis (1984), pp. 363 and 377-379.

money was provided for an additional outbuilding and alterations to an existing outhouse in the observatory grounds.[133]

Despite his assurances to Gassiot in 1866 that he would give up the solar work and other independent research, in the event Stewart continued with both. In 1869 Stewart was still applying, successfully, for grant money from the Royal Society to continue his rotating disc experiments. He also continued to co-author papers on sunspots and their possible periodicities with De La Rue and Loewy, and popularised his solar results in articles such as those in *Macmillan's Magazine* in 1868. It must therefore have been very frustrating for Stewart to have to spend so much of his time on work for the Meteorological Department (known as the Meteorological Office from 1867). It is in this context of extreme frustration that we need to regard his and Lockyer's *Macmillan's* articles. As Gooday points out, to explain to their readers the concept of potential energy, Stewart and Lockyer used the analogy of the upper classes in society automatically having power over the lower orders, which in Stewart's case may well have been a metaphor for the oppressive regime imposed by the wealthy and influential Sabine.[134]

A much more direct and vehement attack on the Kew regime appeared in an anonymously-authored article in the *Athenaeum* on 3 October 1868. Near the beginning, the article described 'a class of observations which may be called Cosmo-Physical observations, of immense importance at the present moment' and asserted that 'we are on the eve of some grand generalization' which would encompass sunspots, magnetic disturbances and meteorology and demonstrate the connections between them (quoted in full in the second epigraph at the head of this chapter). The article praised the 'excellent' techniques with which the observations were being made at Kew and likened the observatory to 'the head-quarters of an invading army' which, however, was now being starved of supplies, in the form of funding to reduce all the data.[135] This military metaphor is surely a reference to Sabine, by now a General of the Royal Artillery. The article's emphasis and phraseology, especially the reference to 'Cosmo-Physical observations', points the finger towards Stewart and Lockyer as authors. The article's call for increased public funding for science is also a hallmark of Lockyer, who after 1870 became an outspoken advocate for state

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[133] BAAS:CM, 4 September 1867.
[134] Gooday (2004), p. 127.
[135] Anon. (1868a), pp. 436-437.

support of science (see Chapter 5, Section 5.4). Stewart's authorship is also made clear by the similarity of this article's language to one by Stewart in *Nature* a year later, in which he criticised meteorology for lacking an overall theory as to the workings of the Earth's atmosphere and again opted for a military metaphor when describing our current picture of meteorology:-

> We are like a soldier in the midst of a great battle, who can give but a very poor and partial account of [meteorology] … and ignorant, as he must be, of the general plan of the whole.[136]

Another anonymous article appeared in the *Saturday Review* on 7 November. Whereas the *Athenaeum* was aimed at learned gentlemen such as Sabine, the *Saturday Review* had a much more general readership and explained the work of Kew Observatory and the Meteorological Committee in layman's terms. Yet it pointed to exactly the same problem as had the *Athenaeum* piece: the lack of funding for meteorological reductions, 'without which the observations might as well not be made'. True to its intended middle-class, non-scientific readership, the article likened this policy to 'a man who should spend 1,000*l*. a year in supplying his household with food, and refuse the additional 100*l*. required for fuel and cooking to fit it for use'.[137] In addition, the article praised the efforts of Stewart and members of the Kew Committee, while hardly mentioning the overseeing Meteorological Committee and not naming its members.

Both articles provoked infuriated responses from Gassiot and Sabine. On 17 November, Gassiot wrote to Lockyer that:-

> the general tone of your friends [*sic*] article [likely the *Saturday Review* piece] is so palpably to exalt Mr. Stewart and the Kew Committee to ignore Mr. Scott, Capt. Toynbee and the Meteorological Committee that the members of the Kew Committee who are also members of the Meteorological department must take some action[138]

Stewart, for his part, claimed that he had not seen the article in the *Saturday Review*, but that: 'Some time since I read an article in the Athenaeum in which I thought Mr. Scotts [*sic*] position was much too slightly mentioned his name not at all'. He went

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[136] Stewart (1869), p. 102.
[137] Anon. (1868b), pp. 622-623.
[138] Gassiot to Lockyer, 17 November 1868, TNA:BJ 1/24.

on to suggest its potential for causing ‘a feeling of awkwardness’ between Robert Scott and himself, and expressed ‘much regret’ at any implied comparison between himself and those in charge of the Meteorological Office.[139]

Stewart had further disagreements with Sabine and the Kew Committee during 1869. In January he made a fruitless request for an assistant dedicated to reducing the results from the outlying meteorological observatories.[140] Then, in April, Stewart tried to farm out the magnetic reductions to an unnamed third party outside Kew. The pressure being borne by Stewart is plainly evident in his defence of this latter move:-

> I do not think any one can be more desirous than myself that the magnetical part of this establishment should be well represented. In the present position of this institution and bearing in mind what we have to do for the Meteorological Committee I have seen that [the magnetic tabulations] can be best done out of the observatory…[141]

Stewart resigned as superintendent of Kew Observatory on 8 October 1869; he also resigned as secretary to the Meteorological Committee three days later.[142] Stewart stated no reasons in his resignation letter. A memorandum written by Gassiot records that he resigned because his health would no longer stand the pressure of work.[143] More revealing are the conditions under which Stewart offered to withdraw his resignation: first, that the meteorological reductions include some important additional elements, notably the degree of vapour and mass of dry air; and second, that Stewart be given more assistance at Kew.[144]

Yet Stewart was never given the chance to withdraw his resignation. According to Gassiot – and also to Arthur Schuster, writing candidly some six decades after the event – as soon as Gassiot mentioned Stewart’s possible resignation to Sabine, the two of them discussed the appointment of a successor. They had in mind Charles Chambers, who had started as an assistant at Kew in 1856 and had earned his spurs there by taking charge of the magnetic work during John Welsh’s final illness. He had left Kew in 1863 and was now, in 1869, in charge of the

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[139] Stewart to Gassiot, 8 November 1868, RS:Sa.1634.
[140] Stewart to Sabine, 15 January 1869, RS:Sa.1637.
[141] Stewart to Sabine, 2 April 1869, RS:Sa.1641.
[142] Stewart to Gassiot, 8 October 1869, with RS:Sa.1656; Statement by Gassiot, [October 1869?], RS:Sa.1656.
[143] Statement by Gassiot, October 1869?, RS:Sa.1656.
[144] Stewart to Gassiot, 13 October 1869, with RS:Sa.1656.

Bombay magnetic and meteorological observatory, but keen to return to Europe for health reasons. Chambers was a loyal colonial observer, very much in Sabine's mould, and so would have been a natural choice of successor to Stewart. According to Gassiot, by the time Stewart had sent his letter with his conditions, Sabine had already posted a letter to Colonel Smythe, Chambers' superior at Bombay, offering him the position.[145] The implication is clear that Sabine and Gassiot were eager to remove Stewart from the observatory now that his initial resignation letter provided them with an excuse for doing so.

Stewart's resignation was not effective immediately. He left the date open until he had found a suitable position. This only happened the following year, when in May he applied for the vacant chair in Natural Philosophy at Owen's College, Manchester, for which Stewart was being head-hunted by Henry Roscoe.[146] Schuster quotes a testimonial from Sabine in support of Stewart's application. Its tone was scathing, saying that had Stewart completed the magnetic work he was supposed to do at Kew he would have been 'in a preeminent position'.[147] His application was successful, however. As a parting shot Stewart, writing to inform Sabine of his appointment as Professor of Natural Philosophy at Manchester, could not resist taunting Sabine. As a possible research topic for the new laboratory that was being built for him at Manchester, said Stewart:-

> I think of suggesting magnetism namely a set of self recording instruments the curves of which are systematically tabulated & reduced – and a set of monthly absolute observations
>
> What should you think of the value of such a series[148]

If Sabine replied, we have no record of it.

The conflict between Stewart and Sabine cannot be attributed entirely to the reorganisation of the Meteorological Department. As we have seen, friction between them over Stewart's theories on sunspot periodicities was evident by (at the latest) January 1865, before FitzRoy's suicide. Yet neither can it be put down solely to a clash between Stewart the natural philosopher on the one hand, and, on the other, the

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[145] Statement by Gassiot, October 1869?, RS:Sa.1656; Schuster (1932), p. 210. Schuster does not name Chambers as the proposed successor to Stewart.
[146] Gooday (1989).
[147] Sabine to Stewart, 31 May 1870, RS:Sa.1661, quoted in Schuster (1932), p. 210.
[148] Stewart to Sabine, 8 July 1870, RS:Sa.1663.

'gentlemanly' natural historians, represented by Sabine and the Kew Committee. Making Kew the Meteorological Office's central observatory did dramatically increase Stewart's workload, especially as the magnetic reductions and instrument standardisation already made for a hectic schedule. The new work, moreover, was of a very routine, utilitarian nature: gathering, collating and publishing statistics. Stewart had done some of his most creative work under Forbes at Edinburgh and he remained a university physicist at heart after returning to Kew, continuing with his sunspot and ether research even after the meteorological reorganisation. Unfortunately for Stewart, an important part of his duties after 1867 had effectively become those of an employee of the Meteorological Office: someone paid to report statistics to the government and who had little time for independent research – as Gassiot emphatically reminded him in 1867. Sabine, for his part, was less a 'gentlemanly' natural historian than what David Phillip Miller has termed a 'scientific serviceman',[149] who saw geomagnetic and meteorological research as a matter of collecting large volumes of data for utilitarian purposes. He was not averse to theoretical speculation – such as on the possibility of aurorae on other planets – but he would not allow this to form the basis of research or to interfere with what he saw as the observatory's main purpose, especially when it meant spending time and money on fundamental concepts such as ether. Sabine's effective dismissal of Stewart may be compared with his similar move against William Radcliff Birt in 1850 (Chapter 3, Section 3.2), in the sense that neither man fitted into the position of loyal subordinate in General Sabine's troops. This was especially true now that by taking control over land observations at the Meteorological Office, Sabine had launched a 'meteorological crusade' similar to his Magnetic Crusade. He had succeeded in the aim that he had had in mind since 1840: making Kew an independent centre for both magnetism and meteorology on a national scale and independent of Greenwich.

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[149] Miller (1986), esp. pp. 112-119. See also Chapter 1 (Section 1.1) and Chapter 2 (Section 2.2).

2.6 Conclusion

Ever since the 1860s, Kew Observatory has been associated with the early years of solar physics – in popular as well as academic histories of science.[150] As we have seen, Kew was indeed gripped by what John Welsh called 'solar spot mania' in the 1850s and 1860s. By 1870, the photoheliograph was being used to take more than 300 images of the Sun per year.[151] It had some great successes to its credit, notably confirmation of the solar origin of the 'red flames' seen during solar eclipses and a system of daily solar photography that would be continued at Greenwich Observatory. Nevertheless, as this chapter has shown, the solar programme was never really central to the work at Kew. Indeed, the story of its origins and practice and then the use of its results by Balfour Stewart, tells us as much about the patronage and control of the physical sciences in the period between the Great Exhibition of 1851 and the Devonshire Commission on British science in the 1870s as it does about the daily routine at Kew Observatory.

This chapter has attempted to address three broad questions posed in the introduction: how and why solar astronomy came to Kew in the 1850s; how the photoheliograph was used in practice; and finally, how the relationship between solar astronomy, geomagnetism and meteorology at Kew worked under Balfour Stewart. As we saw in Section 4.3, that a systematic programme of sunspot observation came to Kew at all and not to some private observatory, as suggested by John Herschel, was not a given. The Kew photoheliograph was not a straightforward result of Herschel's rallying-cries. It is clear that John Welsh was the first to respond to the challenge posed by the discovery of the sunspot-magnetism correlation with his suggestion of a system of daily sunspot photographs and it is likely that Sabine learned of this idea from Welsh before using Herschel's prestige to secure funding for the project. This would explain why it went to Kew.

It is clear from Sections 4.4 and 4.5 that the practice of solar photography remained outside the observatory's central routine. The photoheliograph and the work done with it were largely funded by Royal Society grants from private sources or by Warren De La Rue, a classic example of a self-funded Victorian devotee of science. That neither Elizabeth Beckley, who helped to take the solar photographs on a daily basis, nor Benjamin Loewy, who reduced the sunspot numbers and areas

[150] For an accurate popular account, see Clark (2007).
[151] BAAS:AR 1870, p. xlviii.

into a form usable for calculation, appeared on the Kew payroll reinforces the case that the photoheliograph was an example of private patronage. The priority at Kew was always Sabine's central concern with the collection of magnetic and meteorological data, in addition to the standardisation work for British and overseas governments that brought in essential income. Yet the solar photography programme increased the importance and prestige of Kew Observatory still further. Thanks to the 'Kew photoheliograph', Kew was now a synonym for solar astronomy as well as geomagnetism, meteorology and instrument standardisation.

As shown in Section 4.5, Sabine and the Kew Committee never gave Balfour Stewart a free hand to develop his theory-driven 'cosmical physics'. As superintendent of Kew Observatory and, from 1867, secretary to the Meteorological Committee, Stewart was expected to follow Sabine's empirical style of research, amassing more and more magnetic and meteorological data. Nonetheless, he would not let go of his beloved private research. Part of Stewart's conflict with Sabine may be attributed to the differences in Stewart's background and personality from his predecessor, John Welsh. Whereas Welsh was fundamentally an experimentalist, with a genius for invention and practical problem-solving, Stewart was always more of a theoretician, with a natural philosophical bent more in tune with his countrymen Tait and Maxwell than with his superiors at Kew, Sabine and Gassiot. He was also older and more experienced and so less likely to be subservient to the authoritarian Sabine. Nevertheless, it is clear also that Stewart's conflict with Sabine also owed much to the changed nature of his post after 1865. The mass of data reductions for the Meteorological Department – now renamed the Meteorological Office, with Kew as its central observatory – entailed a huge increase in Stewart's workload, yet the Kew Committee were reluctant to fund the extra staff that this entailed.

By 1870, Kew Observatory had an annual income of over £1,575. Of this, over £600 came in the form of an annual grant from the Meteorological Office.[152] Where meteorology was concerned, Kew could therefore be described as a government observatory, in the sense that it acted as a central observatory that supervised a network of self-recording meteorological stations across the British Isles and processed the results that they sent in. But in every other sense, Kew was *not* a government observatory. Apart from one-off sums from the Royal Society

[152] BAAS:AR, 1870, p. lvii.

Government Grant, the rest of its income came from private sources and the money it made from standardisation. The geomagnetic observations, the solar photography and the standardisation work continued on a privately-funded basis, as before. In particular, the solar photography at Kew was not the work of a public observatory, as Simon Schaffer has suggested.[153] The 'public' observatory's remit was the strictly utilitarian meteorological data collection, while control of the solar research remained very much in the hands of self-funded devotees of science such as De La Rue. With the exception of the work for the Meteorological Office, support of the sciences at Kew continued to rely on the *laissez-faire* system. After 1870, the setting-up of a Royal Commission on Scientific Instruction and the Advancement of Science, which became known as the Devonshire Commission, presented an apparent challenge to this system. Yet *laissez-faire* continued to dominate the subsequent history of Kew Observatory, as we shall see in Chapter 5.

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[153] Schaffer (1995), p. 259.

Chapter 5

Kew Observatory and the Royal Society, 1869-1885

> I need scarcely say that it has afforded me much pleasure, to have had it in my power, through the Royal Society, to assist in maintaining an Establishment with which I have, for so many years, been connected
>
> John Peter Gassiot to William Sharpey (Secretary, Royal Society), 4 July 1871[1]

> '… a large proportion of the various thermometrical determinations made by English physicists are dependent for their accuracy upon that of the verifications at Kew. Many thousands of thermometers have already been verified by the apparatus about to be described.'
>
> Francis Galton, 1877[2]

5.1 Introduction

Chapter 4 discussed the origins, practice and results of the photographic observations of sunspots at Kew Observatory, from the early 1850s to the late 1860s. Until the conflict in the late 1860s between Balfour Stewart and Edward Sabine, the solar observations were established and carried out during a stable and relatively prosperous period for Kew, during which the observatory achieved worldwide fame. The threats of closure that had hung over the observatory for most of the first decade after the BAAS takeover in 1842 were not repeated. This situation changed in the late 1860s, when the BAAS, ever short of money, declared that it no longer wanted to keep running Kew. According to the standard histories, two years later the Royal Society stepped in to take over its management, thanks to a generous donation from Kew Committee chairman John Gassiot. Many sources also simply state that following this, in the early 1870s the solar work went to Greenwich, while Kew consolidated its role as the central observatory of the Meteorological Office and continued with its work in instrument standardisation.[3]

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[1] Gassiot to Sharpey, 4 July 1871, RS:MS.843.30.
[2] Galton (1877), p. 84.
[3] Essentially this story is told in Scott (1885), pp. 62-63, Jacobs (1969), p. 163, Hall (1984), p. 186 and Walker (2012), pp. 102-103.

No historian, however, has produced a critical account of how and why Kew Observatory underwent these changes between the late 1860s and mid-1880s. Nor has there been any assessment of the nature of the regime at Kew after the departure of Balfour Stewart and the observatory's takeover by the Royal Society in 1871. Part of the problem is that, as discussed in Chapter 1 (Section 1.4) the existing literature mostly examines each of the sciences practised at Kew in isolation. For example, James Burton and Malcolm Walker both present Airy's attempt in 1871 to transfer the Kew meteorological observations to Greenwich as a minor temporary setback in the success story of the Meteorological Office.[4] Above all, secondary sources like this are not about Kew Observatory as such: their authors all ask questions very different from those being addressed by this thesis, which is an institutional history of Kew in the context of the changing organisation of nineteenth-century science and the wider world of the observatory sciences.

Indeed, none of these sources sets Kew Observatory in this historical context, particularly that of the 1870s debate on the relations between the British government and science. This debate centred around a Royal Commission, set up to look into the state of science education and institutions for scientific research, which has become known as the Devonshire Commission. As I have discussed in Chapter 1 (Section 1.2), some historians have interpreted the period of the Devonshire Commission as an early sign of the end of *laissez-faire* attitudes towards scientific research: for these historians, it was the start of a move towards the twentieth-century regime of state-funded laboratories and observatories, staffed by professional scientists. But one of my aims in this chapter is to show how, in the years after 1871, Kew remained an example of an institution financed in the older Victorian manner: mostly from private sources, not government. I thus challenge Roy MacLeod's view that there was little private funding for science in the last three decades of the nineteenth century.[5]

This chapter takes as its starting point the announcement in 1869 that relations between the BAAS and the Kew Committee were to be reviewed. It finishes in 1885, the year that saw the publication of Robert Henry Scott's well-known general history of Kew Observatory. As I have shown in Chapter 1 (Section 1.5), Scott's history has some serious limitations, but it is so widely cited that the

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[4] Burton (1988), pp. 113-116; Walker (2012), pp. 104-106.
[5] MacLeod (1971b), p. 211.

year of its publication is a useful landmark in the history of Kew. It also conveniently divides in two the history of Kew between 1869 and 1900. In Section 5.2 I examine in detail how and why Kew was transferred from the BAAS to the Royal Society between 1869 and 1871. I argue that the story is much more complex than has hitherto been supposed, as well as making the case for the importance to Kew of private funding. In Sections 5.3 and 5.4 – respectively on Airy's failed coup over the Kew meteorological observations and his successful one to take over the photoheliograph – I use archival material and the historical context to argue that there is much more to these moves by Airy than the internal histories of Greenwich, Kew and the Meteorological Office imply. I also use the struggles between Airy and the Kew Committee over meteorology to show how meteorology was coming to be governed by its own specialist institution, over which Greenwich had no control – mirroring a contemporary trend towards specialisation in the observatory sciences.[6] Finally, in Section 5.5 I assess the changed working regime and personnel at Kew from 1871 to 1885. I argue that during this period, a decline in income from both the Gassiot Trust and the Meteorological Office grant, in addition to the illness and death of Sabine, forced Kew to change its emphasis from geomagnetism and meteorology to testing instruments in return for fees. This, I suggest, resulted in Kew changing its character from a place of experimental investigation and data-gathering into a commercially-driven laboratory that served industry and government.

5.2 From the British Association to the Royal Society, 1869-1871

Having survived several threats of closure between 1845 and 1850 (Chapter 3, Section 3.2), Kew Observatory enjoyed a long period of stability under the BAAS. Each year the Association consistently voted a substantial grant for running the observatory, rising from £300 in 1850 to £600 in 1869. This was in addition to the income that Kew received from instrument standardisation, grants from the Royal Society (some of them funded by the Government Grant) for specific projects and, from the late 1860s, more than £500 per annum from the Meteorological Office as

[6] Aubin (2011), pp. 115-119.

that organisation's central observatory and one of its stations with self-recording instruments.

Then, at the 1869 annual meeting in Exeter, the General Committee of the BAAS decided 'that the existing relations between the Kew Committee and the British Association be referred to the Council to report thereon'.[7] This was the first time since the 1840s that the future of Kew Observatory as a BAAS institution had been questioned, though this time the language was less direct than the 1845 talk of 'the expediency of discontinuing the Kew Observatory', or the Council's resolution in 1848 to establish whether it was worth 'continuing the present expenditure' on Kew.[8] Also, unlike 1845, the resolution attracted no comment in the wider press such as the *Athenaeum*, so it is harder to say who might have originally moved the motion and what their motives were. It is notable, however, that the incoming BAAS President in 1869 was Thomas Huxley, who had long resented Royal Society President Sabine's alleged preference for the physical sciences over Huxley's own field of biology.[9] If Huxley could not control Sabine's activities in the Royal Society, becoming President of the BAAS might give him more power through that organisation. The £600 that was annually granted to Kew Observatory represented a substantial portion of the Association's modest income, which Huxley might have felt could be put to better use.

On 13 November 1869 the Council appointed a special committee of thirteen members – including two biologists, Huxley and Hooker, as well as most members of the existing Kew Committee – to consider the resolution and report back to the Council.[10] This committee met on 27 November and decided that the Association should continue to run Kew as before until 1872, in which year the ongoing programme of simultaneously monitoring terrestrial magnetism and photographing the Sun would have completed a full ten years, but 'that after that date all connexion between them should cease'.[11] The committee's report, signed by Gassiot (still the Kew Committee chairman) and presented to the Council on 11 December, confirms that the reason for the General Committee's decision to review the relations between the BAAS and the Kew Committee was a financial one: 'whether the sum of £600,

[7] BAAS:AR, 1869, p. xlv.
[8] BAAS:AR, 1845, p. xviii; BAAS:CM, 14 April 1848.
[9] Hall (1984), p. 106.
[10] BAAS:CM, 13 November 1869.
[11] KCM, 11 December 1869.

annually granted by the Association, can be reduced without impairing the efficiency of the Observatory'. More particularly, the report asked whether such a reduction could be made by discontinuing some of the observatory's current work. Gassiot argued that terminating the magnetic observations would save a mere £110 a year, much of which constituted lucrative overtime for staff, who might leave if they lost this. Furthermore, the report rather bluntly stated that if the observatory were to be reduced to a mere depository for instruments, the committee could not recommend continuing the observations currently being made for the Meteorological Office. Therefore, it was not practicable to terminate either the magnetic or the meteorological work. The report concluded that the £600 annually voted by the Association could not be reduced without compromising the work of the observatory.[12]

Nothing more about Kew Observatory is mentioned in the BAAS papers until the annual report of the Kew Committee presented to the next annual meeting, held at Liverpool in September 1870. This ratified the decision to sever the connection between the BAAS and Kew with effect from 1872 and made it clear that this implied considering 'the dissolution of the Kew establishment'.[13] In addition, the report summarised a statement by Balfour Stewart 'on the past and present condition of the Observatory' and used this as evidence of how the observatory now received a large portion of its funding from sources outside the BAAS, notably the Royal Society. The unwritten implication, therefore, was that there was no need for the BAAS to continue supporting it. Indeed, at the same meeting, it was resolved that the President and Council contact the Royal Society and the government, with a view to offering the future use of the Kew buildings to the Royal Society, assuming that the Royal Society wanted them.[14]

Given that Sabine was President of the Royal Society, it is reasonable to infer that this resolution, and perhaps also the decision to terminate the connection between the BAAS and Kew Observatory, amounted to a subtle manoeuvre by Sabine to transfer the observatory to the Royal Society and so allow him to tighten his control over it. Declaring that the observatory could not be run for less than £600 a year would have been enough to force the BAAS Council into giving it up,

[12] BAAS:CM, 11 December 1869.
[13] BAAS:AR, 1870, pp. xlv-xlvi.
[14] BAAS:CM, 5 November 1870.

especially as this annual running cost was the stated reason why the BAAS's relations with Kew were being reviewed in the first place. Similarly, Sabine might have used the threat of the observatory's 'dissolution' as a means of forcing the Royal Society's hand in taking it over. Many besides Sabine might well have been thinking along these lines also, for it is striking how in 1870 many prominent members of the BAAS Council – Galton, Gassiot, Sabine, William Sharpey and William Spottiswoode – were also on the Royal Society Council. Indeed Spottiswoode, General Treasurer of the BAAS for 1869-1870, also served as Treasurer of the Royal Society from 1870 to 1878.

Therefore many on the Royal Society Council would have been well aware of the situation with regard to Kew Observatory when at a Council meeting on 15 December 1870, a letter from the BAAS dated five days earlier was read out, asking 'what the desires of the Council of the Royal Society' were regarding the use of the Kew buildings. The Council deferred the matter until 19 January 1871, when it appointed a special committee to discuss the BAAS proposal. In addition to the presidents and officers of both societies (thus including Sabine as President of the Royal Society), this committee included Gassiot, Galton, Alexander Strange, John Tyndall, Charles Wheatstone and Alexander Williamson – every one of whom was also on the BAAS Council.[15] The committee was given power to co-opt additional members; Warren De La Rue and William Grove were duly added on 16 February.[16]

Gassiot – who, along with Sabine, had been instrumental in introducing standardisation in 1850, thus making it much harder to close down Kew – seems to have taken the initiative well before the committee met on 28 March. Balfour Stewart, George Airy, Humphrey Lloyd, William Henry Sykes, Thomas Romney Robinson, William Thomson and the elderly John Herschel all wrote letters to Gassiot, expressing their views on whether the Royal Society should take over the management of Kew Observatory. Their letters were clearly in response to solicitations from Gassiot. A letter from Gassiot to Herschel, dated 13 February, asks Herschel's 'opinion as to the advisability of the Royal Society obtaining possession of the building with the view of ultimately continuing the Magnetic Observations Verifications of instruments, &c.'. Gassiot wrote an almost identical

[15] RS:CM, 15 December 1870; RS:CM, 19 January 1871.
[16] RS:CM, 16 February 1871.

letter to Airy the same day.[17] With the exception of the reply from Thomson, all the responses were printed in the minutes of the Royal Society Council for 16 March, nearly two weeks before the 28 March meeting.[18] All were dated mid-February 1871, with the exception of the letter from Balfour Stewart, which is dated 8 November 1870, just a month after he had taken up his new post at Manchester, suggesting that Gassiot had been sounding out opinions for at least three months.

Most of the replies strongly supported keeping Kew Observatory going in some form. Balfour Stewart said he believed that 'it would be a *very great misfortune*' if the Kew magnetograph work were terminated after 1872, because, true to his research interests in sunspots and their influences, he saw a need for 'a more intimate comparison' between sunspot frequency and terrestrial magnetic disturbances, which rendered parallel magnetic and solar observations essential. Also, according to Stewart, differences in readings between observatories suggested that locality was important, so if Kew were to be given up, magnetic observations comparable with the Kew series could not be made elsewhere. Stewart also mentioned eleven observatories worldwide where instruments on the Kew design had been set up, 'all of which would suffer were Kew discontinued'.[19] Humphrey Lloyd professed to have no strong views as to whether the Royal Society should start running Kew, though he generally felt that this type of work would be better done under the Royal Society than under the BAAS.[20] William Sykes – who had helped establish standardisation at Kew with verification of thermometers for the East India Company – expressed disappointment that the BAAS proposed to give it up, but strongly supported continuing the work, especially standardisation, under the Royal Society.[21] Robinson, long-time director of Armagh Observatory, who had designed (with Robert Beckley) the anemometer on the Kew dome, thought 'that it would be a great loss to British science' were Kew to be given up, and that if the standardisation work were stopped, the need for another such laboratory 'would be soon imperatively required by Physicists'.[22] William Thomson almost exactly echoed Robinson's sentiments in writing that closing Kew 'would be a national calamity'

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[17] Gassiot to Herschel, 13 February 1871, RS:HS 8.67; Gassiot to Airy, 13 February 1871, RGO 6.394.
[18] Thomson's reply is dated 20 March; it is included in RS:CM, 20 April 1871.
[19] Stewart to Gassiot, 8 November 1870, in RS:CM, 16 March 1871.
[20] Lloyd to Gassiot, 14 February 1871, in RS:CM, 16 March 1871.
[21] Sykes to Gassiot, 14 February 1871, in RS:CM, 16 March 1871.
[22] Robinson to Gassiot, 14 February 1871, in RS:CM, 16 March 1871.

and that the observatory had for the first time offered practitioners in the natural sciences a place for accurate observational work.[23] Airy, predictably, recommended discontinuing the self-recording magnetic instruments at Kew, on the grounds that these had been 'introduced by me' at Greenwich in the 1840s (no mention of Francis Ronalds) and that duplicating this system at Kew was 'an idle expense' – another instance of his long-held attitude towards Kew. But even Airy said that it was 'very desirable that the Royal Society should have possession of the Kew Observatory'. He approved of continuing Kew 'for such purposes as were indicated in the original proposals for making use of Kew Observatory' – that is, improving magnetic instruments and the planning of 'distant' (overseas) magnetic observations and instructing the observers.[24]

The one dissenting voice amongst all these largely positive responses was that of John Herschel. Just as in 1850, when he had expressed the view that 'it should most earnestly deprecate' the Royal Society for it to permanently maintain any observatory or institution (Chapter 3, Section 3.2),[25] he now responded to Gassiot:-

> I should not feel very confident in recommending the Royal Society, as a body, to take on itself the duty of working *any* permanent scientific establishment.

Herschel offered the same rationale for this view as he had in 1850: that supporting scientific institutions was not the Royal Society's mission, which in his view was rather to promote and manage science, and to see that worthy scientific work was published and rewarded. On magnetism and meteorology, he took the same view as his old friend Airy – and a very different one from Robinson: that both these sciences were now firmly established at Greenwich and so, by implication, it was not necessary to keep them going at Kew. As for solar photography, Herschel thought that this should be done by private individuals. In the version of his letter printed in the Council minutes, Herschel was non-committal as to whether instrument standardization was important enough to outweigh his general objection to the Royal Society taking over Kew.[26] Yet in a rough draft of the same letter preserved in

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[23] Thomson to Gassiot, 20 March 1871, in RS:CM, 20 April 1871.
[24] Airy to Gassiot, 13 February 1871, in RS:CM, 16 March 1871.
[25] Herschel to Murchison, 15 February 1850, TxU: 26.11 (L0269).
[26] Herschel to Gassiot, 17 February 1871, in RS:CM, 16 March 1871.

Herschel's papers, he was dismissive of the idea that Kew should even be doing standardization, suggesting that this would best be done at the Society's London headquarters or else should be taken up by the Board of Trade.[27] We do not know when, or why, Herschel changed his mind. Herschel was now elderly and physically frail, but while it is easy to suggest that he was 'in decline' as an authoritative spokesman for science,[28] his mental capacity was still good and he kept an interest in developments in astronomy – not least in sunspots, as is evidenced by his correspondence that same month with George Whipple at Kew, in which he compares some Kew solar photographs with his own observations of the Sun.[29] His response to Gassiot cannot be dismissed as that of an old man out of touch with the cutting edge of scientific research: his views on the functions of the Royal Society show a remarkable consistency with those he had held throughout his career.

Herschel's reservations notwithstanding, the consensus among the seven leading figures in British physical sciences who responded to Gassiot was broadly in favour of the Royal Society taking over the running of Kew Observatory. The issue was then made more complex when at the 16 March Council meeting a letter from Gassiot was read out, in which he made an offer of securities worth £250 per annum for the Royal Society to maintain Kew as 'a Central Magnetical and Physical Observatory', this sum to be supplemented if the Council deemed it insufficient to run the magnetic observations. Only a brief summary of Gassiot's letter was read out at the meeting, but in the manuscript version preserved in the Royal Society's archives, Gassiot specified that this annual sum, nearly half of the £600 currently being voted by the BAAS for maintaining Kew, was not intended to support meteorology, instrument standardisation or experiments by private individuals, all of which, as he noted, were funded from other sources. This substantial offer would reduce – though not eliminate – the financial burden that running the observatory would present to the Royal Society; in Gassiot's own words, it would impose just 'a very moderate charge' on the Society's income.[30] Gassiot seems to have contemplated this offer for some time: the letters to him from Herschel and other

[27] Herschel to Gassiot, 17 February 1871, RS:HS 8.68.
[28] Bartholomew (1976), p. 284.
[29] Herschel to [Whipple?], 19 February 1871, TNA:BJ 1/83; Herschel to Whipple, 1 March 1871, TNA:BJ 1/83.
[30] Gassiot to Sharpey, 13 March 1871, RS:MC.9.178; partly summarised in RS:CM, 16 March 1871.

senior figures, read out later on during the 16 March meeting, in addition to his nearly identical solicitations to Herschel and Airy, suggest that he was canvassing their opinion before parting with his money – though neither of these latter communications give any hint that Gassiot was contemplating making any donation.

The committee that met on 28 March 1871 was chaired by Spottiswoode, the Royal Society's Treasurer. Among the thirteen Fellows present, six were also members of the BAAS Kew Committee; these included De La Rue, Galton and Wheatstone, all stalwart supporters of the observatory under the BAAS. Gassiot and Sabine did not attend, even though both had been invited onto the committee; as we shall see, this may have been more than simply Gassiot wishing to avoid a conflict of interest, now that his offer of a substantial donation was on the table. The minutes contain no record of any discussion at the meeting, other than the reading of the letters from Herschel and the others, plus Gassiot's offer, followed by a resolution that the committee was 'not prepared to recommend the Council to undertake the responsibility of the maintenance of the Establishment'. The only recorded dissent was over the wording of the response to Gassiot's offer, which was amended twice. The words: 'hoping that some other mode of giving the same generous assistance to the maintenance of the magnetical observations at Kew will suggest itself to him [Gassiot]' were omitted and in the final version the committee regretted that it did not see in what way it could recommend that the Council accept Gassiot's donation.

The minutes do not directly record any reasons why the committee decided against the Royal Society taking on the observatory. Some of the objections may have been for financial reasons: £250 was simply not enough to cover the current running costs of Kew, even if meteorology, standardisation and experiments could somehow be dropped from the programme of work. We can also gain clues from the individuals who put the motions. That the Royal Society Council should not take responsibility for running Kew was moved by a figure who hitherto had had little to do with Kew Observatory: Lieutenant-Colonel Alexander Strange. At the 1868 BAAS meeting Strange had presented a paper titled 'On the Necessity for State Intervention to Secure the Progress of Physical Science'. As described in Chapter 1 (Section 1.2), this had started a chain of events leading to the setting-up of a government commission to look into state provision for science education and research, which became known as the Devonshire Commission.[31] As a former inspector of scientific instruments, Strange had a strong interest in instrument standardisation. As the original instigator of the lobby for greater state support of laboratories, he may well have felt that Kew was precisely the kind of institution that should be supported by central government and not private donations in the traditional manner. Also, the first motion rejecting Gassiot's offer was seconded by John Tyndall, Balfour Stewart's old enemy (see Chapter 4, Section 4.5). During the meeting a further letter from Stewart was read out, urging the necessity of continuing the Kew magnetic observations. Although Stewart was now at Manchester, he was still nominally superintendent of Kew (see Section 5.4) and Tyndall would not have wanted to see the Royal Society spending its money on what he would have seen as a hotbed of anti-materialist research.

The committee's resolutions were duly read out at the next Council meeting on 27 April, with Sabine in the chair, and it was resolved to consider the report at the next meeting. This did not take place until 25 May, again with Sabine present. This time Gassiot doubled his offer to £500 per annum, on the condition that the Royal Society maintained Kew 'as a magnetical, meteorological, and physical observatory, with self-recording instruments' and that it be run by an unpaid committee of the Royal Society. Then a memorandum by Sabine was read out, suggesting that if the unpaid committee stipulated by Gassiot were to be identical to the existing Meteorological Committee, whose members were also unpaid, this would overcome the technical difficulty (Herschel's objection, though Sabine did not name him) of the Royal Society supporting a permanent scientific institution.[32] Under this scheme, there would be no worries about the Royal Society running such an institution, because Kew would effectively be run by a government committee. Sabine did not need to remind the Council that Gassiot's offer of £500 per annum covered most of the £600 currently being paid by the BAAS and so removed most of the financial obligation from the Royal Society. If there were any objections at this Council meeting, they are not recorded. The Council resolved that the Royal Society's officers should, with the help of the Society's solicitors, 'prepare a scheme in

[31] MacLeod (1971), pp. 202-203.
[32] RS:CM, 25 May 1871.

reference to the Kew Observatory in accordance with Mr. Gassiot's views' and offer this to the Council.[33]

What caused Gassiot to double his offer? Sabine had already prepared his memorandum in advance of the meeting and so had presumably conferred with Gassiot and agreed on how to proceed. Moreover, three days before, Robert Scott of the Meteorological Office had sent Gassiot a detailed statement of the work being done by every member of the existing staff at Kew, as if Gassiot were asking Scott for a statement of what he was going to be paying for.[34] On 23 May Gassiot seems to have ordered 25 copies of his proposal for forwarding to Council members. In the same letter he claims to have authorised De La Rue by letter prior to the 28 March meeting to increase his offer to £500, but that the letter never reached the committee.[35] This letter, if it ever existed, does not seem to have survived, nor does any evidence that Gassiot thought of offering £500 on 28 March. Gassiot's original letter of 13 March did allow provision for an increase, but it is unlikely that he had a 100 per cent increase in mind. In any case, the original letter specifically excluded meteorology from his offer, whereas the new proposal was for the maintenance of 'a magnetical, meteorological, and physical observatory'. We are left wondering whether Sabine, ever the behind-the-scenes manoeuvrer, either twisted Gassiot's arm or made hints in this direction, especially as the committee's recommendations to reject Kew were not adopted at the next Council meeting, on 27 April, but deferred until 25 May. Sabine may have been buying himself time for such negotiations.

However, between the 27 April and 25 May meetings there occurred a major event that might also have affected Gassiot's and Sabine's thinking. On 11 May John Herschel died. His burial at Westminster Abbey was practically an occasion of national mourning, as exemplified by William Thomson's Presidential Address to the 1871 BAAS meeting: 'The name of Herschel is a household word throughout Great Britain and Ireland – yes, and through the whole civilized world.'[36] More particularly for the fate of Kew Observatory, Herschel had been the one dissenting voice against the Royal Society taking over its management – yet also, in the eyes of elder statesmen of science like Gassiot, Sabine and De La Rue, the most venerable,

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[33] RS:CM, 25 May 1871.

[34] Scott, Robert, 'Copy of statement sent to Mr Gassiott [*sic*] May 22. 1871', TNA:BJ 1/92.

[35] Gassiot to Walter White (Assistant Secretary, Royal Society), 23 May 1871, RS:MC.9.205.

[36] Thomson (1871), p. lxxxv. See also Buttmann (1974), pp. 189-190.

whose views had carried such weight in the scientific world of the 1840s and early 1850s. With Herschel's death there was now no one left to object to Gassiot's proposals. Gassiot would have anticipated that the new proposals read out on 25 May would have been more attractive to Council members, because they would now relieve the Royal Society of most of the financial burden and would even technically relieve it of the practical responsibility of running the observatory. Yet under Gassiot's plan Kew would still be run under the aegis of the Royal Society, something which Herschel had objected to even in principle. We have no way of proving that Herschel's death tipped the balance of Gassiot's mind, or the minds of others on the Council, in favour of the new proposals, but apart from Gassiot's unsupported claim, there is no evidence that Gassiot made any moves towards doubling his offer before 11 May.

Now that agreement had been reached, Gassiot lost no time in implementing his proposals. The day after the 25 May Council meeting Spottiswoode, the Treasurer, reported that he had instructed the Royal Society's solicitor, Charles Few, to talk to Gassiot's solicitor and draw up the heads of an agreement.[37] On 3 June Gassiot gave Robert Scott instructions as to the general financial arrangements for the observatory: that its annual allowance from the Meteorological Office should be the same as under the BAAS (£400), as should the salary of the superintendent (£200). With regard to any overtime to be paid to the assistants, Gassiot was ever the shrewd businessman: 'we must take care not to commence with too high figures, as it is at all times difficult to reduce'.[38] The general terms of the agreement were presented to the Council at its next meeting on 15 June. Gassiot was to present the Royal Society with £10,000 worth of securities, on trust, for 'carrying on and continuing magnetical and meteorological observations with self-recording instruments, and any other physical investigations as may from time to time be found practicable and desirable' at Kew Observatory. The observatory and the trust income were to be managed by a committee appointed by the Royal Society Council. Yet although in both the Council minutes and the trust deed itself, this committee's services were to be gratuitous, 'like those of the present Meteorological Committee nominated at the request of Her Majesty's Government', neither document specified that the new committee's membership was to be identical to that of the

[37] Spottiswoode to Gassiot, 26 May 1871, RS:MC.9.207.
[38] Gassiot to Scott, 3 June 1871, TNA:BJ 1/92.

Meteorological Committee, as in the proposal outlined by Sabine on 25 May.[39] Not only did this allow for flexibility as to which persons might control Kew Observatory in future: as we will see in Section 5.5, the membership of the Kew Committee would cease to be identical to that of the Meteorological Committee in the years after 1871. It also suggests that Sabine had merely used a promise that the new Kew Committee would be identical to the Meteorological Committee in order to sugar the bitter pill of the Royal Society taking on the observatory's management – even after John Herschel, the most distinguished objector to this arrangement, was no more.

The final trust deed was sealed at the 29 June Council meeting. At the same meeting, the Council appointed the new Kew Committee to run the observatory under the Royal Society. The committee's membership – De La Rue, Francis Galton, Gassiot, Admiral George Henry Richards, Sabine, Colonel William Smythe, Spottiswoode and Wheatstone[40] – was indeed identical to that of the Meteorological Committee, so Sabine's promise was fulfilled to begin with, even though it carried no legal weight. Also striking, however, is that of these eight members of the new committee, six had been on the final Kew Committee appointed by the BAAS Council on 5 November 1870[41] – suggesting, once again, that the handover of the observatory from the BAAS to the Royal Society was a pre-planned manoeuvre by Sabine and Gassiot. On 8 July Sharpey, Secretary to the Royal Society, informed his counterpart in the BAAS that the Society was now ready to take over possession of the Kew buildings. Management of the observatory formally passed to the Royal Society Kew Committee on 2 August, when the BAAS Council, meeting at Edinburgh during that year's BAAS annual meeting, declared that the Association could 'give up possession of the Kew Observatory at once'.[42] In his presidential address at the same BAAS meeting, William Thomson praised 'the magnificent services which it [Kew Observatory] has rendered to science' and noted that the observatory now had 'a permanent independence' thanks to 'the noble liberality of a private benefactor, one who has laboured for its welfare with self-sacrificing devotion unintermittingly from within a few years of its creation'. Yet,

[39] RS:CM, 15 June 1871. The trust deed itself is reprinted in, for example, Anon. (1940), pp. 134-138.
[40] RS:CM, 29 June 1871.
[41] BAAS:CM, 5 November 1870.
[42] BAAS:CM, 2 August 1871; MMC, 3 July 1871, TNA:BJ 8/9.

unsurprisingly in a presidential address, which one expects to be celebratory, Thomson skipped over any reference to the BAAS being unable to continue supporting Kew and the complicated story as to how it came within the control of the Royal Society.[43]

Gassiot's donation was not quite the same as, for example, the Mond bequest to the Royal Institution, given by a businessman who had made his fortune in the chemical industry and who believed in the importance of laboratories to that industry.[44] Mond ultimately intended his donation to benefit his industry and increase its profits. Unlike Mond, Gassiot had become rich through activities far removed from those that he was now endowing. Nor was the Gassiot trust an instance of a businessman trying to buy his way into respectability by endowing a scientific institution, as was starting to become fashionable in the United States in the 1870s – as in, for example the case of the Lick Observatory, an astrophysical observatory with state-of-the-art instrumentation funded by wealthy American magnate James Lick.[45] Gassiot had set up the standardisation programme at Kew and had served as chairman of the Kew Committee since 1853, so he had a close and direct interest in the work of Kew Observatory, as he was proud to admit:-

> I need scarcely say that it has afforded me much pleasure, to have had it in my power, through the Royal Society, to assist in maintaining an Establishment with which I have, for so many years, been connected[46]

While Sabine was effectively the director of research at Kew, and may well have persuaded Gassiot to endow the observatory, Gassiot clearly also had an ongoing personal interest in its work. The Gassiot trust therefore seems closer to being a case of a devotee of science privately funding research in which he had an interest, in the traditional Victorian manner. It surely also stands as a dramatic exception to Roy MacLeod's assertion that the Devonshire Commission's calls for greater state support were given greater urgency because 'private philanthropy in support of scientific research was nowhere to be seen'.[47]

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43 Thomson (1871), p. lxxxvii.
44 MacLeod (1971b), p. 227.
45 Osterbrock et al. (1988).
46 Gassiot to Sharpey, 4 July 1871, RS:MS.843.30.
47 MacLeod (1971b), p. 211.

In the next two sections I describe how Airy's failed attempt to take over the Kew meteorological observations, followed by his successful one to transfer the Kew photoheliograph to Greenwich, were intimately related both to Airy's period as President of the Royal Society and also to the controversies in the learned societies of the 1870s as to government funding of science in general and observatories in particular.

5.3 Meteorology and the 'National Observer': Airy's coup attempt, 1871-1872

As noted in Chapter 4 (Section 4.5), when the Meteorological Office was reorganised in the mid-1860s and a system of land observatories was set up, Airy had strongly resented the exclusion of Greenwich from the proposed new system. In the same section I also described how, shortly before this, he had challenged Sabine over the necessity of continuing magnetic observations at Kew, on the grounds that these were best done at Greenwich, by the 'National Observer'. Now, in late 1871, Airy began an attempt to transfer to Greenwich the responsibility for the meteorological observations then being done at Kew as part of the Meteorological Office's system of observatories. Airy was not successful in this move, but the controversy it generated is important for our assessment of the importance of Kew Observatory in the organisation of the physical sciences and, in particular, the observatory sciences in the 1870s. Airy's attempted coup over Kew meteorology has been discussed before. James Burton has described it in some detail, but he does not set it in the context of either Airy's long-term animosity towards Sabine and Kew or the wider politics of science in the 1870s.[48] Similarly, Malcolm Walker presents the episode as something that should not have happened, a distraction from Kew Observatory's role in the triumphant story of the Meteorological Office.[49] No history yet written has set the episode in the history of Kew Observatory. In this section I will describe the controversy in this context and also that of the controversies over science patronage in the 1870s.

On 27 October 1870, Sabine announced his intention of resigning as President of the Royal Society with effect from 30 November 1871. He was succeeded by Airy. There is no evidence that Airy had anything to do with Sabine's

[48] Burton (1988), pp. 113-116.
[49] Walker (2012), pp. 104-106.

resignation; as noted in Section 5.2, Sabine had been under increasing pressure, due to widespread dissatisfaction among Fellows towards his leadership. The candid pamphlet by his friend Gassiot, describing the events leading up to Sabine's resignation, does not implicate Airy in any way.[50] According to Walter White, the Royal Society's full-time Assistant Secretary, who had intimate knowledge of Royal Society politics, Sabine's intention was that his successors would be from the aristocracy: first Lord Salisbury for two years, then Laurence Parsons, the Fourth Earl of Rosse.[51] As Ruth Barton has persuasively argued, it was the influential 'X-Club' – among whose nine members were Huxley, Spottiswoode and Hirst – who were instrumental in nominating Airy for the presidency in 1871. They definitely did not want an aristocrat as President, but rather an eminent, working scientist who, preferably, did not want to remain President for too long. Airy, as head of the world-famous Greenwich Observatory, fitted this bill perfectly.[52] Walter White records that in March 1871 Spottiswoode (an X-Club member) and George Gabriel Stokes (secretary of the Royal Society) visited Greenwich to offer Airy the nomination, that 'he accepted without reserve' and that the nomination was unanimously supported by the Council.[53]

On 11 December 1871, less than two weeks after being elected President, Airy wrote to Meteorological Office director Robert Scott, claiming innocuously that: 'In my new position in connexion with the Royal Society, there has come before me general mention of the Kew Observatory and of its connexion with the Meteorological Office.' He asked Scott how much the meteorological observations at Kew and also the reduction and printing of the results from the other self-recording stations were costing the government. In addition, he signified his wish to visit Kew.[54] Scott's reply informed him that the government were paying £250 per annum for the Kew meteorological observations. As soon as he had received Scott's letter, Airy wrote to Samuel Jeffery, superintendent of Kew Observatory since August 1871 (see Section 5.5) and between them they arranged for Airy to visit Kew on 19 December. Airy's visit seems to have been a fact-finding mission, for he

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[50] Gassiot (1870).
[51] White (1871), p. 229, 4 January 1871.
[52] Barton (1990), p. 67.
[53] White (1871), p. 232, 17 March 1871.
[54] Airy to Scott, 11 December 1871, RGO 6.394.240.

followed it up three days later by writing to Jeffery with some technical questions.[55] By 6 January Airy had written a paper to be circulated to Council members prior to the next meeting. This pointed out that while the government was spending £250 a year on maintaining Kew as one of the self-recording meteorological stations, not far away the Meteorological Department at Greenwich, established several years before that at Kew, was 'more complete in its equipment than the Kew Observatory, at least equal to it in the excellence of its instruments, and under the most careful daily superintendence'. Airy thought it wrong, therefore, 'still to load the Government with this unnecessary expense' and proposed that procedures should immediately be put in place to transfer to Greenwich the observations currently being done at Kew under the Meteorological Committee.[56]

Airy sent his paper to George Gabriel Stokes, Lucasian Professor of Mathematics at Cambridge. Stokes, described by David Wilson as 'one of the great administrators of Victorian science',[57] had been a secretary of the Royal Society since 1854 and so had been intimately aware of the positions of Kew Observatory and the Meteorological Office with respect to the Royal Society ever since the establishment of the Meteorological Department of the Board of Trade in 1854. In the 1850s he had obtained a sum of money from the Royal Society Government Grant to do some experiments of his own at Kew (Chapter 3, Section 3.2). His initial reply to Airy was friendly, though he urged caution, advising that Airy's proposal should be sent to the Kew Committee before the Council decided on it.[58] But four days later, Stokes wrote again to point out that the Kew observations came under the responsibility of the *Meteorological* Committee, whose authorisation was 'quite distinct' from the Kew one – an example of how the two committees, though identical in personnel for the time being, were legally different (see Section 5.2). The Meteorological Committee reported to the Board of Trade, not the Royal Society, and so Stokes now thought it 'hardly proper' for the Royal Society to be questioning how a department of the Board of Trade was being run.[59] Airy went ahead with his proposal anyway, at the Council meeting on 18 January 1872. Very

[55] Airy to Jeffery, 13 December 1871, RGO 6.394.244; Jeffery to Airy, 14 December 1871, RGO 6.394.245; Airy to Jeffery, 22 December 1871, RGO 6.394.247.
[56] Original version with letter from Airy to Stokes, 6 January 1872, RGO 6.394.256; printed version in RGO 6.394.276.
[57] Wilson (2002), p. 118.
[58] Stokes to Airy, 8 January 1872, RGO 6.394.262-266.
[59] Stokes to Airy, 12 January 1872, RGO 6.394.268-275.

near the start of the meeting, he raised the question of whether it was worth continuing the Kew meteorological observations at government expense, while ‘equally efficient’ observations were, ‘and have long been’ done at Greenwich. The minutes merely record that after ‘some discussion’, the matter was not pursued and that Airy announced his intention to follow it up directly with the Meteorological Committee.[60]

The Meteorological Committee, still chaired by Sabine, was by this stage well aware of Airy’s renewed interest in Kew, for Scott had almost immediately informed the Committee of his correspondence with Airy back in December.[61] Three days before the January Royal Society Council meeting, Scott bluntly reminded Airy of the limits of his jurisdiction by quoting a Parliamentary Paper, which pointed out that the Royal Society merely nominated the membership of the Meteorological Committee and had no connection with the Meteorological Office, thus fortifying the Committee’s position with legal sanction.[62] True to his announcement at the Royal Society, Airy wrote to the Committee on 22 January, enclosing the same paper that he had circulated to the Royal Society Council. Airy was careful to note that he was sending this at the suggestion of the Royal Society’s officers, implicitly denying any personal motive.[63] At its next meeting the Meteorological Committee considered ‘various drafts’ of a response to Airy. In the version sent, Scott again deployed the weapon of legal sanction in reminding Airy that the system of meteorological observatories ‘was adopted by Her Majesty’s Government’ and was a matter for the Board of Trade. In addition to there being a technical requirement for Kew having to be one of the self-recording observatories if it were to work properly as the nerve centre for the other stations scattered across the British Isles, moving the meteorological observations conducted there to Greenwich would mean placing them under a different government department – the Admiralty – over which the Meteorological Committee had no control. At the end of the letter Scott called Airy’s bluff: the Committee ‘will be ready to advise the Board of Trade … if they should be consulted in the matter’.[64]

[60] RSCM, 18 January 1872; MMC, 29 January 1872, TNA:BJ 8/9.
[61] MMC, 18 December 1871, TNA:BJ 8/9.
[62] MMC, 15 January 1872, TNA:BJ 8/9.
[63] MMC, 29 January 1872, TNA:BJ 8/9.
[64] Airy to Scott, 2 February 1872, in MMC, 5 February 1872, TNA:BJ 8/9.

Airy does not seem to have approached the Board of Trade on his own, likely because he knew that the Board would throw the question straight back to the Meteorological Committee – or, even worse, its chairman, Sabine. Yet he did propose that the Royal Society Council follow this strategy collectively. On 11 April he announced that he would put three motions before the Council at its next meeting: first, that it was within the 'competency' of the Royal Society to enquire into whether it was necessary for Kew to remain the central observatory and make representations to the Board of Trade if need be; second, that responsibility for the meteorological observations now being made at Kew should be transferred to Greenwich; and finally, that a copy of the second motion should be sent to the Board of Trade. Airy put the first of these motions near the end of the 18 April Council meeting, but no one seconded it and so Airy did not see it as worthwhile to move the second and third resolutions.[65]

No further moves by Airy to transfer the Kew meteorological observations to Greenwich are recorded in any minutes or correspondence for the rest of Airy's tenure as President of the Royal Society. Airy had no jurisdiction over the Board of Trade, a different department from Greenwich's governing body, the Admiralty. Yet neither could the Royal Society simply tell the Board of Trade what to do. Seeing that there was no way of ever persuading the Meteorological Committee, at least for as long as Sabine remained its chairman, Airy used his position as President to seek the Royal Society Council's authority to persuade the Board of Trade. As Walker has noted, we may never know the unrecorded machinations behind the scenes at the Council,[66] but it is reasonable to imagine Airy presuming that, as a majority of its members (eighteen are recorded as present on 18 April) were not involved with the Meteorological or Kew Committees, he had a chance of persuading enough of them to take his side. Yet it is also plausible that the Council members would have agreed with Stokes that it would be 'hardly proper' for the Royal Society to be questioning how well a department of the Board of Trade was being run.

As several historians have shown, Airy had long expressed the view that the burden imposed by Greenwich, and science in general, on the public purse should be minimised as far as possible. He had repeatedly aired the opinion that only observations with a utilitarian purpose should be done at Greenwich, while those of

[65] RS:CM, 11 April 1872; RS:CM, 18 April 1872.
[66] Walker (2012), p. 106.

an experimental nature or with no practical applications should be carried out by private individuals at their own expense, or perhaps with occasional grants from funds such as the Royal Society Government Grant.[67] It is easy to envisage, therefore, Airy taking the same attitude with regard to the Kew meteorological observations, which he saw as an unnecessary duplication of work at public expense. But if he simply wanted to avoid duplication, he might have indicated that he wished to discontinue the Greenwich meteorological work, now that a perfectly good system was running at Kew. Similarly, Airy's attempts in the 1860s to stop the Kew *magnetic* observations could not have been driven by a desire to save public money, as these were privately funded by the BAAS. A wish to keep hold of the staff who ran the Greenwich 'Mag. and Met.' department – especially James Glaisher, one of his most loyal members of staff as well as the most publicly-known – would surely also have been a factor in Airy's desire to continue the meteorological observations at Greenwich. Yet one suspects that a major motive of Airy's in his attempts to wrest control of the magnetic and meteorological observations from Kew – or to stop them from going there in the first place – was to keep his prestige as the 'National Observer', at the top of the hierarchy of observational astronomy and its allied sciences. To Airy, rival establishments like Kew were usurpers. Airy's attempt to take over the Kew meteorological observations can be seen as a failed attempt to put down this long-time usurper.

5.4 The Kew photoheliograph: Airy's successful coup, 1872-1873

Airy was much more successful in transferring to Greenwich another branch of research for which Kew had become famous by the early 1870s: solar photography. The Kew and Meteorological Committees did not create the same difficulties over this, because the Kew Committee was already planning to terminate the programme once a full ten years of continuous solar photographs at Kew had been completed in January 1872. Secondary sources generally recount that the photoheliograph was simply transferred from Kew to Greenwich in 1873, without discussing how or why this happened.[68] In this section I show that Airy acquired the Kew photoheliograph

[67] Higgitt (2014); Chapman (1988b), pp. 45-46 and 55; Alter (1987), pp. 80-81.
[68] The popular science writer Stuart Clark has briefly noted that Airy's opening negotiations with De La Rue to acquire the photoheliograph set back a plan to open a new solar

for Greenwich on his own initiative. As with the meteorological observations discussed in Section 5.3, we will see that Airy's motive was partly to redress the balance of power between Greenwich and Kew. In addition, it would seem that Airy was motivated by a desire to forestall moves by the ongoing Devonshire Commission, and in the Royal Astronomical Society, to set up a new solar physics observatory under the direction of Norman Lockyer. It seems likely, also, that Airy had ulterior motives in accepting the presidency of the Royal Society.

During his visit to Kew in December 1871, Airy seems to have taken an interest in the photoheliograph in addition to the meteorological work there.[69] Then, on New Year's Day 1872, Airy wrote to De La Rue in a private capacity, saying that he was 'sorry to hear' that De La Rue's solar photography project was coming to an end so soon, something that Airy must have been aware of for some time. He asked whether part of the Gassiot money could be diverted from magnetism to continuing the solar work, knowing that this would never happen for as long as Sabine remained in control of Kew. Then, in a postscript, he remarked that 'I set great value on the continuation of the sun-pictures, and regret that I cannot take them up here'. Airy seems to be hinting here that he wanted them for Greenwich.[70] De La Rue's enthusiastic response the next day strengthens this possibility: he expressed the wish that the solar observations should be carried out on a permanent basis and should be funded by the government: 'I wish very much that solar photographic observations could be made the business of a Government Establishment' – of which Greenwich was the only example for astronomy in England. The cost, said De La Rue, would only be around £200 per annum. He finished his letter with the comment that 'if ever meteorology is to be placed on a scientific basis that [*sic*] it will have to be studied in connection with solar phenomena'.[71]

Airy and De La Rue were old friends by the early 1870s, as is clear from their reciprocal New Year's greetings in the above exchange of letters. To Airy, De La Rue must have been a shining example of how he believed astronomy outside Greenwich should work, with new fields like solar physics being pioneered by

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observatory, independent of Greenwich (Clark (2007), pp. 134-135). This agrees with one strand of the argument presented here.

[69] Airy to Jeffery, 26 December 1871, TNA:BJ 1/38; Whipple to Airy, 28 December 1871, RGO 6.394.250.

[70] Airy to De La Rue, 1 January 1872, RGO 6.394.252.

[71] De La Rue to Airy, 2 January 1872, RGO 6.394.253-255.

wealthy devotees of science like De La Rue, funding their research from their own resources. De La Rue's comment about meteorology must also have been music to Airy's ears, not least because Airy himself felt that meteorology needed a stronger theoretical footing before it could properly be called a science.[72] It is therefore not surprising that, at the Board of Visitors meeting on 1 June 1872 De La Rue, as a member of the Board, proposed that 'the time has arrived when it would be for the advantage of Science that continuous photographic and spectroscopic records of the Sun should be made at the Royal Observatory'.[73] By November, Airy had informed the Royal Society Council that pending Parliament's 'financial arrangements', he would soon have authority to commence photographic solar observations at Greenwich. He also said that he wanted the loan of the Kew photoheliograph on the grounds that the government had just spent a great deal of money on several new photoheliographs for the 1874 transit of Venus and so they should not be asked to fund an additional instrument. Once again, Airy used the pretext of saving public money to advance his interests – in this case, transferring the photoheliograph to Greenwich so that no rival could use it. The Council willingly gave its assent to Airy's request: solar photography was now redundant at Kew and had nothing to do with the Meteorological Office.[74] With permission granted, Airy lost no time in moving the photoheliograph to Greenwich. Just a week after the 31 October Council meeting, an agent of Airy's had called at Kew to examine the base of the instrument.[75] By June 1873 the photoheliograph had been placed in a dome at Greenwich and it was in regular use from April 1874.[76]

That Airy should so artfully negotiate the transfer of the Kew photoheliograph to Greenwich might appear inconsistent with his highly utilitarian stance on Greenwich's role, as sunspot observation was surely far removed from timekeeping and navigational astronomy. Indeed, Rebekah Higgitt has suggested that Airy had to be pressed by the Board into diversifying into the new type of astronomy.[77] Simon Schaffer and Roger Hutchins have each suggested that Airy accepted the introduction of solar photography because photography was a form of

[72] Meadows (1975), p. 103.
[73] Minutes of Board of Visitors, 1 June 1872, RGO 55.
[74] Airy to Stokes, 19 October 1872, RS:MC9.419; RS:CM, 31 October 1872.
[75] Airy to Jeffery, 7 November 1872, TNA:BJ 1/42/402.
[76] Reports to Board of Visitors, 7 June 1873 and 6 June 1874, RGO 55.
[77] Higgitt (2014), pp. 614-618.

automation that could reduce observer error, like his device for timing star transits.[78] But why institute solar observation at all, automated or not? Because of its alleged connections with terrestrial magnetism and meteorology, Airy might have considered sunspot research as being no less utilitarian than the magnetic and meteorological observations that he had been running at Greenwich for nearly thirty years. He might have inferred this from the assertion in De La Rue's letter of 2 January 1872, that if meteorology were ever to be considered scientific, connections had to be made between it and solar activity. Acquiring the photoheliograph made perfect sense as an extension to the existing Magnetic and Meteorological Department. For as long as the instrument was operated by his friend De La Rue, Airy was prepared to tolerate it being run at Kew. But now that it was redundant, he did not want it going into anyone else's hands and so he had to have it. As the 'National Observer', Airy saw solar astronomy as his prerogative as much as magnetism and meteorology. Airy did not have any problem with introducing new equipment and programmes at Greenwich, so long as they did not conflict with his utilitarian agenda.

By the time the photoheliograph was in regular use at Greenwich, Airy was no longer President of the Royal Society. He stepped down with effect from the Society's Anniversary Meeting in November 1873, after just two years in the post; indeed, he announced his intention to resign at the previous year's Anniversary Meeting and confirmed his decision at a Council meeting in December 1872.[79] His presidency was the shortest since William Wollaston had held the post for just five months in 1820 after the death of Sir Joseph Banks. Yet it is striking that Airy made his first recorded moves with regard to the Kew meteorological observations on 11 December 1871, less than two weeks after he was elected President, and he made his first enquiries about the Kew photoheliograph just over a fortnight later. Historians have generally accepted the official reasons Airy gave for his resignation in his autobiography and in his final Presidential Address: that the position involved too much work; that he was based too far from central London, where the President of the Royal Society frequently had to attend meetings; and also 'a difficulty of hearing, which unfits me for effective action as Chairman of Council'.[80] Yet it seems scarcely plausible that someone as astute as Airy, a Fellow of the Royal Society

[78] Schaffer (1995), p. 276; Hutchins (2008), p. 284.
[79] Anon. (1872), p. 30; RS:CM, 19 December 1872.
[80] Airy (1896), p. 303; Hall (1984), p. 111.

since 1836 and with long experience of the Society's affairs, was not aware of the nature of the President's role before he took it on. In fact, in December 1870, just six weeks after Sabine announced his resignation, Airy began a letter to De La Rue:-

> Since our last conversation, I have thought repeatedly on the Presidency of the Royal Society. And my feeling is, that it is encumbered with many difficulties.

The 'difficulties' recognised by Airy included that of managing his work as Astronomer Royal so that he could devote sufficient time and attention to the presidential duties, as well as 'the absorption of time and strength by attendance at Councils and Meetings', the fact that he lived 'an hour's journey' from the Royal Society's premises and also his 'slowly increasing deafness'.[81] Thus Airy indeed had few illusions as to the amount and nature of the work involved if he accepted the office of President: in 1870, he anticipated all the reasons that he eventually gave for resigning.

In addition, that Airy wrote to De La Rue as early as December 1870 shows that he was seriously considering taking on the post of President very soon after Sabine's resignation. Moreover, the opening words, 'Since our last conversation' show that verbal discussions about the possibility had already been taking place between Airy and De La Rue. All this suggests that Airy had an ulterior motive in becoming President. Now that Kew Observatory was run by the Royal Society, Airy might have seen the presidency as an opportunity to at last transfer back to Greenwich some of the balance of power which Sabine had stolen for Kew. Further evidence for Airy having such an ulterior motive is contained in a letter by Balfour Stewart dated soon after the announcement of his resignation:-

> I hear that Airy has twice tried to stop the Meteorological Committee and no doubt Kew Observatory also but I fancy it was seen by the Council that his motives were not pure so that he was snubbed and has expressed his intention of resigning[82]

For as long as it offered the possibility of lowering Kew Observatory to what he saw as its correct place in the hierarchy, Airy may have regarded the increased workload that came with the presidency worthwhile. But now that the photoheliograph was securely in his possession – even though his coup attempt over the Kew

[81] Airy to De La Rue, 12 December 1870, RGO 6.396.17.
[82] Stewart to [Whipple?], 20 December 1872, TNA:BJ 1/84.

meteorological observations had been ‘snubbed’ by the Council – Airy clearly saw no point in carrying on as President. The nomination of Airy for the presidency in 1871 may, as discussed in Section 5.3, have suited the X-Club, but for Airy to have allowed his name to go forward, it must also have suited Airy.

Airy may have had a second ulterior motive in acquiring the Kew photoheliograph that would have a much greater significance for our understanding of the ongoing debates in the 1870s about state support for science. The issue of government-funded observatories and laboratories was not addressed until the Devonshire Commission’s eighth and final report, published in 1875, but the relevant hearings took place in the spring and summer of 1872, which was when Airy, De La Rue and Alexander Strange all testified before the Commission. The hearings were conducted by small panels of well-known scientific personalities, notably Thomas Huxley, William Sharpey and George Gabriel Stokes, under the chairmanship of the Duke of Devonshire. Airy, De La Rue and Strange were all questioned as to the possibility of establishing a new, state-funded observatory dedicated to the new astronomical physics, especially photographic and spectroscopic studies of the Sun. Strange expressed the belief that such an observatory, if established, had to be independent of Greenwich.[83] De La Rue took a more ambivalent position: a new observatory, he said, should be under the aegis of Greenwich and come under the Astronomer Royal, but it should not necessarily be built at Greenwich.[84] Airy, on the other hand, did not believe that observatories for open-ended, non-utilitarian research should be established at cost to the public purse – though he did express the view that regular solar observations could be done at Greenwich. Airy specifically said that daily solar photographs like those being done until recently at Kew should be publicly supported – though he did not refer to his correspondence with De La Rue earlier in 1872, cited above, which had set in motion the transfer of the Kew photoheliograph to Greenwich.[85]

By the time Airy had presented his views to the Commission, the idea of setting up a state-funded observatory for astronomical physics had become a contentious issue in the Royal Astronomical Society. At a meeting of the Society on 12 April 1872, Strange presented a paper provocatively titled: ‘On the Insufficiency

[83] Strange (1872a), p. 76; Becker (2011), pp. 139-140.
[84] De La Rue (1872), p. 302.
[85] Airy (1872), pp. 93-94 and 97; Becker (2011), pp. 140-141.

of Existing National Observatories'. Strange very strongly advocated the establishment of a new observatory, separate from Greenwich, dedicated to solar research and stellar spectroscopy, complete with a laboratory for chemical analysis of spectroscopic results, plus a series of other observatories across Britain's imperial possessions. In this regard he expressed particular anxiety at the recent termination of the Kew photographic observations: the Sun was no longer being systematically monitored anywhere in the British Empire and it would be 'an evil' if this situation were to continue. As Barbara Becker has acknowledged, Strange's motive was likely to rally support for his testimony to the Devonshire Commission.[86] As described in Chapter 1, Strange had instigated the chain of events that had led to the Commission being set up; now, in 1872, he was clearly using this paper in order to guide it towards his own aims for greater state involvement in research such as solar physics.

Strange's paper was followed by a discussion, in which Airy responded by asserting that it was not the job of a government observatory to do theoretical research on the physics of celestial bodies and solar-terrestrial relations: 'It was the place of a Government not to establish philosophical institutions, but working bodies.'[87] In the weeks after the April 1872 meeting, the proposed observatory for astronomical physics became the subject of heated debates at RAS Council meetings, with Strange and Lockyer passionately in favour of the new observatory and most of the other Council members firmly against it. The controversy culminated at the Council meeting on 29 June 1872, which voted in favour of sending to the Devonshire Commission a memorandum recommending that no separate observatory for solar physics be established, 'especially as they have been informed that the Board of Visitors of the Royal Observatory at Greenwich, at their recent meeting, recommended the taking of Photographic and Spectroscopic records of the Sun at that Observatory'.[88] This was the first public announcement that solar photographic observations were to be established at Greenwich, as agreed by the Board of Visitors earlier that month and as privately arranged between Airy and De La Rue at the beginning of 1872. This move seems to have been kept secret, for no mention of it

[86] Strange (1872b), p. 240; Becker (2011), p. 137.
[87] Quoted in Becker (2011), pp. 138-139.
[88] Hollis (1923), pp. 174-175; also quoted in Meadows (2008), p. 96; also Becker (2011), pp. 142-143.

was made in any publication prior to 29 June. Only on 12 July, when it was his turn to testify, did De La Rue mention the Board's decision to the Devonshire Commission and remark that 'I believe it is in contemplation to establish such a series of observations' at Greenwich[89] – knowing full well that these had been 'in contemplation' since January.

The narrative of Airy's private moves to acquire the Kew photoheliograph and then the controversies over the proposed solar physics observatory reads very much like the sequence of events in 1840 (Chapter 2, Section 2.3), when Sabine's faction had applied to the government for a separate magnetic and meteorological observatory and then, when Airy had come to hear about it, he had punctured Sabine's plan with a proposal for his own, extended Magnetic and Meteorological Department at Greenwich, at a substantially lower cost to the public purse. Now, in the 1870s, Airy once again put a stop to a plan for a rival observatory by not only offering to take on solar work at Greenwich, but this time arranging the transfer of the photoheliograph with De La Rue months before the plan was announced. Becker has also cited documentary evidence that Huggins and Airy corresponded in February 1872 about starting spectroscopic work at Greenwich.[90] It is likely, then, that these moves by Airy were not only one of the last acts in his long rivalry with Kew, but were also in anticipation of the Devonshire Commission. By early 1872 Airy, as President of the Royal Society and having an intricate web of connections in the London scientific world, would have known about the moves afoot to review public scientific institutions and would have been perturbed by the idea of the Commission's secretary forestalling him with a separate observatory. As early as April 1871 Balfour Stewart was anticipating that he 'shall probably be examined before the Royal Commission in July'.[91] By then, Airy would have seen a similar need to prepare. Lockyer eventually received authority to establish his own solar physics observatory at South Kensington, but this did not happen until 1881, the year of Airy's retirement as Astronomer Royal, by which time daily solar photography was firmly established as part of the routine at Greenwich.

In the next section we shall see how the main focus of the work at Kew shifted from studies of the Sun and terrestrial magnetism, towards the ongoing work

89 De La Rue (1872), p. 302.
90 Becker (2011), p. 141.
91 Stewart to Whipple, 11 April 1871, TNA:BJ 1/84.

of the Meteorological Office and an expansion and diversification of the already lucrative programme of instrument standardisation.

5.5 Meteorology and metrology: the working of Kew Observatory, 1871-1885

When we compare it to the high drama of the 1860s and early 1870s – the solar discoveries, the Sabine-Stewart confrontations, the handover to the Royal Society and Airy's machinations – it is easy to think of the history of Kew Observatory between the early 1870s and mid-1880s as a long period of stability, in which the observatory continued its existing meteorological and standardisation work, in addition to remaining an important centre for geomagnetic observations. It is certainly possible to gain this impression from reading Meteorological Office director Robert Henry Scott's 1885 history of Kew Observatory. The section of Scott's history dealing with the period from 1872 to the early 1880s seems to consist of summaries of the annual reports of the Kew Committee and so presents an 'official' history, in which any unpleasantness, such as the rivalry between Sabine and Airy, is kept firmly offstage.[92] Here I will argue that the period between the Royal Society taking over the observatory in 1871 and the publication of Scott's paper in 1885 was less stable than it seemed. During the mid-1870s, Kew went through a lean time in terms of funding and scientific output. Some key members of the Kew Committee – notably Sabine – withdrew from the scene, leading to a lack of leadership at the top. The observatory's fortunes improved from the later 1870s, but with this came a change of emphasis. Geomagnetism, although still important, became a routine and somewhat secondary aspect of the observatory's work, while meteorology assumed greater relative importance. But above all, instrument standardisation became the dominant activity at Kew, as this programme diversified into testing instruments unconnected with the traditional work done at Kew, notably clinical thermometers. By 1885, standardisation was Kew Observatory's largest single source of income. I will argue that financial pressures, as well as the changing make-up of its governing committee, forced Kew to become essentially a laboratory of *service* to science, rather than a place of research as the BAAS Council had at least partly envisaged it prior to 1871.

[92] Scott (1885), pp. 64-71.

When Balfour Stewart resigned as superintendent of Kew Observatory in October 1869, his job was offered to former magnetic assistant Charles Chambers (see Chapter 4, Section 4.5), but in the event Chambers stayed in his post at the colonial observatory in Bombay. Stewart remained nominally superintendent, even after taking up his professorship at Manchester in the autumn of 1870. The correspondence shows him running the observatory remotely, down to paying the salary cheques.[93] He continued in post even after late November 1870, when he was severely injured in a train crash that left him house-bound in Harrow, Middlesex until the spring of 1871. During these months his wife Katherine, known as 'Katie', wrote to the staff at Kew on his behalf. For example, in January 1871 she wrote to chief magnetic observer George Whipple:-

> Mr. Stewart would like to hear how the magnetic work is getting on?
>
> He is going on very well, he can pull himself from one side of the bed to the other...[94]

By 1871 it might have looked as though Kew Observatory was being run by an extended family, for Katie Stewart was not the only woman helping to run the place. In June 1870 Elizabeth Beckley had married George Whipple.[95] She had played an essential role in taking the sunspot pictures (Chapter 4, Section 4.3) and was still measuring the surface areas of sunspots on the photographs.[96] Katie refers to her as 'Lizzie' in her 27 January letter: from the familiar name she was clearly part of the Kew 'family'.

Lizzie's husband had, in fact, assumed the running of the observatory after Stewart had left for Manchester. Scott's statement to Gassiot of the work being performed by each member of staff has 'general supervision of the daily work of the Observatory' at the top of the list of Whipple's duties. Whipple was also in charge of correspondence and finance, in addition to supervising the magnetic and meteorological observations.[97] As noted in Chapter 3 (Section 3.4), he had joined Kew in January 1858 as a boy of fifteen. He had initially carried out meteorological

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[93] See, for example, Stewart to Whipple, 11 April 1871, TNA:BJ 1/84.
[94] Katie Stewart to Whipple, 27 January 1871, TNA:BJ 1/84.
[95] Clerke and McConnell (2004).
[96] Stewart to [Whipple?], 28 February 1871, TNA:BJ 1/84.
[97] Scott to Gassiot, 22 May 1871, TNA:BJ 1/92.

observations, before progressing to magnetic work. Since Chambers' departure in November 1863 he had been the most senior assistant at Kew and Scott's 1871 letter to Gassiot refers to him as '1st. Assistant'. In 1871, too, Whipple was awarded the degree of Bachelor of Science after completing a University of London degree course.[98] Thus in addition to his lengthy experience of magnetic and meteorological observation, Whipple by 1871 had a university training. With hindsight, he might seem to have been another John Welsh or Balfour Stewart in the making and therefore a logical successor to Stewart when the latter finally resigned as superintendent on 27 June 1871.[99]

Yet on 3 July 1871, at its first meeting, the newly-constituted Kew Committee of the Royal Society appointed Samuel Jeffery as superintendent. Jeffery was a complete newcomer to Kew, as he revealed in a letter to Whipple later that month, in which he expressed his intention to visit Kew before starting his appointment, 'to become somewhat familiar with the daily routine'.[100] Of all the superintendents at Kew between 1842 and 1900, Jeffery is much the least well-known today. As Savours and McConnell have pointed out, no obituary for him has ever been found. The Kew Committee gave no official reason for choosing him in preference to Whipple or anyone else. Like Chambers, Jeffery had served a long apprenticeship at a colonial observatory. He began work at the Rossbank magnetic observatory in Hobart, Tasmania – one of Sabine's original Magnetic Crusade stations (see Chapter 2) – in 1840, initially as a volunteer, before serving as a paid assistant at Rossbank between 1842 and 1853. He was then director of Rossbank until the observatory closed in 1854. Following this he seems to have suffered some years of unemployment, before he joined the Meteorological Office in London in January 1869 as a senior clerk, assisting with reducing the data from the self-recording observatories.[101]

For all the relative obscurity of his career, however, Jeffery had one attribute that was essential for a post at Kew Observatory: he had never found himself on the wrong side of Edward Sabine. It is likely that Sabine was instrumental in recruiting him for Kew: in 1867, Stewart had remarked to Sabine that if a vacancy were to arise

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98 Clerke and McConnell (2004); BAAS:CM, 22 September 1858; BAAS:CM, 27 June 1860; Scott to Gassiot, 22 May 1871, TNA:BJ 1/92.

99 Stewart to Sabine, 27 June 1871, TNA:BJ 1/201/8.

100 Jeffery to Whipple, 25 July 1871, TNA:BJ 1/83.

101 Savours and McConnell (1982), p. 560; Walker (2012), p. 103.

at Kew, 'I will bear in mind what you say of Mr Jeffery'.[102] Sabine may have been motivated by a wish to help out a fellow magnetic crusader now down on his luck. Yet it is also likely that Sabine – and others on the Kew Committee – chose Jeffery precisely *because* Whipple had the makings of another Balfour Stewart. After Stewart's disagreements with Sabine and Gassiot, the Committee did not want another independent-minded scientist. It would have suited Sabine and his colleagues to have someone who, as a colonial observer and later a humble clerk at the Meteorological Office, was used to being in a subordinate position. Both Stewart and Whipple seem to have been surprised at the choice of Jeffery. Whipple might naturally have thought that the post would go to him – also, now married and with a baby shortly due, he would have appreciated the increase in salary.[103] Whipple seems to have at least considered resigning,[104] while Gassiot did 'not like the tone of Stewarts [*sic*] letter, I suppose he is offended at yr. not accepting Mr W. as his successor.'[105]

In its last months under the BAAS, Kew Observatory had a complement of nine assistant staff, plus two temporary, 'supernumerary' assistants to help with the reductions of observations and two part-time assistants working with the photoheliograph.[106] Thanks to the Gassiot Trust, the Kew Committee did not have to lay off any staff – with the notable exception of Robert Beckley, who had played an important role in designing several Kew instruments (see Chapter 3, Section 3.4). In December 1871 he was made redundant, on the grounds that the Committee did 'not consider that they will have sufficient occupation in future for the entire time of a mechanician'. However, the Committee continued to pay him a retainer of £10 a year for any ad hoc design work that they might need.[107] Beckley's dismissal was perhaps an early reflection of how Kew after 1871 became less of an experimental research station and more of a laboratory providing services for the Meteorological Office and commercial instrument makers, as will be discussed below. In the same year, two further magnetic assistants started work at Kew, to help with Sabine's

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[102] Stewart to Sabine, 5 July 1867, RS:Sa.1604.
[103] The baby, born on 1 August 1871, was Robert Stewart Whipple (1871-1953), later to become a well-known collector of scientific instruments. Lang and Bradley (2004).
[104] De La Rue to Whipple, 8 July 1871, TNA:BJ 1/214/6.
[105] Gassiot to De La Rue, 7 July 1871, TNA:BJ 1/201/11.
[106] Scott to Gassiot, 22 May 1871, TNA:BJ 1/92.
[107] Scott to Beckley, 8 December 1871, TNA:BJ 1/214/24; KCR, 1872, p. 40.

magnetic reductions, but they were paid by the War Office, there being no longer any room for a magnetic office at Woolwich.[108]

Jeffery started work as superintendent of Kew on 2 August 1871, the official day of the observatory's handover to the Royal Society. The Kew Committee's wish for a compliant director is evidenced by its simple and rigid definition of Jeffery's duties: first, to act as general superintendent of the observatory; second, to be director of Kew as the 'Central Observatory' of the Meteorological Office; and third, to supervise the meteorological results.[109] Unlike Stewart, he did not become secretary to the Kew and Meteorological Committees; Scott filled both these roles instead. Yet from quite early in his time as superintendent, members of the Kew Committee began expressing dissatisfaction with Jeffery's competence. By the end of 1872, Scott was writing to Jeffery in exasperation:-

> I cannot understand how you mean that the max & min readings were "beyond your criticism" Kew exercises a supervision over every line & figure sent up from the observatories… [110]

Jeffery was not expected to do research and experiments in the manner of his predecessor, but his position still involved running a multi-function observatory that did geomagnetic observations and large-scale testing of instruments as well as meteorology. Yet Jeffery seems to have simply continued what he had been doing as a clerk at the Meteorological Office, supervising the returns from the outlying observatories – and not always competently, as Scott's letter above suggests. By the spring of 1874, the reductions of observations were seriously in arrears. This situation remained unresolved by the autumn of 1875, by which time other tabulations were months behind schedule as well.[111] Jeffery also seems to have lacked the aptitude for managing people. In November 1875, when Jeffery apologised to Scott about the slow progress being made by one of his assistants in clearing the arrears, Scott had to remind Jeffery that 'you are the best judge being on the spot. If … is not up to his work he should be dismissed at once'.[112] Although

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[108] Sabine to Controller-in-Chief, War Office, 15 December 1871, TNA: BJ 3/55.
[109] KCM, 3 July 1871.
[110] Scott to Jeffery, 13 December 1872, TNA:BJ 1/42/441.
[111] KCM, 17 April 1874; Scott to Jeffery, 7 July [18]74, TNA:BJ 1/214/132; Jeffery to Scott, 11 November 1875, TNA:BJ 1/202/231.
[112] Scott to Jeffery, 27 November 1875, TNA:BJ 1/214/252.

Jeffery had briefly been superintendent at Rossbank, he had only ever had one assistant and frequently worked on his own. At Kew he had to manage at least eight full-time staff.

That this situation was allowed to persist for so long seems to have been partly because the Kew Committee was itself in difficulties by the mid-1870s. After 1871 the committee remained dominated by the elder statesmen who had run the observatory under the BAAS since mid-century: men like De La Rue, Gassiot and Wheatstone, as well as Sabine. In 1875 Wheatstone died and Gassiot resigned due to ill health. Neither of these two was immediately replaced, causing the committee to shrink in size. After Spottiswoode resigned in 1873, Richard Strachey (a Lieutenant-General with particular interest in Indian weather and climate) and Lord Rosse (son of the Third Earl of Rosse, who had served as President of the Royal Society from 1848 to 1852) were invited onto the Committee,[113] but its meetings in the early 1870s were often attended by just three or four people, two of whom were Scott and Jeffery. Although Sabine nominally remained chairman until his death in 1883, he last attended a meeting of the Kew Committee on 18 December 1874.[114] There are clear signs that the octogenarian was winding up his affairs by this time, including donating his library to Kew Observatory.[115] By mid-January 1876, Sabine was 'well in health but his mind is inactive now'.[116] This suggests that Sabine's physical and mental powers were in decline even before 1876, the year in which Gregory Good has suggested that this decline began.[117] Of the 'old guard' on the Kew Committee, De La Rue alone remained. He usually chaired Committee meetings on Sabine's behalf, but even he had by now retired from active astronomical observation.

Therefore a lack of leadership on the Kew Committee might well be a reason why Jeffery was allowed to remain superintendent while the backlog of work accumulated. Jeffery resigned at the Kew Committee meeting of 19 November 1875, after the Committee had explained to him that in the future the observatory would need to be headed 'by a scientific man', with 'special scientific knowledge'. It is indicative of the Committee's hidden agenda in 1871 that they could then have

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[113] KCM, 25 July 1873.
[114] KCM, 18 December 1874.
[115] Sabine to Bergsma, 22 November 1873, RS:Sa.1250.
[116] Scott to Meldrum, 21 October 1875, TNA:BJ 1/215/240; Scott to Meldrum, 13 January 1876, TNA:BJ 1/214/258.
[117] Good (2004).

appointed just such 'a scientific man', George Whipple. It is interesting that in the same letter in which he referred to Sabine's 'inactive' mind, Scott was able to inform the head of another observatory that Jeffery was to leave Kew on 1 March 1876 and would probably be succeeded by Whipple.[118] It is possible that Scott and others on the Kew Committee had for some time wanted to dismiss Jeffery and replace him with Whipple, but felt unable to do so without offending Sabine, because Jeffery was Sabine's protégé. But now that Sabine was safely out of the picture, they would have had less inhibition in persuading Jeffery to resign. That the Committee offered Jeffery £100 in gratitude for his efforts, gave him the option to leave before March 1876 and even agreed to buy his furniture for £28, greatly strengthens the idea that its members wanted Jeffery to leave Kew as soon as possible.[119] On Jeffery's departure, George Whipple immediately became acting superintendent; he was appointed superintendent on 14 November 1876.[120]

The events of the mid-1870s mark an important watershed: the end of Sabine's leadership of the observatory. For the first time since 1842, Kew Observatory was on its own and its scientific agenda would no longer be dictated by Sabine. The decline and departure of Sabine might explain why geomagnetic work at Kew from the 1870s onwards was less innovative than it had been in the 1850s and 1860s. The self-recording magnetometers remained operational practically throughout the 1871-1885 period, but less *research* was done with them. Jeffery has no recorded involvement with the magnetometer work; this was left in the charge of Whipple, as it had been before 1871. With Sabine gone and the Kew Committee's Vice-Chairman, De La Rue, increasingly elderly, everyday supervision of the Kew superintendent fell to Scott, who as Director of the Meteorological Office already had more than enough on his schedule. Geomagnetism was certainly not part of Scott's duties as director, as he politely but firmly reminded the son of the Belgian astronomer and statistics pioneer Adolphe Quetelet:-

> Please remember if you write to me on Magnetical business to keep the letter separate from any communications on Meteorological business. This office takes no cognizance of Magnetism.[121]

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[118] Scott to Meldrum, 13 January 1876, TNA:BJ 1/214/258; KCR, 1876, p. 377.
[119] KCM, 19 November 1875 and 25 February 1876.
[120] KCM, 25 February 1876 and 14 November 1876.
[121] Scott to E Quetelet, 20 January [18]74, TNA:BJ 1/214/95.

One of the first recruits to the Kew Committee in the post-Sabine era was William Grylls Adams, James Clerk Maxwell's successor as Professor of Physics at King's College, London. In 1879, Adams persuaded the Kew Committee to stop the long series of tabulations of magnetic curves, in favour of comparing the curves themselves with those of foreign observatories, 'with a view to the development of the theory of magnetic disturbance'.[122] This was another effect of the departure of Sabine and his unquenchable thirst for more and more data that had so exasperated Balfour Stewart in the 1860s. It also reflected Adams' own interest in precision measurement, not least in magnetism, which featured prominently in the physics syllabus at King's.[123] The international status of Kew as a centre for magnetic observations and instruments remained undiminished into the 1880s. Magnetographs and dipping-needles tested at Kew were regularly supplied to foreign observatories such as Imperial Germany's prestigious new Potsdam Astrophysical Observatory in 1876.[124] Kew also sold standard forms to observatories for recording magnetic observations; among the customers for these in 1882 was the Cavendish Laboratory in Cambridge, which had been established in 1874. Among the Cavendish's earliest acquisitions was a magnetometer originally used at Kew. James Clerk Maxwell, the Laboratory's first director, used this to train students in making precision measurements.[125] Yet all this work was in service of other institutions or individuals and not for research of the type that had been done by Sabine. Far from being the command post of Sabine's Magnetic Crusade, Kew was now a kind of service regiment providing instruments and expertise for other crusades.

After 1871, Kew remained the Meteorological Office's central observatory for land meteorology, coordinating, checking and reducing the observations sent in by the six outlying stations: Falmouth, Stonyhurst, Glasgow, Aberdeen, Armagh and Valencia (Ireland), each one equipped with self-recording instruments tested at Kew. The reductions were carried out by two junior assistants at Kew, under the supervision of Jeffery and then, after 1876, under Whipple. This remained the 'bread and butter' of Kew meteorology until the autumn of 1876, when the Meteorological Committee decided to move this work to the Office's headquarters in

[122] KCM, 23 December 1879.
[123] Gooday (1989), Chapter 5, pp. 26-37.
[124] KCR, 1876, p. 373.
[125] KCR, 1882, p. 352; Morus (2005), p. 241; Schaffer (1992), p. 36.

Victoria Street, London, on the grounds that it would be more efficient to do the reductions in the same place where the Office's quarterly weather reports were produced. As a result, one of the assistants doing the reductions moved from Kew to London. This slightly reduced the Kew salary bill, but the Meteorological Office's annual allowance to Kew was reduced from £650 to £400, leading to a significant loss of income. In addition, one of the Kew assistants still had to regularly travel to the outlying observatories to check their instruments and another assistant had to remain on standby to cover for absence at any of these stations.[126] More importantly, the change led to a significant loss of status for Kew: instead of being the Meteorological Office's central observatory, it was now just one of seven self-recording observatories reporting to the Office – a far cry from Galton and Sabine's 1866 plan for the Office to act as 'a branch office in London' for Kew (see Chapter 4, Section 4.5). The Meteorological Office was now taking the lead and Kew Observatory had to follow. The decision to transfer the work to London might have been a consequence of the disorganized state of Kew under Jeffery, but once again it took place neatly after the departure of Sabine. Now that Sabine was no longer actively on the scene, there was no compulsion to follow his cherished plan for Kew as the Meteorological Office's central observatory.

A further change in the balance of power between Kew and the Meteorological Office came in July 1877, when the members of the Meteorological Committee resigned *en bloc* and were replaced at the same meeting by a new 'Meteorological Council'. This was in response to a new Treasury inquiry into the Meteorological Office, instigated in November 1875, asking it to justify its £10,000 annual budget. As Anderson and Walker have both pointed out, this inquiry was somewhat internal, as some of its members were on the existing Meteorological Committee and two of them (Galton and Thomas Farrer) had served on the original 1866 committee that had set up the current arrangements.[127] Perhaps unsurprisingly, the report recommended that the Meteorological Office be kept going much as before, except that members of the new Council should be paid, the total salary bill not to exceed £1,000 a year.[128] From 1877 also, Scott was no longer secretary to the Kew Committee and so was less actively involved in the daily running of the

[126] MMC, TNA:BJ 8/9, 20 November 1876.
[127] Anderson (2005), p. 144; Walker (2012), pp. 113-114.
[128] MMC, 9 July 1877, TNA:BJ 8/9.

observatory. The secretary's role passed to Whipple, while Scott became an ordinary member of the Kew Committee. The main result of the report for Kew was that the Meteorological Council's membership was no longer the same as that of the Kew Committee – in contrast to Sabine's 1871 assurance that the two committees would be identical (see Section 5.2). In 1879 the Meteorological Council was chaired by Henry Smith (Savilian Professor of Geometry at Oxford since 1860); George Gabriel Stokes was also a member. Neither of these two was on the Kew Committee at this time. That same year, some members of the Kew Committee, such as Richard Strachey and George Carey Foster (Professor of Experimental Physics at University College, London since 1865), were not on the Council.[129] This is further evidence that making the two committees identical had been a ruse by Sabine to reassure Fellows of the Royal Society that they would not have to live John Herschel's nightmare of an observatory being run by the Society. More importantly for the future development of Kew Observatory, members of the Kew Committee now had to take their instructions, where meteorology was concerned, from a more explicitly separate body. The separation of the two committees helped to lift the mask off the fact that Kew was no longer the Meteorological Office's nerve centre, but was an independent institution, relying on the Gassiot money plus income from standardisation to keep going.

These shifts in the balance of power between Kew and the Meteorological Office in the post-Sabine era did not mean that Kew meteorology lost any status in the outside world. The 1870s saw summaries of Kew meteorological observations being printed in newspapers such as *The Times* (at the editor's request) and the *Illustrated London News*.[130] After he became superintendent at Kew, Whipple began some innovative experimental work, some of which led to papers being published in Royal Society journals. In 1879, he began a two-year comparison of two types of screen for shading thermometers, one designed by British engineer Thomas Stevenson, the other by Heinrich Wild of the St Petersburg Observatory in Russia.[131] Whipple took charge of a more ambitious experiment five years later, when the Meteorological Council granted the Kew Committee £40 to set up a system of two cameras 800 yards apart, connected by telegraphic cable, for photographing clouds

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[129] MMC, 24 January 1879, TNA:BJ 8/10; KCR, 1879, p. 445.
[130] KCM, 28 April 1876; KCR, 1876, p. 373; KCR, 1879, p. 447.
[131] KCR, 1881, p. 84; KCR, 1882, p. 348.

simultaneously in order to measure their heights and their speeds and directions of motion. Simultaneity was ensured by connecting the two observers with the newly-invented telephone. The photographic work began in July 1885 and over the ensuing weeks Whipple and his assistants made 62 measurements of the speeds and directions of cloud motions.[132]

Yet experiments like these were instigated by the Meteorological Council and were very much in the service of the Meteorological Office. They were also restricted to meteorology. There were no more experiments into geomagnetism or ether in pursuit of private research agendas, of the kind that Balfour Stewart had carried out. In late 1871, the Kew Committee rejected a request by Stewart to have his beloved rotating disk experiments recommenced at Kew. They promptly arranged for Robert Beckley to pack up the equipment and take it to Manchester.[133] Also, after 1871 the Kew staff seldom performed experiments on behalf of private individuals, with the help of grants from the Royal Society Government Grant or the BAAS, as had happened in the 1850s and 1860s. Even in rare exceptional cases, such as a photometer sent to Kew by Henry Roscoe, Chemistry professor at Owens' College in Manchester, this type of work was not given priority. In an 1875 letter to Scott, Roscoe ruefully remarked that 'it seems that the Kew Observatory is not the place to get any new method tried…'.[134] Kew was no longer a centre for private individuals' experiments, as had been envisaged in the original 1842 prospectus for the observatory (Chapter 2, Section 2.5).

An increased emphasis on service to other organisations became a characteristic of Kew as a whole after 1871, as is demonstrated by the expansion and development of standardisation, the single most dramatic development at Kew between 1871 and 1885. Verifications of the two main classes of instruments hitherto tested at Kew – barometers and meteorological thermometers – only gradually increased up to the mid-1870s. But at the end of the 1860s, Kew Observatory began testing a major new class of instrument quite removed from the meteorological, magnetic and astronomical sciences practiced there. Scott's 1885 history mentions the verification of 269 clinical thermometers in the period 1869-1870. By the 1872 report of the Kew Committee, the number had increased to

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[132] KCR, 1884, pp. 466-467; KCR, 1885, p. 318.
[133] KCM, 3 November and 1 December 1871.
[134] Roscoe to Scott, 16 July 1875, TNA:BJ 1/202/206.

1,395; thereafter, a similar number of clinical thermometers was tested at Kew up to the mid-1870s (see Table 5.1).[135] No contemporary documentation makes it clear why Kew entered this field. In his autobiography, Kew Committee member Francis Galton claims that his invention (with the help of De La Rue) of an apparatus for testing thermometers quickly and accurately made this mass standardisation possible.[136] Yet while it is true that Galton did develop such a machine, in which forty thermometers could be placed in a test chamber at any one time, this did not come into operation at Kew until 1874,[137] by which time clinical thermometers had been undergoing tests in large numbers – sometimes outnumbering meteorological thermometers – at Kew for at least two years. There was certainly a demand for clinical thermometers from at least one major instrument maker: Negretti and Zambra's 1864 catalogue offers a variety of thermometers for taking the temperature of the human body.[138]

As Galton himself admitted in his autobiography, the impetus for testing so many thermometers seems to have been financial.[139] The income from the Gassiot Trust, though substantial enough to keep Kew going, never amounted to much more than £600 per annum. In 1874, for no stated reason, it abruptly dropped to £499 and never rose above this amount to 1885. Thus after 1874, the income from the Gassiot Trust was substantially less than the annual grant of £600 that Kew had regularly received from the BAAS in the 1860s. The minutes of the July 1874 Kew Committee meeting clearly suggest that finance was a cause for concern: they record a discussion 'on the financial condition of the Observatory' and a request for a quarterly statement of income and expenditure.[140] Although Kew continued to supply many thermometers and barometers to the Meteorological Office and the Admiralty, the majority of the fees received for instrument verifications were from instrument makers. In 1874-1875, for example, the total verification income from the Meteorological Office and Admiralty amounted to £57; in the same year, that from 'Opticians &c.' was £252 (Table 5.1). In October 1875, the Kew Committee reported with satisfaction that the verifications department was showing 'a very

[135] Scott (1885), p. 76; KCR, 1872, p. 43.
[136] Galton (1909), p. 227.
[137] Galton (1877); KCR, 1875, p. 106.
[138] Negretti and Zambra (1864), price list, p. 6.
[139] Galton (1909), p. 227.
[140] KCM, 16 July 1874.

satisfactory increase in utility'.[141] Earlier that year, Scott had asked the Office of Woods and Forests if a better path could be made through the Old Deer Park to Kew Observatory, as 'the increase in the operations carried on there has rendered such a measure very desirable' and there had been instances of people being unable to find the building in foggy weather.[142] In 1876, the Committee decided to open an office at the Meteorological Office's London headquarters, to receive instruments for verification at Kew, in order to save manufacturers the inconvenience of travelling to the observatory. A notice advertising this new service specifically expressed a wish 'to afford the public greater facilities for the verification of instruments at Kew'.[143]

All this points towards standardisation at Kew becoming an increasingly busy commercial operation, eager to please its customers. The financial incentive to expand instrument verifications was further heightened in November 1876, when Kew ceased to be the central observatory of the Meteorological Office. As noted above, this caused another substantial drop in the income that the observatory had received regularly each year up to then. Already by 1875, income from standardisation was approaching parity with that from the Gassiot Trust: in the year to October 1875, £456 came from standardisation, compared with £499 from Gassiot. Table 5.1 shows that in 1878, the £585 from standardisation substantially exceeded the £495 from Gassiot; from 1880, receipts from standardisation were always higher than the Gassiot income. In 1885, verifications brought in £727, compared to just £491 from Gassiot. Much of the standardisation money came from verifications of clinical thermometers, of which well over 8,000 were being tested each year at Kew by 1885. By the mid-1880s, therefore, standardisation was much the largest single source of the income coming into Kew Observatory.

The importance of this increased commercialisation was symbolised in 1877 by the introduction of a distinctive 'KO' hallmark, designed by De La Rue, etched on thermometers tested at Kew (Figure 5.1). This hallmarking of instruments was another idea of Galton's: he first suggested it to the Kew Committee in July 1876 and the following spring he tried etching thermometers himself, finding the process surprisingly easy.[144] The Committee approved a specimen of the new mark the

[141] KCR, 1875, p. 106.
[142] Scott to C R Gore, Office of Woods and Forests, 6 March 1875, TNA:BJ 1/214/178.
[143] Printed notice, dated 29 January 1876, pasted into KCM, 28 January 1876.
[144] KCM, 31 July 1876; Francis Galton to Scott, 24 April 1877, TNA:BJ 1/202/320.

following July.[145] Hallmarking was initially done for a fee of three pence, but this charge initially led to a disappointing level of demand for the hallmark. In November 1878, therefore, the Committee decided that all thermometers which had passed the verification process should hallmarked free of charge and that no thermometer would be verified if its maker refused to have it marked. The fact that the Committee advertised the service in the *Lancet* as well as *Nature* is further evidence of the commercial agenda: the Committee was clearly trying to attract the lucrative clinical thermometer market as well as the market for meteorological instruments. In November 1878 the Committee requested that 'a female assistant' be engaged to engrave the thermometers with the hallmark; the following month, Whipple reported that he had taken on a Miss H. Clements (first name unknown) for this purpose.[146] The Committee likely employed a woman to engrave the thermometers for the same reason that Elizabeth Beckley was employed to take the solar pictures with the photoheliograph in the 1860s: Miss Clements was cheap labour and could be paid on a piecemeal basis. In November 1880 she was dismissed with a month's notice and a tiny gratuity of £3 3 shillings. Miss Clements was dropped not due to any lack of demand, but to the continued financial pressures on the observatory, for at the same meeting it was noted that the probable income and expenditure for the coming year would be about equal. Also at this meeting, the Committee decided to discontinue receiving instruments at the London office, again for financial reasons.[147] A year later the advertisements in the *Lancet* (and the *British Medical Journal*) were also discontinued.[148]

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[145] KCM, 27 July 1877.

[146] KCM, 29 November and 19 December 1878. KCR, 1879, p. 453, refers to her as 'a special assistant, H. Clements', without mentioning that she was female.

[147] KCM, 24 November 1880.

[148] KCM, 2 November 1881.

Figure 5.1 Two thermometers dated 1885, etched with the 'KO' hallmark. Science Museum, London, Object No. 1995-1800; photograph by Lee Macdonald.

Yet as described above, demand for instrument testing only continued to rise after 1880. Indeed, in 1883 Miss Clements was briefly taken on again to help cope with the large number of thermometers sent to Kew for verification.[149] It would seem that the Kew Committee no longer needed to spend precious money on advertising because this was no longer necessary: the name of Kew Observatory was sufficiently prestigious for the leading instrument makers to automatically send their instruments there to be tested. The Committee even tried to register the Kew monogram as a trade mark; they were only stopped by the refusal of the Commissioners of Patents to do this.[150] In any case, it hardly mattered: with the ever-increasing number of instruments being sent to Kew for verification, even after the advertisements ceased, 'Kew Observatory' was now effectively a trade mark.

After 1876, standardisation branched out into further fields. As noted in Chapter 4 (Section 4.5), the testing of sextants began on a small scale in the 1860s, on the initiative of Francis Galton. Sextants remained a relatively minor part of the standardisation work at Kew until 1881, when the numbers of sextants tested increased sharply to 25, compared with just 5 the previous year (Table 5.1). This increase may have been facilitated by a more robust testing apparatus. Since the late 1860s this apparatus had been used indoors, in the basement of the observatory, which was free from draughts and vibrations (the magnetic instruments were also housed here).[151] Sextant-testing expanded further in 1883, this time on the initiative of Kew Committee member Lord Rosse, who in the previous year had remarked on how few sextants were being tested at Kew and expressed a wish to raise interest in

[149] KCM, 30 March 1883.
[150] KCM, 23 March and 28 May 1880.
[151] KCR, 1880, p. 124; Barrell (1969), p. 175.

the accuracy of 'an instrument on which the safety of a ship so intimately depends'.[152]

In May 1884, the Kew Committee also began 'rating' – that is, testing the accuracy of – watches, for members of the public as well as watchmakers. The initial stimulus for this seems to have been external demand rather than the initiative of anyone on the Kew Committee. As early as 1875, the Committee had considered a letter from William Hartnup of the Bidston Observatory near Liverpool, which had been built to serve that port's prosperous merchant shipping. Hartnup asked about the feasibility of testing chronometers at Kew.[153] The Committee did not make any moves in this direction for several years, but in 1881 the Committee agreed to 'rate' a chronometer – that is, test its performance – 'as an experiment only'.[154] The Committee very likely saw watch-rating as a way of increasing the observatory's revenue: its next meeting began with a gloomy financial report, in which the question of staff salaries was deferred. Whipple then presented a report on the chronometer test, whereupon the Committee immediately authorised Whipple to begin testing other chronometers for a fee of 7s 6d per timepiece.[155] In February 1883 the Committee agreed to adopt a system, devised by Whipple, for rating watches and also to spend £100 on the necessary apparatus – including a special oven that allowed the watches to be tested at different temperatures.[156] During the twelve months to November 1885, watch-rating fees brought a further £185 to the observatory – in addition to £727 for other standardisation work.[157]

Symbolic of the change of priorities at Kew after Sabine's departure was the changed use of space in the buildings there. For example, a room once occupied by Sabine's magnetic clerks was by the early 1880s occupied by assistants in the verifications department, while another room formerly used for experiments on pendulums (also an interest of Sabine's), had now been modified for testing sextants. Of the fourteen staff employed at Kew in 1885, four worked full-time in the verifications department and a fifth worked part-time.[158] Standardisation could be

[152] KCM, 26 May 1882.
[153] KCM, 29 April 1875; KCR, 1875, p. 107.
[154] KCM, 24 November 1881.
[155] KCM, 23 December 1881.
[156] KCM, 23 February 1883.
[157] KCR, 1885, p. 320.
[158] KCR, 1885, p. 324.

said to have employed even more of the staff at Kew if we include under this heading the testing of magnetic instruments for other observatories.

Instrument standardisation at Kew Observatory maintained and enhanced the international reputation that it had already gained. For example, in 1881 Leonard Waldo of Yale College in the United States discussed a rigorous test that he had performed on three Kew thermometers, in which he had measured each degree separately. He found that their errors were ‘practically insensible and too small to be detected with certainty’.[159] It was symbolic of the observatory’s status that it was no longer possible to change its name. The Royal Society Council received such a request in January 1883 from William Thiselton-Dyer, director of the neighbouring Kew Botanic Gardens. He asked if it was possible if the observatory could be known as something other than ‘Kew Observatory’, as confusion with the Botanic Gardens was causing mail to be wrongly delivered and the building, when built for George III, had originally been known as the King’s Observatory at Richmond. Thiselton-Dyer’s request for a complete change was firmly rejected by the Royal Society; the only change they agreed to was to call it ‘The Kew Observatory, Richmond’.[160] It must have been hard to imagine either the Kew Committee or the Royal Society dropping the name ‘Kew Observatory’, now that it had become a name and a brand worldwide. The name ‘Kew Observatory’ had stuck.

Thus due to the financial pressures caused by the drop in income from the Gassiot Trust and the Meteorological Office, as well as changes in priorities following by the departure of Sabine, Kew Observatory became much less a place of experimental enquiry, where gentlemen scientists did experiments on sunspots or the discharge of gases, than a laboratory that served government and private industry. By 1885, service to the latter had become the largest single source of income at Kew.

5.6 Conclusion

In the early 1870s, Kew Committee member William Spottiswoode wrote to Balfour Stewart regarding a difficulty in supplying observational results to Stewart’s Manchester colleague Henry Roscoe: ‘Kew is, as you know an establishment no longer supported by the funds of a public body’. Spottiswoode wrote these words

[159] KCR, 1881, p. 87.
[160] RS:CM, 18 January 1883 and 15 February 1883.

about Kew after crossing through a version which describes the observatory as 'a private establishment not a public one'.[161] The crossed-out version is the most revealing: it shows a member of the Kew Committee acknowledging that Kew after the Royal Society's takeover was, in effect, a private institution. Kew Observatory had, of course, been 'private' ever since 1842, in the sense that its main source of income was an annual grant from the BAAS, which was itself funded by members' subscriptions and donations. Yet it is clear from this chapter that after 1871, when the Royal Society Council agreed to take responsibility for Kew Observatory, the institution's financial viability was by no means guaranteed and it had to seek its own sources of income. This led to Kew Observatory becoming a very different kind of organisation from what it had been under the BAAS earlier in the nineteenth century.

It is clear from Section 5.2 that the secondary sources are correct in asserting that the motive of the BAAS Council in deciding to relinquish Kew Observatory in 1870 was financial. The annual grant of £600 was too much for an organisation with limited funds and many competing priorities. It is very likely that Sabine, as President of the Royal Society, used the BAAS's decision as an opportunity to gain ultimate control over Kew Observatory. Indeed, he may even have manipulated it to suit his aim: the BAAS's decision to contemplate the 'dissolution' of Kew and close it down in 1872 gave Sabine the perfect excuse for the Royal Society to take it over. Sabine's subsequent actions substantiate this notion. When the elderly but still influential John Herschel raised objections to the Royal Society assuming responsibility for Kew, Sabine allayed any fears among Council members by assuring them that the observatory's new managing committee under the Royal Society would be identical to the existing Meteorological Committee – without pointing out that the Gassiot Trust deed did not make this legally binding. Sabine completed his control over Kew by appointing as superintendent Samuel Jeffery, whose principal qualification for the position seems to have been his loyalty to Sabine.

It is easy to see Airy's failure to transfer the Kew meteorological observations to Greenwich as being due to Sabine, his old rival, but as I have shown in Section 5.3, the failure of Airy's coup owes as much to the fact that responsibility

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[161] [Spottiswoode] to Stewart (draft letter, no date, probably May 1872), TNA:BJ 1/214/37.

for the Kew observations was vested in the Meteorological Office, which was run by the Board of Trade, a separate department of government from the Admiralty. Airy had no authority in the affairs of the Board of Trade. This demonstrates how, by the 1870s, meteorology in Britain had gained official status as a science quite separate from astronomy. Airy's successor as Astronomer Royal from 1881, William Christie, made no attempt to tread on Meteorological Office ground the way Airy had: Edward Maunder's 1900 account of the Royal Observatory modestly describes Greenwich as one of many stations reporting to the Meteorological Office.[162] This official separation of meteorology from astronomy parallels a similar development that happened in France in the 1870s, with the establishment of the Bureau Central Météorologique that ran French meteorology separately from Paris Observatory.[163]

Airy's 1872 machinations to acquire the Kew photoheliograph for Greenwich resulted in a success for Airy in his long rivalry with Kew. This, in addition to his meteorological manoeuvres, also goes a long way towards explaining why Airy became President of the Royal Society in 1871 and then resigned from this prestigious position after just one year. Becoming President gave Airy the opportunity he needed to bring the Kew meteorological and solar observations into his Greenwich empire. Even more importantly, it enabled him to undermine the power of the Devonshire Commission's calls for a separate solar observatory, something that was anathema to Airy. This ulterior motive to take the wind out of the Commission's sails may be an example of a moderate measure of modernisation and diversification being instituted in order to weaken the case for much more radical reform – as Roy MacLeod has suggested was the aim of some in the Royal Society reform movement in the 1840s.[164] Airy's masterful undermining of the proposal for a separate solar observatory shows him deviously manipulating the *laissez-faire* system, by offering to do the same work at Greenwich for less money.

Historians, as well as Scott, have all noted how the Gassiot Trust saved Kew Observatory from closure. This is true, but simplistic. In the event, the Gassiot money proved insufficient to meet the observatory's running costs, especially after the abrupt drop in dividends from the fund in 1874. The reduction in the Meteorological Office grant two years later made matters worse. The smallness of

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[162] Maunder (1900), pp. 232-233.
[163] Davis (1984), p. 381.
[164] MacLeod (1996), p. xii; MacLeod (1983), esp. pp. 77-81.

the grants from the Gassiot Trust and the Meteorological Office forced Kew to change its mission, especially after Sabine was incapacitated by illness in the mid-1870s. Above all, these financial constraints led to standardisation becoming the central feature of the work at Kew and to this standardisation work diversifying into fields far beyond geomagnetism and meteorology. Importantly, the majority of these instrument tests were for private instrument-makers, not government departments. The opening of a London office for the reception of instruments in 1876, the establishment of a hallmark the following year and the steep climb in the numbers of clinical thermometers tested from the mid-1870s further point to the observatory becoming more commercially orientated after the sharp drop in grant income in these years. In 1881, for example, the Kew Committee was initially reluctant to become involved in testing watches, but later that year, immediately after a bleak assessment of the observatory's financial situation, Whipple was duly authorised to begin rating chronometers on a commercial basis. By the time Scott wrote his 1885 paper, Kew was less a 'physical observatory' of the type conceived in 1842 than a laboratory of service, operating on a predominantly commercial basis. Spottiswoode's crossed-out remark of the early 1870s was prescient: Kew was now indeed 'a private establishment' that had to earn its keep. This central characteristic of a laboratory of service would be a powerful influence on the subsequent development of Kew Observatory into the 1890s and beyond, as we shall see in Chapter 6.

Table 5.1 Kew Instrument Verifications, 1871-1885

	71-2	**72-3**	**73-4**	**74-5**	**75-6**	**76-7**	**77-8**	**78-9**	**79-80**	**80-81**	**81-82**	**82-83**	**83-84**	**84-85**
Met. thermometers	1219	782	1471	1238	1410	1428	1435	1286	1487	1704	1518	1165	1225	1825
Clinical thermometers	1395	1233	1255	1439	1560	2281	2032	3405	3638	4217	5365	7255	8726	8238
Deep-sea therm.	0	0	0	0	0	0	0	53	22	36	27	51	13	38
Total thermometers	2661	2096	2780	2761	3130	3863	3595	4828	5344	6085	7261	8610	10240	10268
% clinical	52	59	45	52	50	59	57	70	68	69	74	84	85	80
Barometers*	124	179	160	214	230	209	222	196	224	202	183	211	208	256
Sextants	3	0	1	1	0	3	2	4	5	25	36	55	64	130
Income from stdsn. (£)	125	236	253	456	419	456	585	469	538	595	621	615	759	727
Total income (£)	2084	1979	2401	2642	2801	2437	3000	2657	2364	2214	2648	2590	3075	2651
% total income	6	12	11	17	15	19	20	18	23	27	23	24	25	27
Income from Gassiot	600	608	499	499	498	497	495	495	496	496	496	493	494	491

* Including aneroids.

Total thermometers does not include deep-sea thermometers.

Data from Reports of the Kew Committee in *Proc. Roy. Soc. Lond.*, 1872-1885.

Chapter 6

Kew Observatory
and the origins of the National Physical Laboratory, 1885-1900

> It has been represented to me by Dr. Schuster that at the present juncture it might be well for us to communicate [with] the Kew Committee of the Royal Society, [&?] consider whether it is desirable or feasible, or both, to utilise that Institution as a nucleus of the proposed National Laboratory.
>
> The Chairman of the Kew Committee, Mr. Francis Galton … has also been good enough to write similarly…
>
> Oliver Lodge, 22 February 1893[1]

> The present work of the [Kew] Observatory is therefore of a character which is strictly consistent with a large portion of the work which would find a place in a national physical laboratory.
>
> BAAS report, 'On the Establishment of a National Physical Laboratory', 1896[2]

6.1 Introduction

The years between Robert Henry Scott's 1885 history of Kew Observatory and the formation of the National Physical Laboratory in 1900 are the most poorly documented in all the secondary literature on Kew Observatory in the Victorian era. Almost the only secondary literature that discusses Kew after 1885 is on the origins of the NPL. This has been the subject of several scholarly and semi-popular accounts, yet none of these describe what actually happened at Kew after 1885, nor whether and to what extent events at Kew influenced – or were influenced by – the NPL. All of them merely note that Kew Observatory offered a convenient first home for the NPL, while giving little acknowledgement to any role that the Kew Committee might have played in the NPL's origins. These histories tend to tell the story of the foundation of the NPL as that of an organisation intended to rival imperial Germany's flagship national laboratory, the Physikalisch-Technische

[1] Lodge to BAAS Committee on a National Physical Laboratory, 22 February 1893, TNA:BJ 1/210/1151F

[2] Anon. (1896), p. 84.

Reichsanstalt (PTR), built in 1887 at Charlottenburg on the outskirts of Berlin. More importantly, they present the establishment of the government-supported NPL as a triumph of twentieth-century state-supported science over nineteenth-century *laissez-faire* ideology. Such is the story told by Russell Moseley, Peter Alter, Edward Pyatt and – albeit with slightly more historical context – Eileen Magnello.[3]

It is easy to see why this might be so. As explained in Chapter 1, many of the classic works on the history of Victorian science, including works on the NPL, were written in or around the period 1950 to 1980, when the physical sciences enjoyed generous funding and so the displacement of *laissez-faire* by state-supported laboratories might have seemed inevitable. More particularly, the NPL came into existence in January 1900, making it easy to associate the new century with the new way of supporting science. The turn of the twentieth century thus marks a convenient beginning for the NPL, distracting attention from what went before. This is reinforced by the fact that when the NPL was officially opened in March 1902, it had moved to its present site at Teddington, Middlesex, further removing Kew Observatory from the picture. Moreover, by 1902 Queen Victoria was dead and the Victorian era was over, thus all the more isolating the history of the twentieth-century NPL from that of the Victorian Kew Observatory.

This marginalisation of Kew Observatory in the story of the NPL's origins has partly also been the result of historians mostly using sources internal to the NPL itself, such as the NPL's published annual reports and the minutes of its Executive Committee. Perhaps reasonably, given how easy it has been to leave Kew out of the picture, they have overlooked primary sources relating to Kew. It is easy to see why historians might not have looked at, for example, the annual reports of the Kew Committee when attempting to trace the NPL's origins. Even more importantly, these scholars have relied mostly on *published* sources. Even the Kew Committee's reports say only a limited amount about what happened at Kew in the fifteen years after Scott's paper, or about the role of Kew in the origins of the NPL. It is from the unpublished sources – especially the private letters of those associated with Kew Observatory after 1885, as in the first epigraph above – that we can extract a much fuller account.

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[3] Moseley (1976); Moseley (1978); Alter (1987), pp. 138-149; Pyatt (1983), pp. 12-33; Magnello (2000), pp. 11-30.

In this chapter, I argue that Kew Observatory was much more important to the origins of the NPL than has hitherto been acknowledged – indeed, that the establishment of the NPL was in many ways a change of name to an existing institution, because well before 1900 Kew Observatory had changed from being a magnetic, meteorological and experimental observatory into an institution that made most of its income from standardisation work. As we have seen in Chapter 5, this trend was already well under way before 1885. In this chapter, I show that the change of direction towards standardisation became even more marked after this date, so that by the late 1890s Kew Observatory was already doing a substantial part of what Douglas Galton, Oliver Lodge and others believed should form the programme of work for a national physical laboratory – exactly as described in the 1896 BAAS report, quoted in the second epigraph above. I thus argue that Kew Observatory was a precedent for the NPL and also a centre around which it could be built. In Section 6.2 I argue that in the 1890s, the observatory became a self-supporting company in its own right, rather like the NPL was expected to be in its first years. I also show that the Kew Committee became dominated by university-based physicists, as the NPL Executive Committee would be. In Section 6.3 I describe how Kew Observatory in these years became primarily a standardisation laboratory, with magnetism and meteorology now almost afterthoughts. In Section 6.4 I narrate the story of the origins of the NPL in relation to Kew Observatory. I use this to argue that Kew Observatory and its committee were central to the planning of the NPL and that the NPL began as Kew Observatory under a different name. In demonstrating this continuity between Kew and the NPL I thus present a challenge to existing narratives of early twentieth-century science as a new departure from the nineteenth-century world of *laissez-faire*.

6.2 Incorporation, boy clerks and university physicists: the management of Kew Observatory, 1885-1900

After 1885, the management of Kew Observatory underwent some profound changes that are of great significance when we consider the role of Kew in the origins of the National Physical Laboratory (NPL) in the late 1890s, to be discussed in Section 6.4. Here I will use the largely unexplored primary literature to demonstrate two important characteristics of Kew Observatory that emerged during this period. First, Kew was acknowledged to be a business, effectively independent of the Royal Society and predominantly self-financing. This self-supporting aspect was to be an important characteristic of the NPL after 1900 and so Kew provided a precedent. Secondly, after superintendent George Whipple died in 1893, the Kew Committee selected his replacement through an open competition, because the committee's membership – of which a new generation of university physicists formed an important part – wanted a high-calibre laboratory director who would bring additional prestige to the observatory. This, plus the observatory's hierarchy of low-paid workers, also set an important precedent for the NPL.

The continuing trend towards standardisation being the most profitable activity at Kew meant that the Gassiot Trust became a small, secondary income. In 1885 the observatory earned £727 from standardisation versus £491 from the Gassiot Trust; in 1899, the last year before the NPL takeover, standardisation brought in £2175, compared to just £455 from Gassiot. Even by 1890, standardisation was generating more than three times as much money as the Gassiot Trust.[4] It is likely because the observatory was now effectively self-supporting that in March 1891, the Kew Committee asked for the Royal Society Council's permission to apply for a licence of incorporation under the 1862 Companies Act, as did the Meteorological Council. The Meteorological Council's stated reason for applying was to protect itself 'against the possible inconveniences which might at any time arise in connection with their business transactions from the peculiar constitution of their body'. The Council minutes merely record that a similar proposal from the Kew Committee was read out and agreed to.[5] The initiative on the Kew Committee was taken a fortnight before by Richard Strachey, who was then chairman of the Meteorological Council.[6] This, plus the fact that neither set of minutes states any reasons for the Kew Committee's proposal, suggests that the Kew Committee's reasons were the same as those of the Meteorological Council. Strachey might well have thought that incorporation would make Kew Observatory less of a risk from the Royal Society's point of view. The Kew Committee was legally appointed by the Royal Society, yet its ever-growing business with scientific instrument makers and watchmakers also carried with it an element of risk. Manufacturers defaulting on

[4] KCR, 1885; *ibid.*, 1899; *ibid.*, 1890.
[5] RS:CM, 12 March 1891.
[6] KCM, 27 February 1891.

payments could potentially have made the Royal Society liable for large amounts of money. Such debts are likely to have been 'the possible inconveniences' resulting from the Meteorological Council's 'business transactions' and it is reasonable to suppose that this applied to the Kew Committee as well. Incorporation under the Companies Act would make those serving on the Kew Committee effectively members of a company in its own right and therefore liable for any debts they incurred.

Further evidence for a motive to protect the Royal Society appears in the minutes of the January 1892 Council meeting. These report that the proposed Memorandum and Articles of Association of the Kew Committee had been amended by Few & Co., solicitors to the Royal Society, to allow the Royal Society to retain control of the Gassiot Trust, while absolving them from responsibility for the Kew Committee's actions.[7] Four months later, the Council suggested that the words 'Of the Royal Society' should be dropped from the new company's title, further suggesting that the Royal Society wanted to distance itself from the business activities of the Kew Committee.[8]

The latter suggestion does not seem to have been taken up, for on 9 February 1893 the Kew Committee officially became registered as the 'Incorporated Kew Committee of the Royal Society'.[9] Being granted a seal of incorporation (Figure 6.1) was not only a prestige symbol in its own right. More importantly, it meant that the members of the Kew Committee officially acknowledged that Kew Observatory was now primarily a *business*, something it had effectively been for some years. This was symbolised by the incorporation of the Kew Observatory monogram – now famous and a trade mark in all but name (see Chapter 5, Section 5.5) – into the seal of incorporation. By the mid-1890s the Kew Observatory business was making enough money to invest its own revenues. At the end of 1894, partly because the bank balance was 'unusually large', the Committee purchased £900 of India stock. A further £400 of India stock was bought in November 1896.[10] That Kew was now a business, operating practically independently of the Royal Society and mostly supporting itself through fees for testing instruments, set an important precedent for

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[7] RS:CM, 21 January 1892.
[8] RS:CM, 5 May 1892.
[9] KCR, 1893, p. 307.
[10] KCR, 1895, p. 392; KCR, 1896, p. 106.

the formation of the NPL, which, as will become clear in Section 6.4, the government initially envisaged should pay a large part of its running costs from verification fees.[11]

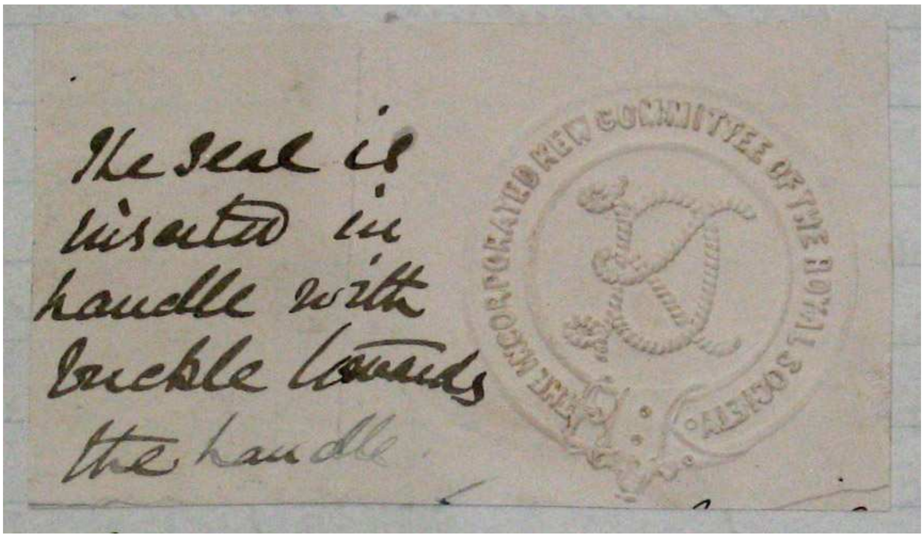

Figure 6.1 The Kew Committee seal of incorporation. (From KCM, 24 February 1893; photograph by Lee Macdonald, reproduced by kind permission of the Royal Society.)

George Whipple did not live to see the Kew Committee's incorporation. Since mid-1892 he had been suffering from an undefined serious illness that had prevented him from working, possibly related to the rupture of a blood vessel sustained in 1883. During his illness, his duties were covered by his Chief Assistant, Thomas Baker.[12] Whipple died on 8 February 1893, aged fifty. The need to appoint a successor was not unexpected, for in January 1893 Francis Galton had written to the Royal Society Council about the possibility of granting a pension to Whipple after Easter 1893, 'when his full salary will cease to be paid', indicating that Whipple was already planning to retire due to ill health.[13] After Whipple's death, the day-to-day running of the observatory (including responsibility for signing cheques) was carried on by Baker,[14] but the position of superintendent did not go automatically to him. Baker's name does not even appear on the list of candidates who applied for the position. Instead, when it met on 24 February 1893, the Kew Committee decided to advertise the post in *Nature* and the *Athenaeum* for a period of

[11] Moseley (1978), pp. 234 and 249.
[12] KCM, 25 May 1883; KCR, 1892, p. 322.
[13] RS:CM, 19 January 1893.
[14] Francis Galton to Bank of England, 8 February 1893, TNA:BJ 1/210.

three weeks. Those answering the advertisement were to be sent a printed leaflet outlining the duties of the post.[15]

The job description leaflet (Figure 6.2) tells us much about the kind of person the Kew Committee was looking for. Its first paragraph is a brief description of the main work at Kew:-

> The primary work at the Observatory is carrying on meteorological and magnetical observations with self-recording instruments. It also includes experiments in various directions, and the verification of scientific instruments of numerous descriptions.

As we have seen, by 1893 the 'primary work' of Kew was really standardisation. This description seems to have been slanted in order to attract a particular type of applicant: by presenting Kew as a research institute, the Kew Committee might have hoped to attract a researcher of the highest calibre. If the leaflet had presented the work at Kew as predominantly routine testing of instruments, the Committee might have had a less enthusiastic response from the best potential candidates now emerging from the university physics laboratories of the late nineteenth century. That the Kew Committee was looking for a high-flying candidate is further evidenced by the list of qualifications specified in the leaflet: as well as knowledge of the sciences practiced at Kew, the Committee was seeking someone with 'experimental aptitude, business habits[,] administrative faculty, energy, and scientific status'.[16] Placing the phrase 'scientific status' at the end of the sentence makes it resound in the reader's mind, suggesting that this might have been an especially important quality being sought.

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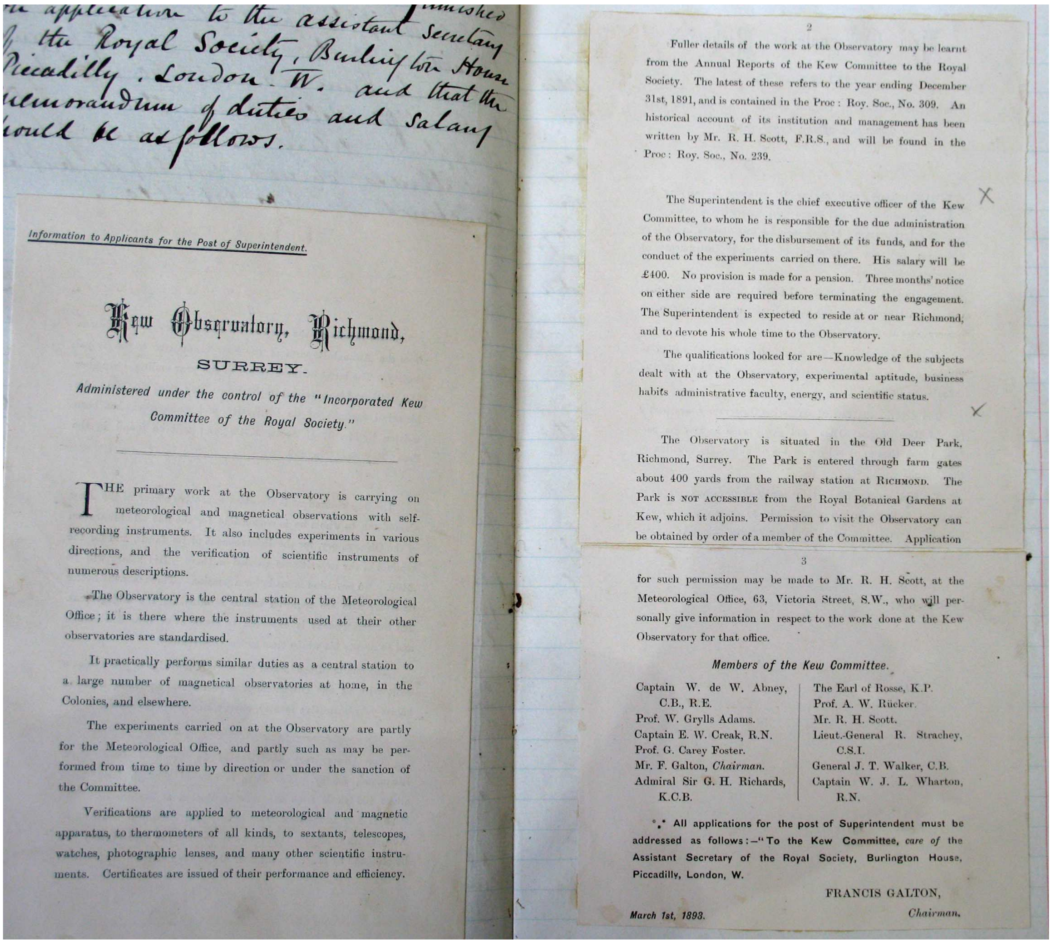
[15] KCM, 24 February 1893. The advertisement appears on the front page of *The Athenaeum*, No. 3412, 18 March 1893.
[16] 'Information to Applicants for the Post of Superintendent'. Job description dated 1 March 1893 and inserted in KCM, 24 February 1893.



application to the assistant Secretary [furnished]
the Royal Society, Burlington House
Piccadilly. London. W. and that the
memorandum of duties and salary
should be as follows.

Information to Applicants for the Post of Superintendent.

Kew Observatory, Richmond,

SURREY.

Administered under the control of the "Incorporated Kew Committee of the Royal Society."

THE primary work at the Observatory is carrying on meteorological and magnetical observations with self-recording instruments. It also includes experiments in various directions, and the verification of scientific instruments of numerous descriptions.

The Observatory is the central station of the Meteorological Office; it is there where the instruments used at their other observatories are standardised.

It practically performs similar duties as a central station to a large number of magnetical observatories at home, in the Colonies, and elsewhere.

The experiments carried on at the Observatory are partly for the Meteorological Office, and partly such as may be performed from time to time by direction or under the sanction of the Committee.

Verifications are applied to meteorological and magnetic apparatus, to thermometers of all kinds, to sextants, telescopes, watches, photographic lenses, and many other scientific instruments. Certificates are issued of their performance and efficiency.

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Fuller details of the work at the Observatory may be learnt from the Annual Reports of the Kew Committee to the Royal Society. The latest of these refers to the year ending December 31st, 1891, and is contained in the Proc: Roy. Soc., No. 309. An historical account of its institution and management has been written by Mr. R. H. Scott, F.R.S., and will be found in the Proc: Roy. Soc., No. 239.

The Superintendent is the chief executive officer of the Kew Committee, to whom he is responsible for the due administration of the Observatory, for the disbursement of its funds, and for the conduct of the experiments carried on there. His salary will be £400. No provision is made for a pension. Three months' notice on either side are required before terminating the engagement. The Superintendent is expected to reside at or near Richmond, and to devote his whole time to the Observatory.

The qualifications looked for are—Knowledge of the subjects dealt with at the Observatory, experimental aptitude, business habits administrative faculty, energy, and scientific status.

The Observatory is situated in the Old Deer Park, Richmond, Surrey. The Park is entered through farm gates about 400 yards from the railway station at RICHMOND. The Park is NOT ACCESSIBLE from the Royal Botanical Gardens at Kew, which it adjoins. Permission to visit the Observatory can be obtained by order of a member of the Committee. Application

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for such permission may be made to Mr. R. H. Scott, at the Meteorological Office, 63, Victoria Street, S.W., who will personally give information in respect to the work done at the Kew Observatory for that office.

Members of the Kew Committee.

Captain W. de W. Abney, C.B., R.E.	The Earl of Rosse, K.P.
Prof. W. Grylls Adams.	Prof. A. W. Rücker.
Captain E. W. Creak, R.N.	Mr. R. H. Scott.
Prof. G. Carey Foster.	Lieut.-General R. Strachey, C.S.I.
Mr. F. Galton, *Chairman.*	General J. T. Walker, C.B.
Admiral Sir G. H. Richards, K.C.B.	Captain W. J. L. Wharton, R.N.

*** All applications for the post of Superintendent must be addressed as follows:—"To the Kew Committee, *care of* the Assistant Secretary of the Royal Society, Burlington House, Piccadilly, London, W.

FRANCIS GALTON,
Chairman.

March 1st, 1893.

Figure 6.2 Leaflet for applicants giving job description of superintendent of Kew Observatory, 1893. (From KCM, 24 February 1893; photograph by Lee Macdonald, reproduced by kind permission of the Royal Society.)

By 24 March, the Committee had received forty enquiries about the post; by mid-April twenty individuals had sent in applications. A sub-committee looked at the applications and reported back to the Kew Committee. Of the sub-committee's four members, two (William Grylls Adams and Arthur Rücker) were university physicists, one (Robert Scott) was a government scientist and the other (Francis Galton) was a self-funded gentleman-scientist.[17] The sub-committee shortlisted the applicants to just four, all of whom indeed had 'scientific status'. Herbert Tomlinson was a demonstrator and lecturer at King's College, London and had been a Fellow of the Royal Society since 1889.[18] William Dampier Whetham had gained a First in the Cambridge Natural Sciences Tripos in 1889; he was now a researcher in the

[17] KCM, 24 March and 28 April 1893.

[18] Herbert Tomlinson, Royal Society Election Certificate, EC/1889/16 and associated documentation at www.royalsociety.org, accessed 10 February 2015.

Cavendish Laboratory and a Fellow of Trinity College, Cambridge.[19] Charles Chree also worked at the Cavendish and held a Cambridge fellowship, at King's College.[20] Only Thomas Blakesley, an instructor in physics and mathematics at the Royal Naval College in Greenwich since 1885, was from a non-university background – though even he was a Cambridge mathematics Wrangler.[21]

Eight members of the Kew Committee interviewed each of the shortlisted candidates on 28 April 1893. Just one member of this interview panel, Galton, was a gentleman-scientist. Otherwise, the panel was made up of one government scientist (Scott), three university physicists (Adams, Rücker and George Carey Foster) and three scientific servicemen (Captain William Abney, General Richard Strachey and General James Walker).[22] They decided 'unanimously' to appoint Charles Chree as the new superintendent. The minutes state no reason for the Committee's choice, but we can derive some interesting clues from an undated document that lists all the twenty applicants. Here, each applicant is ranked with the letters a, b or c, according to unspecified criteria. All the shortlisted candidates are marked 'a', except Tomlinson, who is 'b or a'. But pencilled next to the names of the shortlisted candidates are figures that correspond exactly to the ages of these four men in 1893. From this, it seems possible that one factor in selecting Chree was that at 32 and with a Cambridge fellowship, he had the right combination of age, level of experience and 'scientific status'. Committee members may have considered Tomlinson, aged 47 and FRS, too senior and over-qualified, as they might have thought Blakesley, 45 years old and an established instructor at the Royal Naval College. The 27-year-old Whetham, on the other hand, might have been seen as too young and inexperienced, especially on the people management side that was an essential part of the superintendent's role.[23]

Chree was certainly not selected for his background in experimental physics and laboratory measurement that had been the chief characteristics of most of his predecessors from John Welsh onwards. At the time of his appointment, Chree was

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[19] William Cecil Dampier Whetham, Royal Society Election Certificates, EC/1901/15 and associated documentation at www.royalsociety.org, accessed 10 February 2015.
[20] S[impson] (1929).
[21] Anon. (1929).
[22] See Chapter 1 (Section 1.1) for a discussion of 'scientific servicemen'.
[23] Ranked list of candidates who applied for the Kew superintendent's position; undated, but likely to have been drawn up on or around 21 April 1893, the date of the selection sub-committee's meeting, TNA:BJ 1/210/1154.

primarily a theoretician. At Cambridge he had gained first class honours in the Mathematical Tripos as well as Natural Sciences. After graduation he did research into electric currents at the Cavendish Laboratory under Joseph John Thomson, but most of his research output by 1893 was in the theory of elasticity. Even throughout his thirty-two year tenure at Kew, he tended not to carry out laboratory work in person, preferring instead to write papers based on the results of work done by others at Kew and elsewhere. One obituarist humorously recounts how outdated his ideas about laboratory equipment were: once, when he was asked to update his facilities, he presented a list including 'four rings for a retort stand' and a 'nest of four beakers'.[24] In fact, Chree was rather like Thomson, in the sense that Thomson headed an experimental laboratory yet had a primarily mathematical background.[25] Therefore it is likely that in appointing Chree, the members of the Kew Committee were looking not for a hands-on, practical physicist like Whipple, but rather a laboratory director, who was interested in the results of research done by practical workers reporting to him and who therefore would concentrate on directing that research.

Yet most striking of all is how different was the method of Chree's recruitment from that of his predecessors. All the Kew superintendents from Welsh onwards had been appointed at least partly through personal patronage. Welsh was selected on the recommendations of William Sykes and Thomas Makdougall Brisbane (Chapter 3, Section 3.2). Stewart was one of six applicants for the post, but he had been chosen on the grounds that Welsh, before he died, had recommended that Stewart succeed him (Chapter 4, Section 4.4). Samuel Jeffery owed his appointment to Sabine's influence. Finally, Whipple was appointed internally without any competition (Chapter 5, Section 5.5). But now, in 1893, the job was advertised openly in the *Athenaeum* (on the front page) and *Nature* – two journals widely read by scientists and in university common rooms – and a detailed job description sent to those answering the advertisement. The most suitable candidates were then shortlisted and interviewed by the Kew Committee, completing a narrative very similar to the process of recruiting professional scientists in the twentieth century.

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[24] S[impson] (1929), p. viii.
[25] Sviedrys (1970), p. 143.

There is no evidence here of any conscious wish to professionalise the position of superintendent at Kew. Rather, this new appointment through open competition reflected the changed attitudes by this time towards appointments to official positions, notably in the Civil Service. This was also the case at Greenwich: in 1873, to run the recently-acquired photoheliograph, Airy reluctantly had to employ Edward Maunder, who had passed the Civil Service examinations, rather than a hand-picked man from Cambridge, as had been his custom.[26] But more particularly for Kew Observatory, the change reflected the extent to which the make-up of the Kew Committee had altered by the early 1890s. Gentlemen scientists like Gassiot and De La Rue no longer dominated it. Even Galton, though self-funded, firmly believed in science as a full-time occupation; indeed, shortly after Whipple's death, he had written to the Royal Society Council outlining a procedure for appointing a successor, suggesting that it was Galton's idea to advertise the post and appoint an outsider, rather than make an internal promotion.[27] Of the committee that interviewed Chree and the other candidates, the largest categories were the scientific servicemen and university physicists. The servicemen had always been represented on the Kew Committee to some extent, but the university physicists were a new category that had emerged on it since the 1870s. As Romualdas Sviedrys and Graeme Gooday have shown, the last third of the nineteenth century saw a rapid growth of research and teaching laboratories in a number of British universities, stimulated partly by the research required by the electrical industry and also by the need for teaching laboratories to train a new generation of engineers and science teachers.[28] The directors of these laboratories – among whom can be numbered Adams, Foster and Rücker, the three academic members of the Kew Committee – had a strong interest in standardisation and precision instruments such as thermometers, because of the need to train their students in the all-important skill of measurement. Therefore Kew Observatory, by now a world-famous standardisation laboratory, was of great interest to these three.

David Grier has argued that the Board of Visitors that oversaw the work of Greenwich Observatory, and also the committee inspecting the Nautical Almanac Office, were rather like the board of directors of a company that oversaw the factory

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[26] Kinder (2008), pp. 23-24.
[27] RS:CM, 16 February 1893.
[28] Sviedrys (1976), esp. pp. 422-427; Gooday (1990).

production of astronomical observations, because they represented ‘those with a stake in the institution’.[29] With the increasing influence of the university physicists, the Kew Committee had now become like a board of directors as well, for the physicists had a similar stake in Kew. In contrast to the middle years of the century, when the likes of Gassiot and De La Rue were personally involved in the experiments at Kew, the Committee was increasingly dominated by physicists who were more interested in the *results* of that work, especially standardisation (see Section 6.3 below). In fact, with its seal of incorporation, the Kew Committee was literally a board of directors, something emphasised by the job description of the superintendent as ‘the chief executive officer of the Kew Committee, to whom he is responsible…’.[30] In appointing Chree, the university physicists were recruiting one of their kind: young, enthusiastic, and with training and background in their community.

Yet some correspondence that took place in the days before the 24 February meeting suggests the most important clue of all as to why Chree was selected. As I shall describe in Section 6.4, a few days before the meeting Kew Committee chairman Francis Galton had sounded out Liverpool physics professor Oliver Lodge as to the possibility of extending Kew Observatory in order to turn it into a ‘national physical laboratory’, the need for which Lodge had urged in a speech to the BAAS in 1891. Lodge was chairman of a small committee of university physicists set up by the BAAS to look into the idea of such a national laboratory. On receiving Galton’s letter, Lodge wrote to the other members of this committee, commenting that:-

> It is plain that the possibility of developing the Kew Observatory into an institution comparable with some of those which exist in the capitals of the Continent must depend to some extent on the kind of man they may decide to go for.[31]

One member of the BAAS committee, Arthur Schuster, who in 1887 had succeeded Balfour Stewart as Professor of Natural Philosophy at Manchester, agreed with this: the instrument-testing work at Kew, he felt, would be made ‘more generally useful to the country’ if Kew had ‘a head of sufficient scientific attainments to be able to point

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[29] Grier (2005), p. 53.
[30] Information to Applicants for the Post of Superintendent’. Job description dated 1 March 1893 and inserted in KCM, 24 February 1893.
[31] Lodge to BAAS Committee on National Physical Laboratory, 22 February 1893, TNA:BJ 1/210/1151F.

out to the makers of instruments in which direction there is room for improvement'.[32] Similarly, Richard Glazebrook, deputy director of the Cavendish Laboratory in Cambridge, agreed that the Kew Committee should bear in mind the possibility of developing Kew into a larger laboratory 'in any plans they may form for filling up the vacant post'.[33] It is likely, therefore, that the Kew Committee appointed Chree as somebody who might one day have to take on the responsibility for a much larger organisation than any of his predecessors had done. Chree must have been the candidate most ideally suited to a post with such development potential. He was young – yet old enough to have some managerial experience – and was fresh from the Cavendish Laboratory, which by the early 1890s had earned a reputation as an electrical standards laboratory in addition to being an elite training centre in experimental physics.[34] Moreover, Chree had sufficient 'scientific status' for the holder of what might become a senior position in British physical science. Schuster's comment about the need to recruit someone 'of sufficient scientific attainments' is directly echoed by the 'scientific status' specified in the job description. One of the other candidates, Herbert Tomlinson, FRS, had more scientific status, but at 47 years of age he might have been considered quite old to become head of a laboratory that might not come into existence for some years yet.

Chree began work as superintendent at Kew on 15 May 1893. Baker, who had run the observatory throughout Whipple's illness and after his death, never rose above the position of Chief Assistant. He retired in 1912, after some 52 years' service at Kew.[35] Baker was paid £250 per annum, though he was given a bonus of £50 each year from 1897 to 1900 inclusive,[36] perhaps in recognition of the extra work involved while negotiations were in progress to develop Kew into the proposed National Physical Laboratory. The salaries of the other senior assistants were capped at £150: when they had reached this amount, they could not be increased further. Occasionally the assistants were paid small bonuses. In February 1893, for example, three were given bonuses of £10 each.[37] The Kew Committee's refusal to increase the salaries caused much frustration among the assistants in the 1890s, for

[32] Schuster to Francis Galton, 22 February 1893, TNA:BJ 1/210/1151F.
[33] Glazebrook to Galton, 23 February [1893], TNA:BJ 1/210/1151F.
[34] Schaffer (1992).
[35] Jacobs (1969), p. 169.
[36] KCM, 17 December 1897; KCM, 15 December 1899.
[37] KCM, 24 February 1893.

while their salaries remained fixed, the level of responsibility they had to take on greatly increased, especially with the ever-increasing number and variety of instruments being sent to Kew for testing. This is made clear in a letter to the Committee from Senior Assistant E G Constable, who by then had worked at Kew for twenty years and was now, he pointed out, in charge of all the watch- and chronometer-testing:-

> The work entails much responsibility, and my salary after so many years service is small indeed, and I shall be very grateful for an increase.[38]

The situation had not improved by 1898, by which time the idea of siting the NPL at Kew was being publicly aired. In February of that year, Constable and four other senior assistants wrote to the Committee, pointing out that while at Kew the senior assistants received no more than £150 to £175, their equivalents at Greenwich earned £300 to £450 for quite similar work. Constable and his colleagues believed that 'the present low standard of salaries is a source of discouragement' and asked if Committee members could use their influence to increase salaries if Kew were to become part of the proposed new laboratory.[39]

Yet it was not just the assistants that were poorly paid. Even Chree was paid only £400 per annum (rising to £500 in 1897), compared with the £1,000 per annum earned by the Astronomer Royal at Greenwich. Furthermore, the published job description in 1893 specifically stated that 'no provision is made for a pension', in contrast to the generous pensions paid to the Astronomer Royal and his assistants at Greenwich. This was despite the great responsibility that went with Chree's role: by 1900 he was in charge of eighteen staff and running a central standards laboratory that tested thousands of instruments each year, including many valuable watches and chronometers. This underfunding of staff salaries remained a characteristic of the NPL after 1900[40] – and for a similar reason: the early NPL, like Kew, was expected to support itself, to a large extent, through verification fees.

The junior assistants at Kew were paid correspondingly less than the senior staff. In 1890, for example, W Gough, a nineteen-year-old junior assistant, was on a

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[38] Constable to Secretary, Kew Committee, 21 January 1893, TNA:BJ 1/209/1150.
[39] E G Constable, W Hugo, J Foster, J Gunter and W Boxall to Chairman & members of Kew Observatory Committee, 14 February 1898, TNA:BJ 1/213.
[40] Moseley (1978), pp. 237-8 and 245.

salary of 19 shillings per week, or approximately £50 per year – no more than what Royal Artillery Sergeant John Galloway, the very first assistant at Kew under the British Association, had been paid in the 1840s (see Chapter 2, Section 2.6).[41] Small salary increments were sometimes granted if assistants had certificates of good conduct – as in 1899, when £5 was awarded to each of the junior assistants.[42] Much of the basic, routine clerical and calculation work was handled by 'boy clerks' aged between fifteen and seventeen and paid between 10 and 14 shillings per week on appointment, rising to a maximum of 20 shillings (£1) per week. These were not an innovation at Kew in the late nineteenth century: George Whipple had begun his career at Kew aged just fifteen in 1858. But as the volume of work increased, more clerks were needed; six boy clerks were working at Kew by 1899.[43] The boy clerks at Kew can be considered as roughly parallel to the 'boy computers' at Greenwich, who did much of the tedious arithmetic involved in reducing raw astronomical data to a useable form. As at Kew, most of the Greenwich computers were of school-leaving age and were not guaranteed permanent work.[44] At both observatories, the clerks and computers were cheap and expendable labour – though as with their more senior colleagues, the Greenwich computers were better paid than their equivalents at Kew. The 10 to 20 shillings per week – that is, £26 to £52 per year – earned by the boy clerks at Kew was at the lower end of the £40 to £84 per annum earned by the computers at Greenwich.[45] The Kew Committee does not seem to have emulated the short-lived Greenwich experiment, begun in 1891, of employing women as computers. The only women employed in science-related work at Kew before 1900 were Elizabeth Beckley, who helped photograph the Sun in the 1860s and 1870s (Chapter 4, Section 4.3), and Miss Clements, who temporarily engraved the thermometers with the Kew Observatory monogram (see Chapter 5, Section 5.5).

Charles Chree's sixteen-page article for the 1897 edition of the *Record of the Royal Society* gives a predictably uncritical picture of the work done in various parts of the Kew buildings on the eve of the NPL era and says little about the staff.[46] But an unpublished description of the observatory produced for the benefit of the NPL's

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[41] Gough to Whipple, 19 May 1890, TNA:BJ 1/209.
[42] KCM, 15 December 1899.
[43] Document for inspection of Kew Observatory by General Board of NPL, October 1899, TNA:BJ 1/213/1361.
[44] Grier (2005), pp. 50-52.
[45] Hutchins (2005), p. 69.
[46] Chree (1897).

recently-constituted General Board (see Section 6.4), whose members inspected the premises in October 1899, reveals a further detail. The different ranks of staff at Kew were identified by the wearing of coloured ribbons: the boy clerks wore blue ribbons, the junior assistants white and the senior assistants red.[47] Further evidence of the regimented regime at Kew is provided in a later reminiscence, citing stories told by staff who had worked at Kew in the late nineteenth century – including one which claimed that the Superintendent stood on the front steps of the building and blew a whistle to call the staff back to work after lunch.[48] Some historians have likened Airy's regime at Greenwich to a factory, in which 'profit was measured in terms of public utility and scientific prestige, rather than Pounds Sterling'[49] and it is clear that in this regard Kew bore strong similarities to Greenwich. Thus right up to the end of the nineteenth century, for all the changes in the make-up of the Kew Committee, Kew Observatory remained as hierarchical as it had been in the 1850s, with each man – including the superintendent – in his place. When it became part of the NPL in 1900, it was still a traditional Victorian observatory.

Yet although its management structure remained traditional (as did that at Greenwich), between 1885 and 1900 the character of Kew Observatory did undergo changes that would set important precedents for the future. With its seal of incorporation in 1893, Kew Observatory was officially admitted to be a business by both its managing committee and the Royal Society. Although in theory the observatory was still a part of the Royal Society, for most practical purposes it was independent of it. Therefore in this sense it was much like the National Physical Laboratory after 1900, which was run by an executive committee appointed by the Royal Society Council, yet was independent of the Royal Society and expected to support much of its work through the fees charged to its customers. In appointing Charles Chree, the Kew Committee had a laboratory director whom they hoped would be in the mould of the university physicists, who formed a new and powerful group on the Committee. Chree was young, energetic and had scientific prestige. In the next section I shall discuss how the changing scientific programme at Kew also provided a precedent for the NPL.

[47] Document for inspection of Kew Observatory by General Board of NPL, October 1899, TNA:BJ 1/213/1361.
[48] Scrase (1969), p. 181.
[49] Chapman (1985), p. 321; see also Smith (1991), pp. 13-17 and Grier (2005), pp. 52-53.

6.3 Geomagnetism, meteorology and standardisation at Kew to 1900

In George Whipple's last years as superintendent, geomagnetic work at Kew continued as it had since Sabine's withdrawal from the scene in the mid-1870s (Chapter 5, Section 5.5). The magnetic instruments in the basement continued their automatic recording of changes in the Earth's magnetic field and Kew maintained its international status as a magnetic observatory. The observatory was still used as a reference station for magnetic surveys. For example, in 1887 Arthur Rücker and Thomas Thorpe, Professor of Chemistry and a colleague of Rücker at South Kensington, visited Kew to make base observations for a magnetic survey of Ireland, part of a new magnetic survey of the whole British Isles. In their resulting paper they used magnetic data from Kew going back to 1858.[50] Kew also remained a centre to which overseas observatories sent their instruments to be calibrated: in 1890, instruments for observatories in Hong Kong, Italy and Portugal were examined at Kew.[51] Yet none of the research done with these instruments was directed from Kew. Although Arthur Rücker became a member of the Kew Committee in 1889, he ran the magnetic survey in his capacity as Professor at South Kensington and not under the auspices of Kew Observatory. Whipple was never pressed into service to make the field observations in Scotland the way John Welsh was in 1857 (Chapter 3, Section 3.4). Rather than being the centre of a new Magnetic Crusade, Kew was now more of a standardisation centre for magnetic instruments used for research at other institutions.

Geomagnetism at Kew underwent something of a revival after Charles Chree arrived as superintendent in 1893. Chree had originally made his name as a physicist in the theory of elasticity, but after coming to Kew he switched to terrestrial magnetism. This remained Chree's main research interest for the rest of his career and is the work for which he is best remembered. As early as 1895 he announced his first major result: that so-called 'quiet days', which had hitherto been considered to be days in which there was little or no magnetic activity, were themselves variable and could not be used as the default in studies of magnetic cycles. Variations in the quiet days also had to be taken into account in studies of magnetic cycles. Chree

[50] KCR, 1887, p. 212; *ibid.*, 1889, p. 475.
[51] KCR, 1890, p. 495.

later extended his research into solar-terrestrial relations. By the end of his career – he only retired from Kew Observatory in 1925 and died in 1928 – he had greatly strengthened the link already known to exist between solar activity and magnetic disturbances on Earth, by demonstrating that such disturbances tended to repeat themselves every 27 days, exactly the same as the Sun's rotation period as seen from Earth.[52]

This confirmation of the link between the Sun and terrestrial magnetism might seem like Kew Observatory coming round full circle and again becoming the kind of organisation that it had been under Sabine. It was Sabine, after all, who had discovered the correlation between the sunspot and magnetic cycles in 1852 and who had transformed Kew into a world-class geomagnetic and solar observatory. Yet there was now an important difference. Although Chree used Kew data in his analyses, he did not work in the capacity of a director of a network of observatories across the globe, as Sabine had done. Even the 'quiet days' so important to Chree's discoveries were not selected by Chree himself. From 1891, the annual reports of the Kew Committee regularly listed the days 'selected by the Astronomer Royal, as suitable for the determination of the magnetic diurnal variations', because they were magnetically quiet.[53] Greenwich and not Kew was now setting the pace as to which days were suitable for these observations. George Airy had retired as Astronomer Royal in 1881. He was succeeded by William Christie (the son of Samuel Hunter Christie, one of those who had attempted to set up a Royal Society physical observatory in 1840, as described in Chapter 2, Section 2.3). Christie was by all accounts a more genial figure than Airy, but he still saw himself as the head of a national observatory and so believed that direction of observations in solar-terrestrial relationships was his prerogative. Indeed, Christie wanted to expand the 'physical' side of the work at Greenwich, including the magnetic and solar observations, which was part of the reasoning behind his new 'physical observatory' building at Greenwich.[54]

Although he was a theoretician and not a laboratory worker, Chree did not isolate himself completely from the day-to-day magnetic work at Kew. His obituarist credits him with personally training the two magnetic observers of the

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[52] S[impson] (1929), pp. ix-xi.
[53] KCR 1891, p. 167.
[54] Higgitt (2014), esp. p. 625.

'Southern Cross' Antarctic expedition in 1899 and also with training members of Robert Falcon Scott's two Antarctic expeditions in the early twentieth century.[55] But one might question whether he needed to have been at Kew to make the discoveries in Sun-Earth interactions that formed his most important work. The sophisticated statistical analyses in his magnetic papers were facilitated by his background in Cambridge mathematics and he might well have been able to do exactly the same work if he had remained at Cambridge.

Sabine's cherished magnetic instruments did not remain at Kew for long after the start of the NPL era in 1900. Early in 1898 Parliament sanctioned the building of a new electric tramway between Kew Bridge and Hounslow that would pass within 1,300 yards of Kew Observatory. In the belief that the tramway as proposed 'would ruin the magnetic work at Kew Observatory', the Kew Committee appointed a sub-committee, chaired by Rücker, to see that the tramway would minimise the disturbance to the Kew magnetic instruments.[56] The Committee managed to persuade the Board of Trade, via the Royal Society Council, to require that the power lines be thoroughly insulated and that this be a requirement for any future tram lines that might affect Kew Observatory. Yet in its report for 1898 the Committee admitted that it was 'impossible to contemplate the future without some misgivings'.[57] These misgivings eventually proved to be well-founded. Electrified local transport systems continued to encroach on Kew and just three years later, the Royal Society Council agreed to the Kew magnetic instruments being removed 'to some other suitable site'.[58] Eventually, the Executive Committee of the NPL approved construction of a new magnetic station at Eskdalemuir, a remote location in south-west Scotland.[59] Opened in 1908, the Eskdalemuir Magnetic Observatory continues to monitor the terrestrial magnetic field to this day and so can be considered as the successor to the magnetic side of the work at Kew. By 1926, all geomagnetic observations at Kew had ceased.[60] In its 1860 description of Kew Observatory the BAAS Council had noted that 'the repose produced by its complete

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[55] S[impson] (1929), p. xii; KCR, 1898, p. 4.
[56] KCM, 7 February 1898.
[57] KCR, 1898, p. 12.
[58] RS:CM, 21 March 1901.
[59] Magnello (2000), pp. 31-32; Pyatt (1983), p. 41; Walker (2012), pp. 135-136.
[60] Eskdalemuir Magnetic Observatory website:
http://www.geomag.bgs.ac.uk/operations/eskdale.html, accessed 5 March 2015.

isolation is eminently favourable to scientific research'.[61] Thanks to the encroachment of London's developing transport links, that isolation no longer existed by 1900.

Although Kew Observatory had in 1876 ceased to be the 'central observatory' to which data from the Meteorological Office's network of outlying observatories were sent (Chapter 5, Section 5.5), throughout the period from 1885 to 1900 senior members of staff at Kew still had responsibility for inspecting these observatories on behalf of the Meteorological Council, to ensure that their instruments were working as efficiently as the Kew standards. Whipple personally inspected some of the observatories; the others were inspected by Thomas Baker, the Chief Assistant. The volume of work increased towards the end of the nineteenth century, as the Meteorological Council added several new stations to its network. By the late 1890s, in addition to the original six established by Sabine in 1867 (Aberdeen, Glasgow, Stonyhurst, Armagh, Falmouth and Velencia), there were now also stations at Fleetwood, Deerness (on the Orkney Islands), Fort William, Alnwick Castle, North Shields, Yarmouth and Dublin.[62] In 1890 the Council also established an observatory at the summit of Ben Nevis, the highest point in Britain, with an accompanying out-station at the base of the mountain. In the summer of that year, Baker duly visited the observatory at the base to set up the barograph and thermograph.[63]

The experiments on cloud photography, begun in 1884, continued at Kew until 1892. In 1888 these were extended to time-lapse photographs of cirrus clouds, taken with one camera, which were successful in showing extensive structural alterations in these high clouds at time intervals of as little as two minutes. As before, the work was not independent but directed by the Meteorological Council.[64] By the early 1890s, Kew was by no means the only observatory photographing clouds. In 1891 the BAAS set up a committee to coordinate a national project to photograph and classify cloud formations and Kew contributed some photographs at this committee's request.[65] This was an ironic reversal of roles since the middle of the century, when the Kew Committee, then under the BAAS, had coordinated

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[61] BAAS:CM, 27 June 1860.
[62] See, for example, KCR, 1894, p. 503.
[63] KCR, 1890, pp. 493-494; Walker (2012), pp. 120-121.
[64] KCR, 1888, p. 78.
[65] Anderson (2005), p. 225; KCM, 30 January 1891; KCR, 1891, pp. 156-7.

observing efforts, such as the ground observations by volunteers made during John Welsh's balloon ascents in 1852 (Chapter 3, Section 3.4). Now, the Kew Committee of the Royal Society was humbly complying with a request from the BAAS. Similarly, in 1894 Kew contributed cloud photographs to an exhibition organised by the Royal Meteorological Society. As early as 1887, this society had sent a circular to some two hundred private individuals with an interest in meteorology, asking them to take photographs to resolve queries as to the nature of lightning and cloud formations. As Jennifer Tucker has described, the 1880s saw the widespread availability of simple hand-held cameras, together with 'dry' photographic plates that required no complex preparation before exposure and were easy to develop afterwards. There was therefore a large pool of volunteer photographic talent and the RMS hoped that the many resulting photographs of clouds would have more scientific authority than the often sketchy and sometimes contradictory reports based on visual observations. Thus at the 1894 exhibition, the Kew photographs of clouds were only part of a much larger display, in which many of the pictures were taken by volunteers.[66] It was a very different scenario from the 1855 International Exposition at Paris, in which Kew had its own display of magnetic and meteorological instruments (Chapter 3, Section 3.4).

Chree played little direct part in Kew meteorology after he became superintendent in 1893. From the beginning, he played a much more modest part than Whipple had in the inspection of outlying observatories. In 1894, for example, he visited the stations at Aberdeen (his native city) and Glasgow, but by the late 1890s he was leaving the work to his senior assistants.[67] One aspect of meteorological research that did show a revival in Chree's early years was atmospheric electricity. As described in Chapter 2, this had formed an important part of the earliest observations carried out at Kew in the 1840s, when it was linked to the ongoing Magnetic Crusade. Even after the retirement of Francis Ronalds in 1852 and the subsequent replacement of Ronalds' electrometer in the dome with the photoheliograph, studies of atmospheric electricity at Kew never wholly died out. In 1860 an electrometer designed by William Thomson began working at Kew.[68] At the 1881 Annual Meeting of the BAAS, Whipple presented a summary of the results

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[66] KCR, 1894, p. 507; Tucker (1997), pp. 386-389.
[67] KCR, 1894, p. 503; *ibid.* 1897, p. 164.
[68] BAAS:CM, 16 November 1860.

obtained at Kew with a Thomson electrometer over the year 1880, together with a discussion on what light they shed on relations between atmospheric electricity and meteorological phenomena.[69]

Soon after Chree's arrival, the electrometer was overhauled and a new series of observations commenced.[70] Chree published the results in an extensive paper in the *Proceedings of the Royal Society* in 1896. Again, however, Chree did not make the observations himself. At the end of his paper he acknowledged that 'Mr. Constable [a senior assistant at Kew] took all the electrical observations and the measurements of the meteorological curves'.[71] Observations with the electrometer continued after 1896, but in 1899 the Meteorological Council allowed the Kew Committee to lend the results to a near-contemporary of Chree and a fellow graduate of the Natural Sciences Tripos, Charles Thomson Rees Wilson.[72] Wilson is now best remembered for the invention of the cloud chamber, which facilitated the study of subatomic particles and enabled Joseph John Thomson to measure the charge on the electron, but his initial interest was meteorology.[73] It is likely that Chree, wanting to concentrate on terrestrial magnetism and otherwise busy with running the observatory, was glad to hand the electrometer work over to Wilson, his old Cambridge colleague. In Wilson's work we see another example of how the Kew Committee was no longer directing the cutting edge of research. Although Wilson used data from Kew, he carried out the research at Cambridge. In meteorology as much as magnetism, Kew continued as a routine monitoring station, yet other bodies – including the BAAS and the Royal Meteorological Society, as well as Cambridge – were leading the research programme.

While Kew Observatory after 1885 no longer played a leading role in geomagnetic and meteorological research, it became more than ever a leading centre for standardisation, especially in the form of instrument testing in return for fees. As noted in Section 6.2, by 1899 the income from instrument tests dwarfed the annual dividend received from the Gassiot Trust (see also Table 6.1). Tests of clinical thermometers continued to provide a substantial part of the standardisation income and the numbers tested continued to rise after 1885. The 1886 report of the Kew

[69] KCR, 1881, p. 83.
[70] KCR, 1894, p. 503.
[71] Chree (1896), p. 132.
[72] KCR, 1899, p. 344.
[73] Longair (2004).

Committee claims that 9,054 clinical thermometers were tested at Kew; the corresponding figure for 1899 was over 16,000.[74] But the rise in income must also be due to the great diversification in the range of instruments tested after 1885. Tests of sextants, never more than 100 per year before 1885, rose sharply in 1889 and from the mid-1890s more than 500 were tested every year. Also in 1889, Kew began testing large numbers of telescopes and binoculars for the Royal Navy.[75] As with sextants, around 500 telescopes and a similar number of binoculars were being tested at Kew by the late 1890s. In 1891 Kew also began testing camera lenses, though until the late 1890s never more than 31 lenses were tested each year. Only in 1899 did the figure jump to 160 lenses.[76]

At the same time as the Gassiot income was shrinking, Kew's annual allowance from the Meteorological Council – in return for Kew being one of the system of self-recording observatories and also for its officers inspecting the other observatories on the Council's behalf (see above) – remained static at £400 throughout the last fifteen years of the nineteenth century. The Kew Committee therefore had a clear financial incentive for diversifying the standardisation work. Yet there is also evidence that Kew began testing some new types of instruments in response to customer demand. The testing of camera lenses, for example, was originally suggested to the Kew Committee by the Camera Club – another example of the growing importance of amateur photography in the 1880s.[77] The testing of Royal Navy telescopes and binoculars was first proposed in 1888 by the Secretary of the Admiralty, who asked that all such telescopes be tested at Kew before purchase. The following year, the Kew Committee began hallmarking these naval instruments with the 'KO' monogram that had become famous on the thermometers – a sign that the Admiralty wanted the prestige of instruments bearing the Kew hallmark.[78] The Navy likely needed to purchase a large number of optical instruments as part of its programmes in the 1880s and 1890s to build a new generation of battleships of the latest design. In particular, the building of a new class of battleships, launched in 1895 and 1896 under a programme directed by Lord Spencer, First Lord of the Admiralty in Gladstone's last government, may explain a large jump in the optical

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[74] KCR, 1886; *ibid.*, 1899.
[75] KCR, 1889.
[76] KCR, 1881; *ibid.*, 1899.
[77] KCR, 1888, p. 83.
[78] KCR, 1888, p. 83; *ibid.* 1889, p. 480; KCM, 29 November 1889.

testing at Kew in 1893: 913 telescopes and 466 binoculars.[79] The Kew Committee actually had to reject a proposal to test the lamps, lenses and shades on ships' lights for the Merchant Navy, on account of the observatory's inland position, far from any port, in addition to the lights being heavy and bulky to transport and there being no money to set up a suitable outstation at a port.[80] With this exception, however, it is clear that the Kew Committee did not hesitate to comply with the requests to test new types of instruments. Indeed, once a proposal for a new type of test was accepted, the Committee advertised its services, as with the 1891 circular sent to lens manufacturers describing the proposed camera lens tests.[81]

External demand was behind another striking innovation at Kew after 1885: the extension of the existing service of watch-rating to testing marine chronometers for the Admiralty and the Board of Trade. Marine chronometers were precision timepieces that enabled ships' officers to determine longitude at sea. In November 1885 the Kew Committee received a request from Dent, the well-known clockmaker, to have chronometers tested at Kew. The Committee lost no time in acquiring a second-hand oven from the Meteorological Office, to test the timepieces' performance at a variety of temperatures, representative of the different climates encountered on ocean voyages.[82] Kew began testing chronometers in August 1886. The trial initially used at Kew tested the chronometers for five periods, each lasting six days, at temperatures between 55 and 80 degrees Fahrenheit. The chronometers were given one day's rest between each temperature test, making an entire trial last 35 days. If the difference between the chronometer's daily error (or 'rate') at the different temperatures was sufficiently small, it was given a certificate.[83] A total of seventeen chronometers were tested at Kew in 1886. The number declined over the next few years, before gradually rising again and peaking at 70 in 1898.[84]

Chronometer rating was Kew's biggest incursion yet into territory traditionally held by Greenwich. Indeed, it formed part of Greenwich's original mission, going back to 1675, of enabling sailors to find longitude. In Airy's time, for Kew to be testing the most important piece of equipment for finding longitude

[79] Ensor (1936), p. 287; KCR, 1893.
[80] KCR, 1888, p. 83.
[81] KCM, 30 January 1891; KCR, 1891, pp. 160-161.
[82] KCM, 6 November 1885 and 27 November 1885.
[83] KCR, 1886, p. 409; specimen of a Kew chronometer rating certificate, accompanying letter from George Whipple to William Christie, 16 February 1888, RGO 7.95.
[84] KCR, 1886, p. 409; *ibid.* 1898.

would have been unthinkable. However, as noted earlier in this section, William Christie, Airy's successor from 1881, wanted to expand the work at Greenwich beyond its traditional navigational remit. This, together with Christie's relatively easy-going personality, might explain why Christie was tolerant towards Kew Observatory rating chronometers. Indeed, Christie was initially very helpful in his attitude to chronometer rating at Kew. In 1888, in response to a letter from Whipple, Christie recommended a more stringent test than that in current use at Kew. He advised that Kew should increase the maximum temperature used in the test to 95 degrees Fahrenheit and also reduce the allowance it made for changes in temperature when determining a chronometer's rate.[85] The Kew Committee eventually implemented these recommendations. It called this tougher test the 'Class A' test, while a modified version of the old test was called 'Class B' and charged an accordingly lower price.[86]

In the early 1890s, with the introduction at Kew of a chronometer test as tough as that at Greenwich, Christie's staff at Greenwich *did* come to see the chronometer rating business at Kew as competition. In May 1893 Thomas Lewis, an assistant astronomer at Greenwich, warned an official at the Admiralty about an advertisement for chronometer tests at Kew and of the need to take immediate action 'to stop the Clerkenwel [*sic*] people sending their best chronometers to Kew' and that 'if a possible number to be purchased could be named we might do this'. Clerkenwell had long been London's traditional instrument-making district. The official replied that the Admiralty could not 'interfere' with the Kew advertisement, but reassured Lewis that he could tell the chronometer makers that the Admiralty would be willing to spend around £1,000 on chronometers that year, 'provided they are recommended for purchase by the Astronomer Royal'. Ten days later, Lewis had written 'to the Clerkenwell people'.[87] That Greenwich was thus tipped off about the Admiralty's plans to purchase a large number of chronometers might explain why only ten chronometers were tested for British makers at Kew in 1893. But as the 1890s progressed, the number of chronometers tested at Kew continued to rise: in the long run, Greenwich was unable to stop makers from having their instruments tested

[85] Whipple to Christie, 16 February 1888, RGO 7/95; Christie to Whipple, 21 February 1888, RGO 7/95.
[86] KCM, 30 January, 26 March and 24 April 1891; KCR, 1891, p. 160.
[87] Lewis to Tizard, 18 May 1893, RGO 7.104.683; Tizard to Lewis, 20 May 1893, RGO 7.104.684; Lewis to Tizard, 30 May 1893, RGO 7.104.685.

at Kew. In any case, Kew may have been no great threat to Greenwich, whose principal client was the Admiralty. The Kew Committee could sell its services to other customers, not least the merchant shipping sector, which it targeted in 1891 with a circular sent to all the main British steamship companies, advertising chronometer rating at Kew.[88] More dramatically, in April 1893 the Committee agreed to a request from the Italian naval attaché in London to test some chronometers being bought by the Italian government. Beginning in June 1893, some thirty chronometers were tested in a specially-built oven in the basement of the observatory, at temperatures of up to 100 degrees Fahrenheit, presumably to allow for the Italian climate.[89] The following year, the Kew Committee performed a similar trial of chronometers for the Portuguese government.[90] Both requests indicate that Kew now had an international reputation in this field, in addition to its established name in testing magnetic and meteorological instruments.

By the 1890s, this renown was also firmly established among makers of ordinary watches, whose letterheads proudly claimed that their wares were tested at Kew and Greenwich. Makers could choose to have watches tested at Kew in one of three classes of trial, A, B and C, of which Class A was the toughest. The performance of watches in class A was further rated by them being given marks between 0 and 100, with a watch only just passing the Class A standard being given 0 and a watch with no measurable error at all assigned 100. The cream of the Class A watches were given certificates marked ‘especially good’.[91] The watches scoring the highest marks in each year’s tests were listed, along with their marks and the manufacturers’ names, as an appendix to that year’s report of the Kew Committee, which turned the Kew Class A test into a fierce competition among the elite watchmakers of London and Coventry. By the late 1890s, some chronometer makers were calling for the marks to be made less explicit, because they found that watches with even slightly lower marks than their very best ones were taking longer to sell.[92] That one manufacturer in 1899 allegedly exaggerated the number of watches he had

[88] KCR, 1891, p. 160.
[89] KCM, 28 April 1893; KCR 1893, p. 314.
[90] KCR, 1894, p. 506.
[91] KCR, 1886, p. 408.
[92] Bonniksen to Chree, 3 December 1897, TNA:BJ 1/212; also copy of an article from December 1897 *Horological Journal* signed by S Smith & Son, TNA:BJ 1/212. The letterhead of Bonniksen’s letter advertised that 60 of his watches were marked ‘especially good’ at Kew in 1896.

had tested at Kew is further evidence of the importance of Kew Observatory to the British watch trade.[93] Watches continued to be tested at Kew after it became part of the National Physical Laboratory in 1900 and the certificate given to watches that met the standard was still called the Kew Class A certificate after watch-rating was moved to the NPL's Teddington site in 1912 (see Section 6.4). The Kew Class A test was only superseded at the NPL in 1951. Watches bearing 'Kew Observatory' test certificates are still sought after by antiques dealers today.[94]

As with geomagnetism and meteorology, from the mid-1890s standardisation at Kew became influenced by the Cavendish Laboratory. Hitherto, thermometers tested at Kew had generally measured temperatures of up to 100 degrees Celsius. In January 1895 the Kew Committee discussed obtaining a 'platinum thermometer', which measured temperature using the resistance of a length of platinum wire.[95] Because platinum thermometers could measure temperatures accurately up to around 600 degrees Celsius, they had many industrial as well as scientific uses, such as measuring the freezing points of metals. They also had the advantage of allowing temperatures to be measured remotely.[96] In October 1895 the Kew Committee obtained £100 from the Royal Society Government Grant to begin investigations into the working of platinum thermometers.[97] Three months later, Charles Thomas Heycock of the Cavendish Laboratory visited Kew to compare the performances of platinum and mercury thermometers at temperatures above 100 degrees Celsius. In 1896 the Kew Committee asked the physicist John Allen Harker to continue the experiments, in particular to compare the performance of the platinum thermometers with a gas thermometer used by the Bureau International des Poids et Mesures (BIPM) at Sèvres, near Paris.[98] The BIPM had been opened in 1878 as an international standardisation centre for metric weights and measures authorised by an 1875 treaty under which seventeen countries – excluding, controversially, the United Kingdom – committed themselves to the metric system.[99] Harker's collaborative

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[93] KCM, 15 December 1899 and 19 January 1900.
[94] *English Dictionary of Jewelry* [*sic*], http://www.jewels-gems-clocks-watches.com/gemdict_en/index.php?le=K&la=E&entry=115189, accessed 9 March 2015; Magnello (2000), p. 122.
[95] KCM, 25 January 1895.
[96] Middleton (1966), pp. 179-180; Cattermole and Wolfe (1987), esp. pp. 185-188.
[97] KCR, 1895, pp. 387-388.
[98] KCR, 1896, p. 100; KCR, 1897, pp. 165-166.
[99] Crease (2011), pp. 136-138.

work with the BIPM was published in an 1899 paper by Harker and a physicist at Sèvres, Pierre Chappuis. In November 1899, just weeks before the handover to the NPL, the Kew Committee authorised the building of an apparatus for comparing mercury thermometers with a platinum thermometer.[100]

Harker was not a Cambridge graduate: he had studied at Owens College in Manchester. Yet it is noticeable that in addition to the experiments being started under Heycock, important technical assistance in improving the apparatus was given by William Napier Shaw, another Cavendish physicist who had been on the Kew Committee since 1894.[101] Further assistance was lent by the Cambridge Scientific Instrument Company, of which Shaw was a director, and which had begun making platinum thermometers commercially.[102] As with watches and chronometers, the impetus to enter this field was external. A remark in the 1897 Kew Committee report indicates that the Committee and staff at Kew were under some pressure to produce results in this new field:-

> This is a subject of increasing urgency in view of repeated requests for direct high temperature verifications which cannot as yet be satisfactorily dealt with.[103]

In fact, even before the £100 grant had come in, the Kew Committee authorised Rücker and Shaw to buy the platinum thermometry apparatus.[104] It is quite possible that Shaw and the Cambridge Scientific Instrument Company were the source of at least some of the pressure, as the company, which worked closely with the Cavendish and was keen to sell its wares to laboratories, would have had an interest in developing a reliable platinum thermometer with the Kew hallmark as a seal of quality.[105] Indeed, the company's 1893 catalogue proudly informed potential buyers of its wares that its platinum thermometers would all come with tables of corrections similar to those that Kew Observatory included with instruments tested there – a further indication of the prestige of the Kew instrument tests.[106] The importance of Harker's work is emphasised by his being taken on at Kew as a 'special assistant to

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[100] KCR, 1899, p. 345; KCM, 10 November 1899.
[101] KCM, 29 March 1895.
[102] Cattermole and Wolfe (1987), p. 49.
[103] KCR, 1897, p. 166.
[104] KCM, 21 June 1895.
[105] Glazebrook rev. McConnell (2004).
[106] Quoted in Cattermole and Wolfe (1987), p. 47.

the Superintendent' in 1898. He was still listed as such on the payroll after Kew was handed over to the NPL in 1900 and went on to become head of the NPL's heat and thermometric division, where he continued the work he had commenced at Kew.[107] Harker's work on platinum thermometers demonstrates not only the increasing influence of the Cavendish Laboratory on Kew, but also that, several years before 1900, something like the NPL's thermometric division was already in existence at Kew.

The multiplicity of work being carried out at Kew Observatory by the late 1890s must have made the place seem crowded. The observatory had been extended somewhat since the BAAS acquired it in 1842. A one-storey outbuilding, just south of the main building, was built in the late 1860s after Kew became the Meteorological Office's central observatory. By 1897 it was known as the 'clinical house', because by then it was used for testing the clinical thermometers. In 1887, the Kew Committee agreed that to install additional equipment in the observatory more space would be needed. Accordingly, an additional storey was built on top of the east wing of the observatory in 1888, followed by an identical storey on the west wing in 1891. The building of both these extensions was financed by loans from the Royal Society Council.[108] The completion of the western extension gave the building the general appearance that it retains today. Yet Chree's 1897 article in the *Record of the Royal Society* glosses lightly over the fact that the prestigious rating of watches was taking place in the same western room on the ground floor where the standard barometers and thermometers, as well as the engraving machine used for making new standard thermometers, had been in use since the 1850s.[109] This is, however, apparent from the document drawn up for the inspection of the premises by the NPL Executive Committee in October 1899.[110] It may be that by the time the NPL took over, Kew Observatory had reached the limits of its spatial capacity. George III's former private observatory had served well as an experimental observatory as conceived by the BAAS, yet for a national standardisation centre branching out into ever more types of work, larger premises were needed. In Section

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[107] KCM, 21 October 1898; KCR, 1898, p. 7; Pyatt (1983), pp. 32 and 230.
[108] KCM, 25 March 1887; KCR, 1888, p. 84; Lord Rayleigh to Francis Galton, 9 May 1891, TNA:BJ 1/209/1114; KCR, 1892, p. 331.
[109] Chree (1897).
[110] Document headed 'KEW OBSERVATORY INSPECTION. OCTOBER 16 & 18, 1899, TNA:BJ 1/213/1361.

6.4 I shall discuss the role of Kew Observatory in the creation of the NPL, a role whose importance has hitherto been insufficiently acknowledged by historians.

6.4 Kew Observatory and the origins of the National Physical Laboratory

We have seen in Sections 6.2 and 6.3 how by the 1890s, Kew Observatory was a very different institution to what it had been under the BAAS in the 1850s and 1860s. The Kew Committee was now dominated by a new generation of professional, university physicists, who had largely displaced the wealthy gentlemen scientists who had previously directed the committee. At the same time, the observatory was making most of its income as a national – indeed imperial – standardisation laboratory. Yet very little of this finds its way into the official and academic histories of the National Physical Laboratory. In the most detailed scholarly account that we have of the NPL's origins, Russell Moseley describes how Kew Observatory was seemingly selected as a site for the new laboratory at the last moment by BAAS president Douglas Galton, apparently on his own initiative.[111] In this section I use the unpublished minutes of the Kew Committee and the correspondence of Kew Committee and Royal Society Council members – which were confidential at the time and so allow many private opinions to be expressed – to track the relationship of Kew Observatory to the origins of the NPL, as seen from the standpoint of our institutional history of Kew Observatory. This narrative reveals that Kew Observatory and its governing committee were central – indeed essential – to the foundation of the NPL. I will use this to argue that far from being a PTR-like institution, heralding the displacement of *laissez-faire* by state-funded science, the NPL in its first years was a continuation and extension of Kew Observatory and that its origins were thoroughly a part of the *laissez-faire* world.

The histories described above typically trace the origins of the NPL to Alexander Strange's 1868 paper on state funding for science and the subsequent Devonshire Commission, among whose recommendations in 1875 were physical laboratories for determining national standards. In his 1871 presidential address to the BAAS, William Thomson also argued for the setting up of government-supported laboratories that would do research in the physical sciences. Thomson

[111] Moseley (1976), pp. 18-71; see also Moseley (1978), pp. 225-226.

alleged that university physics laboratories had no time for research, because they were fully occupied with teaching.[112] But neither of these called for a single, central laboratory supported by the government. The earliest public call for this type of institution came in 1891 from Liverpool physics professor Oliver Lodge. Like the Kew Committee members George Carey Foster and Arthur Rücker, Lodge was one of the younger generation of professional physicists who held full-time academic posts. On 20 August 1891, Lodge gave a speech to Section A (Mathematical and Physical Science) of the BAAS, in which he urged that physics, especially 'the quantitative portion' dealing with standardisation and constants, needed to be pursued 'in a permanent and publicly-supported physical laboratory on a large scale'. Lodge acknowledged the importance of the work currently being done at Kew and also at the Board of Trade's standards department at Westminster. The latter looked after the national standards of weight and measure; since 1889 the Board of Trade had also maintained an electrical standards laboratory that ran a limited programme of electrical instrument-testing. Now, however, Lodge wanted to see a much bigger establishment on a national scale: 'a Physical Observatory, in fact, precisely comparable to the Greenwich Observatory'. Such a national institution, Lodge said, would house Britain's national standards and, in an echo of Thomson's 1871 speech, would also carry out long-term researches, for which university laboratories were inadequate, because 'in most college laboratories, under conditions of migration, interregnum, and a new regime, continuity of investigation is hopeless'.[113]

After Lodge's speech, the BAAS appointed a committee to discuss the question of such a national laboratory.[114] The committee was chaired by Lodge, and its other members were all leading university physicists: Richard Glazebrook of the Cavendish Laboratory, William Thomson, Lord Rayleigh, J J Thomson, Arthur Rücker, Robert Bellamy Clifton (Oxford), George Fitzgerald (Trinity College, Dublin), George Carey Foster and Viriamu Jones (University College, Swansea). Two of these, Foster and Rücker, were serving members of the Kew Committee. Historians have claimed that the BAAS committee was very pessimistic about the prospects of setting up a national laboratory, citing, for example, Glazebrook as

[112] Thomson (1872a), p. lxxxviii.
[113] Lodge (1892), esp. pp. 549-551.
[114] The committee was formally described as 'the Committee on a National Physical Laboratory'. (BAAS:AR, 1892, p. xiii.) This seems to be the earliest use of the exact phrase 'National Physical Laboratory'.

saying that 'it was felt to be hopeless to approach the Government' for funds and that the committee's discussions went nowhere. But this seems to be based on reminiscences after the event – in the case of Glazebrook's alleged 'hopeless' feeling, an article in *Nature* from 1901, after the NPL had been established, together with Glazebrook's own reminiscences in 1933.[115] In fact, unpublished archival evidence shows that the BAAS committee was still very much alive in early 1893 and that several of its most influential members were far from pessimistic. On 21 February 1893 Lodge, the committee's chairman, replied to a letter from Francis Galton, chairman of the Kew Committee, which apparently suggested that Kew Observatory could form a centre around which the proposed National Physical Laboratory might be built. Lodge claimed that Arthur Schuster of Owens College, Manchester had written to him the day before with a similar suggestion.[116] Whether Galton or Schuster had the idea first, we do not know, but it was Galton who seems to have triggered what happened next.

Lodge immediately wrote to the various members of the BAAS committee about the possibility of using Kew 'as a nucleus of the proposed National Laboratory' and asking them to send their views urgently to Galton in time for the next meeting of the Kew Committee, scheduled for the following Friday, 24 February. As described in Section 6.2, the most urgent subject of this meeting was the recruitment of a new superintendent for the observatory and it was in this letter that Lodge suggested that the possibility of developing Kew into a national laboratory would depend 'on the kind of man they may decide to go for'.[117] In a separate note to Galton, Lodge asserted that the need to appoint a new superintendent presented 'a fitting opportunity' to move forward the idea of a national laboratory.[118] Thus Galton and Lodge between them used the vacancy at Kew as an opportunity to advance the idea of making Kew the 'nucleus' of a larger laboratory.

Schuster was the first to respond to Lodge's circular letter. Although he thought that there was 'little hope' that the government would right now do anything so radical as fund a new laboratory to compare with the Berlin PTR, he believed that the BAAS committee could certainly obtain part of what it wanted 'if the work of the

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[115] Moseley (1976), p. 44; Moseley (1978), pp. 224-225; Alter (1987), p. 139.
[116] Lodge to Francis Galton, 21 February 1893, TNA:BJ 1/210/1151F.
[117] Lodge to BAAS Committee on National Physical Laboratory, 22 February 1893, TNA:BJ 1/210/1151F.
[118] Lodge to Galton, 22 February 1893, TNA:BJ 1/210/1151F.

Kew Observatory could be extended in certain directions'. Schuster underlined Lodge's view that now was an ideal opportunity to consider whether to extend Kew into a national laboratory. If the Kew Committee did not act now, he said, the movement for a national laboratory might not go anywhere for some time.[119] Similarly, J. J. Thomson had 'no hesitation' in asserting that the prospects of founding and running a national laboratory were better under the Kew Committee than under any other organisation he knew.[120] Richard Glazebrook, Thomson's deputy, agreed that the activities at Kew Observatory 'might form a nucleus around which other investigations might centre'.[121] Thus although the four physicists who responded to Lodge and wrote to Galton were not optimistic about government funding for a PTR-like institution, they were certainly not pessimistic about the idea of enlarging Kew to form a national laboratory.

The minutes of the 24 February Kew Committee meeting merely record that Galton had communicated with members of the BAAS national physical laboratory committee as to whether they had taken into consideration the existing laboratory facilities at Kew. They also note the encouraging replies from Lodge and the others.[122] No actions or agreement on this subject are recorded in the minutes of this or any subsequent meetings of the Kew Committee before the mid-1890s. The next recorded discussion of the idea of a national physical laboratory did not take place until more than two years later. At the BAAS annual meeting in September 1895, Francis Galton's cousin, Douglas Galton, addressed the BAAS as President. His speech included a survey of the assistance currently given to British scientific research, in which he noted that Kew Observatory carried out, on a small scale, part of the work done by the PTR in Berlin, but that its further development was 'fettered by want of funds'. He now suggested:-

> There could scarcely be a more advantageous addition to the assistance which Government now gives to science than for it to allot a substantial sum to the extension of the Kew Observatory, in order to develop it on the model of the Reichsanstalt.[123]

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119 Schuster to Galton, 22 February 1893, TNA:BJ 1/210/1151F.
120 Thomson to Galton, 23 February 1893, TNA:BJ 1/210/1151F.
121 Glazebrook to Galton, 23 February [1893], TNA:BJ 1/210/1151F.
122 KCM, 24 February 1893.
123 Galton, Douglas (1895a), p. 34.

It is important to note that in this speech, Douglas Galton was very conservative in his views as to state support of science. Earlier in the speech he said that while the expansion of scientific research meant that scientists 'occasionally' had to seek government help, 'it would be unfortunate if by any change [*sic*] voluntary effort were fettered by State control'.[124] Galton still supported the *laissez-faire* system. Even if he was just saying this to please his audience, his use of such rhetoric only emphasises the ideological environment in which he was speaking. At the same BAAS meeting, Douglas Galton also presented a paper to Section A (Mathematical and Physical Science) about the PTR, in which he opined that Kew Observatory 'appears to afford a nucleus which might be gradually extended into an establishment analogous to the Reichsanstalt' – using the same language as that used by Oliver Lodge and Richard Glazebrook in their replies to Francis Galton in early 1893. Now, in his 1895 speech to Section A, Douglas Galton urged that the BAAS committee on the new laboratory be reconvened and report back to the 1896 BAAS meeting on the work that such a laboratory would do and on how it should be managed.[125]

The similarity of the language in Douglas Galton's 1895 speech on the PTR suggests that it was almost certainly inspired by the correspondence from Lodge and others on the BAAS committee with Francis Galton in early 1893. Douglas Galton had little direct connection with Kew Observatory. By 1895 he was retired from a distinguished career in civil engineering. He had, though, served as a secretary of the BAAS since 1870, so would have been well informed about Kew Observatory. Yet probably crucial to his 1895 speeches was his direct family connection with Kew through his cousin Francis. We have no recorded correspondence on this issue between the Galton cousins, but it is plausible that Francis suggested to his cousin that the possibility was being mooted of turning Kew into a national laboratory. That nothing further happened with regard to the NPL on the Kew Committee or the BAAS committee for more than two years after February 1893 makes it likely that Francis Galton bided his time until his cousin became BAAS president before going ahead with the issue. It is likely, too, that Francis Galton took the initiative in 1893 to develop Kew into a national laboratory because he saw it as a way of securing the observatory's financial future. As discussed in Chapter 5 (Section 5.5) and Section

[124] Galton, Douglas (1895a), p. 32.
[125] Galton, Douglas (1895b), pp. 607-608.

6.3 above, he had been instrumental in introducing the testing of watches and clinical thermometers at times when Kew needed the money. Now, if it were to be turned into a general laboratory that did a full range of testing and standardisation, including work for the burgeoning electrical industry, possibly backed up by government grants, Kew potentially had a new and much more lucrative career.

At the September 1895 meeting the BAAS followed Douglas Galton's suggestion and reconvened its committee on a national laboratory. This time it was larger – fourteen members instead of ten in 1891 – and was chaired by Douglas Galton instead of Oliver Lodge (who remained a member). It now contained three influential Kew Committee members: Foster, Rücker and Francis Galton – a further hint of a partnership between the Galton cousins. When the committee reported back a year later, it recommended the establishment of a national laboratory supported principally by the government. Importantly, it briefly summarised the work currently being carried out at Kew and noted that:-

> The present work of the [Kew] Observatory is therefore of a character which is strictly consistent with a large portion of the work which would find a place in a national physical laboratory.[126]

Its members started a petition headed by a memorandum that expressed the need to found 'a National Physical Laboratory' similar to the Berlin PTR and that:-

> The undersigned give their general approval to the scheme for making Kew Observatory the nucleus of such an Institution.

The memorandum ended by urging that the government find the funds for the foundation and maintenance of such an institution. The petition was eventually signed by sixty prominent scientists, mainly physicists, including both Galtons.[127] Again, note the identical phraseology to the 1893 correspondence: Kew as 'the nucleus' of a national physical laboratory.

Douglas Galton made the first move towards presenting the petition to the government. The following month he sent the petition to the secretaries of the Royal Society, along with a letter saying that the BAAS General Committee had advised

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[126] Anon. (1896), p. 84.

[127] Document headed 'NATIONAL PHYSICAL LABORATORY.', enclosed with Douglas Galton to Secretaries of the Royal Society, 21 October 1896, RS:MC/16/335.

the Association's Council to seek the approval and help of the Royal Society and other learned societies in impressing upon the government the importance of enlarging Kew Observatory into a national physical laboratory.[128] Galton strengthened his case with something that gave a useful urgency to the whole project: a proposal from the town of Richmond to acquire part of the Old Deer Park, the site of Kew Observatory, for civic purposes, 'which would probably put an end' to the idea of obtaining the land needed to enlarge the observatory into a physical laboratory. He now asked Foster to put in hand organising a deputation from the Royal Society to the government.[129] There was an unwritten implication here: no land in the Old Deer Park meant that there could be no NPL, because building a new laboratory from scratch somewhere else would cost much more, making it much more difficult to convince the government to fund the project. We can see here a further demonstration of the centrality of Kew Observatory to the NPL project. In an age when it was still difficult to convince the government to fund any new large-scale expenditure on science, Britain's answer to the PTR had to be 'gradually' built by extending an existing institution, Kew Observatory.

Just two days after Douglas Galton's letters to the Royal Society, his cousin informed the Kew Committee of these moves. The Kew Committee passed a resolution approving 'generally' of the idea of building a national physical laboratory connected with Kew and asked to be kept informed of what was proposed to be done next in this regard. Francis Galton quickly communicated the Kew Committee's approval back to the Royal Society.[130] The Kew Committee's concurrence in the project is not surprising: of the five members present at the October 1896 meeting, four were signatories to the BAAS petition of the previous month. Moreover, the committee's members had known all about the possibility of turning Kew into a national physical laboratory ever since Francis Galton, as Chairman, had informed them about it in February 1893.

Douglas Galton's letter and enclosures were read at the next Royal Society Council meeting, on 5 November. The Council resolved to reply to Galton that they were 'wholly in sympathy' with his proposal and suggesting that the Royal Society

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[128] Douglas Galton to Secretaries of the Royal Society, 21 October 1896, RS:MC/16/335.
[129] Douglas Galton to Michael Foster, 21 October 1896, RS:MC/16/334.
[130] KCM, 23 October 1896; Francis Galton to Michael Foster, 24 October 1896, RS:MC/16/337.

form a joint committee with the BAAS and other learned societies, ‘to consider the matter, and to take such action as they may find desirable’. At the same meeting the Council nominated Joseph Lister (President of the Royal Society), William Thomson (now Lord Kelvin), Lord Rayleigh, Arthur Rücker and Francis Galton to serve on this joint committee.[131] The joint committee formed a 28-strong deputation that visited the Prime Minister, Lord Salisbury, on 16 February 1897. In addition to many leading physicists, the deputation included the chemist William Ramsay and engineers such as William Ayrton and William Preece. On 3 August the Treasury agreed to set up a government committee with a brief ‘to consider and report upon the desirability of establishing a National Physical Laboratory’ for standardising scientific instruments, for establishing and preserving measurement standards and for determining physical constants and data for science and industry. The Treasury also requested the committee ‘to report whether the work of such an institution, if established, could be associated with any testing or standardizing work already performed wholly or partly at the public cost’ – an indirect reference to Kew Observatory as well as the Board of Trade’s electrical standards laboratory.[132]

The committee was chaired by Lord Rayleigh; Moseley has speculated that Rayleigh’s class connections in the government – Arthur Balfour, the First Lord of the Treasury, was Rayleigh’s brother-in-law – might have helped the proposal gain support in government circles.[133] Two of its other members, Courtenay Boyle of the Board of Trade and Robert Chalmers of the Treasury, were senior government officials. The others – Andrew Noble, John Wolfe Barry, Roberts-Austen, Arthur Rücker, Alexander Siemens and Thomas Thorpe – all represented science, engineering and industry. Rücker was the sole member of the Kew Committee represented. As with the Devonshire Commission and the commission of 1877 on the Meteorological Office, the committee’s hearings were somewhat internal, as many of the witnesses from whom it heard evidence in the ensuing months had been on the BAAS committee that had advocated a national laboratory in the first place, or had at least been associated with it: they included both Galtons, Oliver Lodge and Richard Glazebrook. Importantly, four of the witnesses – Francis Galton, Robert Scott, George Carey Foster and Richard Strachey – were Kew Committee members.

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[131] RS:CM, 5 November 1896.
[132] Anon. (1898a), p. iii.
[133] Moseley (1976), p. 58.

The government committee also interviewed Charles Chree, the superintendent at Kew.[134]

The Treasury published its report on 6 July 1898. The report recommended that 'a public institution' for standardising instruments, testing materials and determining constants 'should be established by extending the Kew Observatory in the Old Deer Park, Richmond'. The report specified that the existing buildings at Kew should be improved and new buildings erected 'at some distance from the present Observatory'.[135] It is striking how the idea – the very phrase – of establishing a national laboratory by 'extending the Kew Observatory' had emerged from the government's report unchanged since the initial correspondence in the early 1890s. We have seen how, in his letter to Francis Galton in February 1893, Arthur Schuster had suggested that such a laboratory could be started 'if the work of the Kew Observatory could be extended in certain directions'. The same language appears in Douglas Galton's 1895 presidential address to the BAAS, in which he had called for 'the extension of the Kew Observatory'.

Three months later, the Treasury informed the Royal Society that the government was prepared to adopt the report's recommendations. The government offered to pay £12,000 for new buildings on the Old Deer Park site in addition to the existing Kew Observatory, plus a grant-in-aid of £4,000 per annum 'for 5 years certain'. Otherwise, the government stipulated that the existing Gassiot Trust of around £470 per annum should contribute towards the new laboratory's running costs and it followed the report's recommendation that the standardisation and testing work undertaken should be self-supporting through fees – exactly as had been the case at Kew since the 1870s. The Treasury even recommended, in view of the new large endowment of £4,000 per annum, that the £400 currently being paid each year to Kew Observatory by the Meteorological Council should now be stopped.[136] This latter recommendation annoyed members of the Royal Society Council, who objected to it in the Royal Society's official reply to the Treasury on 28 November,

[134] Anon. (1898b), pp. iii-iv.
[135] Anon. (1898a), p. 6.
[136] E W Hamilton to [Lord Rayleigh], 7 October 1898, TNA:BJ 1/213/1327.

pointing out that in return for the annual £400, Kew provided services which the government would have to pay for if they were carried out somewhere else.[137]

In all other respects, the Royal Society Council was happy to accept the government's offer. In their official reply to the Treasury, the Council members confessed that they 'cannot conceal from themselves' that the money offered was less than they had hoped for, but said that as the NPL was to be in the form of 'an extension of the Kew Observatory' (once again, the language of 'extension'), the money would 'greatly increase the utility and range of the work there done'. They declared themselves willing, in principle, to accept the government's offer and informed the Treasury that the Royal Society had appointed a committee to discuss the details of the new laboratory with the Treasury.[138] The proponents of the NPL knew, as they had known since the early 1890s, that a modest extension of Kew Observatory was the best that they could hope for in the circumstances – indeed, it was all that the BAAS committee had applied for. The artillery expert Sir Andrew Noble likely spoke for many when he recommended accepting the government's offer, in the hope that once the NPL had proven its 'utility', 'a future Chancellor of the Exchequer may see his way to be a little more liberal'.[139]

The committee of seven appointed by the Royal Society Council to negotiate with the Treasury included two Kew Committee members: Rücker and Adams.[140] Early in 1899 its members drew up a 'Scheme of Organization' detailing how the NPL was to be managed. The NPL was to be run on a day-to-day basis by an Executive Committee, whose 23 members were to represent industry and engineering as well as physics; a similar balance of members was to make up a 'General Board' that would provide overall direction. Six members of the Executive Committee were to be from the 'members of the Kew Observatory Committee at the time when the Kew Observatory is incorporated into the National Physical Laboratory'. Two of these Kew Committee members were to retire from the Executive Committee every two years and the vacancies thereby left would not be

[137] M Foster and A W Rücker, Secretaries of RS, to Secretary to HM Treasury, 28 November 1898, RS:MS/538.
[138] *ibid.*
[139] Noble to Rücker, 19 October 1898, RS:MS/538. Noble was a member of the government committee that reported on the NPL in July 1898.
[140] RS:CM, 3 November 1898.

filled up.[141] Thus the committee that had run Kew Observatory for half a century was absorbed into – and ultimately dissipated by – the NPL, which the Kew Committee had done so much to give birth to. There only remained the legal formality of winding up the Kew Committee itself, as this had been incorporated under the Companies Act in 1893. This procedure was overseen by the Royal Society's Treasurer, Alfred Bray Kempe, a Cambridge mathematician who became a barrister and put his legal and financial acumen to the benefit of the Royal Society.[142] The Kew Committee was wound up at two extraordinary general meetings, held on 10 November and 1 December 1899. Its property and assets were transferred to the Royal Society.[143]

No member of the Kew staff was made redundant after the NPL formally took charge of Kew on 1 January 1900: the NPL's annual report for 1901 records practically the same number of staff at Kew as there had been during the last years of the Kew Committee.[144] In the event, however, Charles Chree did not become director of the new NPL – even though, as discussed in Section 6.2, he seems to have been chosen as superintendent in 1893 partly with the possibility in mind that his role might develop into the directorship of a larger organisation. The Executive Committee instead chose Richard Glazebrook, one of the members of the original BAAS committee on a national laboratory and Assistant Director of the Cavendish Laboratory. We do not know why Glazebrook was chosen. The minutes of the Executive Committee record that each of the members present at its first meeting in May 1899 suggested a name.[145] By mid-June, this list had been shortlisted to two names, neither of them specified.[146] The earliest official record that we have of Glazebrook being chosen is in the Executive Committee minutes of 5 July 1899, though as early as 7 June Courtenay Boyle wrote privately to Rücker that 'I doubt if we can give Glazebrook [£]1400 – at any rate I think we must use all our efforts to find some other solution first'.[147] Thus just one month after the Executive

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[141] 'NATIONAL PHYSICAL LABORATORY. Draft Scheme of Organization. Revised at a Meeting of the Committee on January 11th. 1899', TNA:BJ 1/213.
[142] Geikie (1923), pp. v-ix.
[143] KCM, 10 November and 1 December 1899.
[144] National Physical Laboratory, 1901.
[145] NPL Executive Committee Minutes, 5 May 1899.
[146] RS:CM, 15 June 1899.
[147] NPL Executive Committee Minutes, 5 July 1899; Boyle to Rücker, 7 June 1899, RS:MS/538.

Committee came into existence, Glazebrook was the favoured candidate. That Glazebrook was chosen instead of Chree might well have been due to the influence of former Cavendish Laboratory director Lord Rayleigh, who was now vice-chairman of the NPL Executive Committee. Glazebrook had been Rayleigh's preferred candidate to succeed him to the headship of the Cavendish in 1884; to the frustration of both, J. J. Thomson was appointed.[148] Rayleigh would likely have wanted to see 'his' man become director of the new national laboratory. Glazebrook also had much more administrative and financial experience than Chree: from 1891, Glazebrook had been assistant director of the Cavendish and in 1895 he became bursar of Trinity College, one of Cambridge's wealthiest colleges.[149]

In November 1899 the Kew Committee, in one of its final meetings, authorised the NPL Executive Committee to convert a room on the first floor of the observatory into accommodation for Glazebrook.[150] In February 1900 the Royal Society Council accepted the Office of Woods's offer of a fifteen-acre plot in the Old Deer Park for the use of the National Physical Laboratory.[151] All seemed set for work to begin on new buildings on the Old Deer Park site. Glazebrook did briefly operate from the Kew Observatory site: some of his earliest letters as director of the NPL bear the same address as Kew Observatory.[152] In the spring of 1900, however, some influential local residents had objections raised in Parliament about the disruption that the new buildings might cause.[153] As noted in Section 6.3, the Old Deer Park was becoming encroached by London's expanding suburbs and transport network as the nineteenth century drew to a close. At the same time, it was being increasingly used as a semi-rural location for leisure pursuits, notably by the Mid-Surrey Golf Club. It is easy to see why many local people would have been perturbed by the plans to build a complex of buildings here, one of which was to house a turbine to generate electricity for the new laboratory. Over the following months these objections became serious enough for the government to reconsider using the Old Deer Park as a site. By late October the government 'felt bound to consider whether any alternative site could be secured which would be reasonably

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[148] Schaffer (1992), p. 41; Moseley (2004).
[149] Moseley (2004).
[150] KCM, 10 November 1899.
[151] RS:CM, 15 February 1900.
[152] See, for example, Glazebrook to Foster, 10 January 1901, RS:MS/538.
[153] Hansard, HC Deb 07 May 1900 vol. 82 cc882-3; Hansard, HC Deb 14 May 1900 vol. 83 cc39-40; Hansard, HC Deb 28 May 1900 vol. 83 c1511; Moseley (1976), p. 75.

satisfactory for the purposes of the Laboratory'.[154] On 24 October the NPL Executive Committee considered the government's offer of such an alternative site: Bushy House in Teddington, Middlesex, which was conveniently accessible to the west of London, like Kew. Ironically, Bushy House was now in a similar situation to the Kew building in 1841: it was Crown property, most recently leased to the exiled French royal family, yet had been lying unused since 1897. The Executive Committee considered that 'a reasonably satisfactory' NPL could be built around Bushy House and did not recommend that the Royal Society oppose the Treasury's changed offer. Two months later, the Treasury once again made a formal offer of a site, this time Bushy House and its grounds.[155]

During the course of 1901, the interior of Bushy House was converted into laboratories and part of one floor became Glazebrook's new accommodation. The NPL staff moved from Kew to Teddington in September 1901,[156] though the testing of meteorological instruments, clinical thermometers, watches and chronometers, as well as the meteorological observations, remained at Kew until 1910, when responsibility for the observatory passed to the Meteorological Office (see Chapter 7). From 1900, Kew was formally known as the 'Observatory Department' of the NPL. When the NPL at Teddington was formally opened by the Prince of Wales (later King George V) in March 1902, Kew's significance had shrunk: it was now just an outlying department of a much larger organisation, located some miles away from the NPL's main site and its annual reports became a small part of the much larger annual reports of the NPL.

6.5 Conclusion

In his 1909 autobiography, Francis Galton devotes about one-third of a chapter to Kew Observatory and his relations with it. Yet he glosses over the role of Kew in the origins of the National Physical Laboratory with a few brief sentences that could have been derived from the published sources available at the time. Kew, according to Galton:-

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[154] Francis Mowatt (Treasury) to PRS, 30 October 1900, RS:MS/538.

[155] RS:CM, 25 October 1900; Pyatt (1983), p. 12; Lord Esher (HM Office of Works) to Secretary, Royal Society, 22 December 1900, RS:MS/538.

[156] National Physical Laboratory, 1901, p. 8.

> was wholly unequal in its scale to the rapidly growing requirements of the day. This feeling found expression in the Anniversary Address to the British Association in 1895, by my cousin Sir Douglas Galton; powerful support was given to his suggestions and efforts, and finally the Kew Committee was merged into the much larger and more important National Physical Observatory [*sic*], under the directorship of Mr. Glazebrook, which swallowed at a single gulp the whole of our thrifty savings.[157]

Galton might have been motivated by feelings of respect towards his cousin, who had died in 1899. But crucially for historians, his summary perpetuates the myth that Kew Observatory was just a convenient first site for the NPL, or at most a Victorian precursor that did some of its work on a small scale and had little relation to the twentieth-century NPL. Indeed, it is possible that Galton's widely-read memoirs helped to create the myth. More than two decades later, during a lecture to the NPL, Richard Glazebrook claimed that in the political climate of the 1890s, it 'seemed impossible' to obtain government funding for a national laboratory and that the BAAS committee appointed after Lodge's 1891 speech 'lapsed without taking further practical action'.[158] As we have seen, this story of the laboratory being dismissed as a lost cause in the early 1890s, until Douglas Galton's happy intervention propelled the government into at last providing state support for a national laboratory, has largely been followed by later historians. Both Glazebrook's and Francis Galton's reminiscences marginalise the role of Kew Observatory in the birth of the NPL.

It is clear from this chapter that, far from Kew being merely incidental to the inevitable rise of the NPL, Kew was central, in fact essential, to the NPL's origins. For in the political climate of the 1890s, the NPL might never have become a reality without it being first presented to government as an extension of the existing Kew Observatory. It is fair to say also that the Kew Committee was instrumental in giving birth to the NPL. The Kew Committee was important not only in the behind-the-scenes moves from the early 1890s onwards to establish a national laboratory, but also in changing the nature of Kew Observatory itself so that it in many ways it came to resemble the proposed laboratory and enabled the 1896 BAAS report on the proposal to comment accurately that the work at Kew was 'of a character which is

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[157] Galton (1909), p. 228.
[158] Glazebrook (1933), p. 3.

strictly consistent with a large portion of the work which would find a place in a national physical laboratory'.[159] This was dramatically symbolised by the instigation in the mid-1890s of research into platinum thermometers and high-temperature thermometry more generally, so that by 1896 an unofficial NPL thermometry department existed several years before the inauguration of the NPL itself.

Kew did some important research in geomagnetism and meteorology in the years after 1885, but neither the Kew Committee nor the superintendent directed that research in the way that they had done under the BAAS. Gone were the days when Kew led the way in Balfour Stewart's all-embracing 'cosmical physics', that encompassed geomagnetism, meteorology and sunspots in a single theory of the universe. Research in these areas at Kew was largely done in the service of other institutions. Meteorological observations were carried out for the Meteorological Office, the BAAS and university-based physicists. Magnetic work very often took the form of contributions to magnetic surveys directed from universities, or otherwise testing instruments and training scientists from elsewhere in the use of those instruments. Charles Chree's own research into terrestrial magnetic variations was important, and ultimately a vindication of Sabine's discovery of the correlation between the sunspot cycle and terrestrial magnetism, but it was the work of a lone scholar and not the director of a revived Magnetic Crusade.

By the early 1890s, therefore, Kew Observatory was even more of a laboratory of service than it had been in 1885. It was also effectively a business, as symbolised by its seal of incorporation under the Companies Act. In its everyday running it was largely self-supporting – just as the early NPL was expected to be. Finance remained the main motive for the growing programme of standardisation work, already Kew's most important source of income by 1885. Not only the amount but the range of instruments tested at Kew increased enormously over the next fifteen years, so that by 1900 Kew was already a central standardisation laboratory, whose monogram and certificates leading instrument makers were proud to display on their wares. Although some standardisation work was done elsewhere – at the Cavendish Laboratory and the Board of Trade's standards department – the standardisation service at Kew was the largest and most comprehensive. Some of this expansion of the Kew standardisation programme was, as we have seen, in

[159] BAAS:AR, 1896, p. 84.

response to external demand, but the work's potential to earn the observatory lucrative income meant that the Kew Committee seldom hesitated to meet that demand.

This increased emphasis on standardisation meant that it was an easy step from Oliver Lodge's 1891 speech on the need for a national laboratory to the idea first mooted privately in 1893 of making Kew the 'nucleus' of such a laboratory, especially when the political climate of the 1890s would have made it difficult to approach the government for a laboratory from scratch. It is clear from the narrative of the early moves to establish a national physical laboratory that these were largely internal to the Kew Committee. The discourse of Kew as a 'nucleus' of a larger laboratory can be traced from the correspondence of early 1893 through to Douglas Galton's 1895 speech and the proposal to approach the government a year later. That of the NPL as an 'extension' of Kew runs with similar consistency from 1893 right through to the Treasury report of 1898 recommending the establishment of a national physical laboratory. The NPL might have remained quite literally an extension of the Kew Observatory buildings, had it not been for local objections to the proposed new buildings in the Old Deer Park in 1900, by which time the NPL was already in existence at Kew.

Therefore the NPL was neither established nor conceived as a new laboratory from the bottom upwards, backed by generous state support like the PTR. Rather, it grew out of an existing institution in which the need to make money constrained it into becoming a laboratory of service that carried out an important part of the work that would be done at the NPL. This 'extension' of Kew Observatory into the NPL, largely directed by members of the Kew Committee, was thus very much a part of the *laissez-faire* world of the 1890s and not that of twentieth-century, state-supported science. As I will discuss in my concluding chapter, this narrative is consistent with the whole history of Kew Observatory, which provides a major case study in the patronage of science throughout practically the whole Victorian era.

Table 6.1 – Kew Instrument Verifications, 1886-1900

	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900
Met. thermometers	1320	1370	1074	1910	4901	2289	1875	2246	3225	2647	4098	2874	3296	2892	2786
Clinical thermometers	9054	8668	10442	10116	12536	15692	16850	14682	15593	16699	13772	17270	17962	16020	20476
Deep-sea thermometers	32	35	77	100	40	58	31	69	35	125	74	119	79	19	83
Total thermometers	11490	12989	13502	12805	18125	18600	19018	17260	19095	19767	18170	20523	21603	19244	23547
% clinical	79	67	77	79	69	84	89	85	82	84	76	84	83	83	87
Barometers[1]	247	202	279	232	268	279	227	237	245	494	309	375	404	367	416
Sextants	139	145	157	292	346	428	463	517	461	532	591	694	750	876	813
Telescopes	0	0	0	99	152	374	487	913	249	456	546	707	681	561	1345
Binoculars	0	0	0	341	336	470	168	466	417	376	455	661	374	404	963
Camera lenses	0	0	0	0	0	19	18	31	27	14	14	10	13	160	136
Watches	490	510	639	528	513	709	1044	1521	737	746	583	680	483	469	403
Marine chronometers[2]	17	14	12	10	3	18	19	40*	21	58	61	65	70	56	53
Income from stdsn. (£)	1072	1229	1422	1327	1597	1629	1857	1865	1944	2004	1996	2309	2196	2176	2550
Total income (£)	3097	3621	3790	3546	3467	3912	3848	3485	4173	4377	3507	3848	4226	4394	8294
% total income	35	34	38	37	46	42	48	54	47	46	57	60	52	50	31
Income from Gassiot	490	490	493	488	488	488	488	486	484	485	445	459	458	456	454

See page 254 for notes.

Notes to Table 6.1

* 30 of these chronometers were tested for the Italian government.

[1] Including aneroids. [2] Not including those for Portuguese government, 1894.

Total thermometers does not include deep-sea thermometers.

Income from verifications includes that from rating of watches and chronometers.

Data from Reports of the Kew Committee in *Proc. Roy. Soc. Lond.*, 1886-1900.

Chapter 7
Conclusion

> The recording instruments [at Kew] designed by Stewart and Beckley have been in operation for nearly 70 years and in one way and another have played their part in teaching us about our climate. Long may they continue the good work.
>
> F J W Whipple, 1937[1]

> Regular photographs of the sun would be – if only the practical problems could be solved – a quick means of building up an impersonal record of sunspot numbers and distribution. These problems were first solved at the Kew Observatory, which the British Association for the Advancement of Science supported near London.
>
> Karl Hufbauer, 1991[2]

7.1 Introduction

The first quotation above is the concluding paragraph of a presidential address given to the Royal Meteorological Society by Francis John Welsh Whipple, Charles Chree's successor as superintendent of Kew Observatory. To the historian, it offers an early illustration of how in the twentieth century, Kew Observatory was consecrated as a holy place for meteorologists, where 'the good work' begun in the nineteenth century was carried on. The address bears the generic title of 'Some aspects of the early history of Kew Observatory', yet perhaps naturally in a lecture to Britain's professional body of meteorologists, Whipple deals exclusively with the meteorological observations and instruments at Kew, making no mention of the geomagnetic, solar and standardisation work that was so important there in the nineteenth century. On the other hand, the second epigraph, from a modern history of solar astronomy, mentions Kew only for its early contribution to solar physics, without acknowledging that solar photography was just one activity among many at Kew in the nineteenth century. Taken together, these two quotations dramatically illustrate a fundamental problem with the existing literature on Kew Observatory, already alluded to in Chapter 1: that Kew Observatory has meant different things to

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[1] Whipple (1937), p. 135.
[2] Hufbauer (1991), p. 49.

people working in different branches of science. To the meteorologist, it was a pioneering meteorological observatory; to the astronomer, it was an early centre for solar physics. This multiplicity of meanings of Kew Observatory may do much to explain why, so far, there has been no serious attempt to understand the *whole* of its work in the Victorian era. In this thesis I have attempted to do just that by writing its history as an institution, not just isolated aspects of its work. In this concluding chapter, after briefly summarising the post-1900 history of Kew Observatory and its significance for the historian, I return to the three great questions outlined in Chapter 1 and show how the findings presented in Chapters 2 to 6 have helped to answer them. I will conclude with some ideas for further research that I believe these findings have suggested.

7.2 The twentieth-century legacy

The operation of Kew Observatory continued relatively unchanged throughout the first decade of the twentieth century. As the ‘Observatory Department’ of the National Physical Laboratory, Kew continued to test instruments; it also acted as the ‘central observatory’ for the Meteorological Office, in the sense that it standardised instruments to be used at the Office’s other stations across Britain and Ireland. Then, in January 1910, negotiations between the NPL, the Meteorological Office and the Treasury resulted in a decision to transfer responsibility for running Kew Observatory to the Meteorological Office and that the instrument-testing work should go to the NPL’s main site at Teddington. The NPL’s Annual Report for 1910 gives no reasons for this decision.[3] However, in 1900 Cavendish Laboratory physicist (and Kew Committee member) William Napier Shaw had succeeded Robert Scott as director of the Meteorological Office. Shaw would likely have appreciated being able to deal with Kew Observatory directly and not having to go through the NPL’s administrative machinery, as Malcolm Walker has hinted.[4] NPL director Richard Glazebrook, for his part, would have welcomed the saving in costs that relinquishing Kew would have offered to the ever cash-strapped NPL: to him, Kew would probably have seemed an expensive, extraneous site, now that the NPL was firmly established at Teddington. The decision might well have been helped

[3] National Physical Laboratory (1910), pp. 4-5; Walker (2012), pp. 171-172.
[4] Walker (2012), pp. 171-172.

along by the fact that Glazebrook and Shaw were old friends. Both had had long careers at the Cavendish Laboratory prior to 1900 and they were the joint authors of *Practical Physics*, a popular textbook for students in laboratory physics, first published in 1884.[5]

With the removal of standardisation to Teddington, Kew became a purely meteorological observatory, especially after the last of the geomagnetic instruments were transferred to Eskdalemuir, far from any interfering trams and railway lines, in the mid-1920s. For the first time in its history, Kew Observatory specialised in just one science: even during the reign of George III, both astronomical and meteorological measurements had been carried out at Kew. Some important research was done at Kew in the twentieth century, including innovative measurements of air pollution and pioneer work with radiosonde balloons.[6] A full history of the activities at Kew after 1900 remains to be written. Yet, as had happened with the magnetic and meteorological work from the mid-1870s onwards, these researches were not directed from Kew, but carried out there on behalf of a client elsewhere. No longer was the research at Kew directed by a Kew Committee composed of private gentlemen, scientific servicemen and, later on, university physicists. As early as 1920, the young meteorologist F. J. Scrase noted a faded elegance about the building: 'the place had more the air of a rather musty museum with a large number of instruments of historic interest…'.[7] Kew was no longer a centre from which research was directed, the way it had been in the middle decades of the nineteenth century, nor a central testing laboratory, as it had been until the early 1900s. The observatory's reduced prestige, plus its specialisation in just one branch of science, meant that it was much less indispensable than it had been before 1910 and hence much more vulnerable to closure when in 1980, Margaret Thatcher's government introduced severe funding cutbacks. The Meteorological Office made the decision to close Kew Observatory, which ceased operations as a meteorological observatory at the end of 1980.[8]

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[5] Schaffer (1992), p. 37; Kim (1995), pp. 204-205.
[6] Harrison (1969); Scrase (1969), p. 183.
[7] Scrase (1969), p. 180.
[8] Walker (2012), pp. 398-400; Galvin (2003), p. 483. The observatory building remained Crown property. Until 2011, it was leased to a private company and used as an office building. At the time of writing (2015) it is empty and in the hands of a property developer.

The memory of some aspects of Kew Observatory in the nineteenth century lived on into the twentieth. The middle names of Francis John Welsh Whipple clearly recall John Welsh, superintendent from 1852 to 1859. Francis' older brother, Robert Stewart Whipple, had a middle name recalling Welsh's successor, Balfour Stewart. The memory was also preserved in watches bearing 'Kew Observatory' test certificates, still sought after by antiques collectors even today (see Chapter 6, Section 6.3). Apart from watches, however, the legacy of Kew Observatory today is often one of either meteorology only or solar astronomy only, as discussed above. With the institutional history presented in this thesis, I have attempted to correct this fragmented view of the history of Kew Observatory. In the next section, I summarise my findings by returning to the three fundamental questions posed in Chapter 1.

7.3 Research questions

1) What can the history of Kew Observatory tell us about how the physical sciences were organised in the Victorian era?

In Chapter 1, I divided this question into three sub-questions. How were the physical sciences funded? How were they managed? What kind of people did them? Through the history of Kew Observatory we can see that there were some clear changes in the patronage of science between 1840 and 1900, yet the story also highlights an important similarity between the earlier and the later part of the period. In Chapter 2 I have argued that it was Edward Sabine who steered the project of a magnetic and meteorological observatory towards the privately-funded British Association for the Advancement of Science. Airy's astute moves in 1840 – among them his stated wish to reduce the strain on the public purse – diverted what little government funding there was for geomagnetism and meteorology towards Greenwich, but that did not stop Sabine from establishing a scaled-down project at Kew with private funds. Thus in the 1840s, one man could manipulate the Royal Society and the BAAS towards establishing an observatory, even with no government funding.

It is easy to think of the Royal Society Government Grant, introduced in 1850 by Lord Russell's government, as heralding the start of a new era in organised science. As described in Chapter 3, even some contemporaries thought that it might be used to support the running of Kew Observatory. Yet it is debatable whether the grant in itself saved Kew from the attempts by the BAAS in the late 1840s to close it down. The government intended the money for one-off projects by private individuals and not as an annually-renewable grant to run larger institutions. Sabine and the Kew Committee were successful in obtaining Government Grant money, but only for individual projects. The Kew Committee obtained as much money from other sources, such as the Royal Society's private Donation Fund, as it did from government. The saving of Kew Observatory from closure almost certainly owes more to the astuteness of Sabine and the initiative of the businessman John Gassiot to commence instrument tests at Kew in return for fees. This standardisation work was vital to keeping Kew running, not only through the income it generated, but also because it made the case for closing down the observatory much harder to make – especially when the East India Company and then the Meteorological Department of the Board of Trade created a demand for large numbers of standardised instruments.

It could be argued that Kew was saved by the government in the 1850s, thanks to this demand from government departments. Yet it is important to remember that Kew remained independent of government. Its largest single source of income up to 1871 was the annual BAAS grant. It also did lucrative work for private individuals, instrument makers and foreign governments. Although the Kew Observatory of the late 1850s was no longer entirely dependent on gentlemanly patronage, it was still a mostly privately-funded organisation. The successful 1860 expedition to Spain to photograph a solar eclipse, discussed in Chapter 4, tells a similar story: government support was largely restricted to the loan of a ship, while equipment and personnel were largely paid for by another wealthy businessman and devotee of science, Warren De La Rue. Similarly, funding for solar photography at Kew was entirely independent of government: its sources were the BAAS, the Royal Society and, again, De La Rue, who often paid assistants out of his own pocket.

The transfer of Kew Observatory from the BAAS to the Royal Society in 1871 accelerated a trend that began in the 1850s: the observatory became ever more dependent on standardisation for income. Gentlemanly patronage, in the form of the Gassiot Trust, proved to be insufficient, especially after the Trust's revenues dropped in the mid-1870s. So too was the even more paltry grant from the Meteorological Office: even as the Office's 'central observatory', Kew was little more dependent on government than before. As shown in Chapter 5, by the time Robert Scott wrote his oft-cited 1885 history of Kew Observatory, standardisation was much the largest source of the observatory's income. This trend continued after 1885. Thus by the time of Oliver Lodge's 1891 speech calling for a national laboratory like the prestigious new Physikalisch-Technische Reichsanstalt in Berlin, Kew was already a laboratory of service and no longer the experimental observatory that it had been under the BAAS. When the BAAS committee appointed to discuss the possibility of establishing the new laboratory was confronted with a lack of government support for a PTR-like institute, it was therefore an easy step for the committee to recommend a simple expansion of Kew Observatory, using it as the 'nucleus' of a larger laboratory. Thus the origins of the NPL highlight an important similarity between the 1840s and the 1890s with regard to government patronage of science. The NPL came into existence in the way it did due to the sheer *lack* of government funding – in a similar way to that in the 1840s, in which, as described above, the BAAS came to set up a scaled-down meteorological observatory, independent of government. The NPL was as much a product of *laissez-faire* as the Kew Observatory of the 1840s and 1850s, not a bold new departure by government. Exploring the NPL's origins through the evolution of Kew Observatory allows us to see more clearly the continuing importance of *laissez-faire* in the patronage of science throughout the Victorian era.

The most striking change in the management of Kew Observatory over the 1840-1900 period is the gradual replacement of the gentlemen scientists who dominated the Kew Committee until the 1870s with university physicists, reflecting a change that took place in the overall management of the physical sciences in the Victorian era. The university physicists came to direct much of the research agenda, especially with regard to magnetic surveys and instrument standardisation. The scientific servicemen remained well-represented on the Kew Committee after the 1870s, though none was ever as powerful as Sabine. However, aristocrats and other independent men of wealth and influence remained important in seeking patronage for science at Kew, as they did in government. Francis Galton, the last of the gentlemen scientists on the Kew Committee, remained its chairman right up to 1899 and was vital in the initial liaison between the BAAS and the Kew Committee that made the first move to turn Kew into a national laboratory. The 1897 deputation to Lord Salisbury that lobbied for the new laboratory was largely composed of university physicists and engineers, yet it was led by Lord Rayleigh, a hereditary peer as well as a physicist. Moreover, as Magnello and Moseley have noted, the First Lord of the Treasury, Arthur Balfour, was Rayleigh's brother-in-law.[9] Indeed, this deputation bears a striking resemblance to the deputation to Lord Melbourne in 1840 that lobbied for a physical observatory (Chapter 2, Section 2.3): in both cases, well-connected, wealthy men of science negotiated directly with aristocratic political leaders.

Some important changes in the kind of people who did science at Kew took place between 1840 and 1900. Kew Observatory's first superintendent after 1842 was a gentleman volunteer, Francis Ronalds. All the superintendents from 1852 onwards were paid employees of the Kew Committee. Of these, all (except, as far as is known, Samuel Jeffery, who served as superintendent from 1871 to 1876) had received a university training in the physical sciences. John Welsh and Balfour Stewart had both studied at Edinburgh under James Forbes, but by the end of the century, the postholder of superintendent had a different background. Charles Chree, although a Scot, had studied at the Cavendish Laboratory in Cambridge, by then a major training ground for physicists. We need to be cautious, however, in reading the appointment of Chree as indicative of the supremacy of the Cavendish at the end of the nineteenth century. Of the four candidates shortlisted for interview in 1893, only two were from the Cavendish.[10] Chree's appointment perhaps tells us more about the relative decline of the Edinburgh natural philosophical tradition and the larger number of university physics departments and teaching laboratories by the 1890s. Edinburgh now had competition from many other universities. The high standard of applicants – one of whom was already FRS – also tells us something about the prestige of Kew Observatory itself. The competition for the Kew superintendentship in 1893 was as fierce as that for a university post at the time.[11]

As described in Chapter 6, the scientific qualifications of the assistants at Kew became more formalised towards the end of the century. No longer were the instrument readings being taken by a former sergeant from Sabine's army regiment, as had been the case in the 1840s. Even the 'boy clerks' had to have formal examination qualifications. Yet right to 1900 the assistants remained chronically

[9] Magnello (2000), p. 18; Moseley (1976), p. 55.
[10] Hughes (2005), esp. pp. 299-300, has pointed to the richness of physics teaching in the London colleges and elsewhere at the beginning of the twentieth century, in contrast with the received view of the primacy of the Cavendish Laboratory.
[11] Hughes (2005), esp. pp. 271-272.

low-paid, compared to their counterparts at Greenwich. This was a further continuity between Kew and the NPL: in the NPL's early years, well-qualified university physicists worked for salaries no better than those of the senior assistants at Kew.[12] The cheapest – and most piecemeal – assistance of all was provided by women, such as Elizabeth Beckley, who took the solar photographs and helped to analyse the results. This study has suggested that greater consideration needs to be given to the roles of lesser-known people in scientific practice. As the work of Elizabeth Beckley and John Welsh demonstrates, nineteenth-century scientific institutions, instruments and discoveries were not straightforward realisations of the ideas of major figures like John Herschel. They were much more complex and often reflected the social structure of Victorian England, in which credit often went to the grander figures at the expense of the lesser-known ones.

2) How did the 'observatory sciences' at Kew develop over the course of the nineteenth century?

Until the early 1870s, the observatory sciences at Kew showed a trend towards diversification. Geomagnetism, standardisation and solar physics were gradually added to the initial agenda of meteorology and atmospheric electricity. Astronomy was not central to Kew Observatory after 1842, the way it was at Greenwich, the university observatories and the numerous private observatories operated by self-funded men of science. The closest it came to being central was in the late 1860s, when Balfour Stewart's theory-driven solar physics became key to his 'cosmical physics' that connected solar activity with terrestrial magnetism and meteorology via the putative all-pervading ether. Yet as I have shown in Chapter 4, this cosmical physics was frustrated partly by Sabine's insistence that Stewart devote his time to magnetic and meteorological data collection and also by the vastly increased workload at Kew when it became the central observatory of the reformed Meteorological Department, known from 1867 as the Meteorological Office – the only part of the regime at Kew that could be called the work of a government observatory.

[12] Moseley (1978), pp. 237-238.

With this multiplicity of activities, the diversification of the observatory sciences at Kew reached its peak in the late 1860s. After 1871, the transfer of the observatory to the Royal Society and the consequent lack of money reversed this trend by forcing Kew to become more specialised. Solar physics at Kew all but disappeared. Kew remained the Meteorological Office's central observatory, which standardised the instruments for the Office's other observatories, but from 1876 it no longer directed the observations. From then onwards, the balance of power in this regard lay firmly with the Meteorological Office, as shown in Chapter 5. Geomagnetism remained important at Kew, which was used as a base station for magnetic surveys and was still a place where other observatories – overseas as well as British – sent their instruments to be tested and their personnel to be trained in their use. Yet as with meteorology, Kew no longer led the work, which increasingly came to be directed by university physicists. As discussed above, Kew came to rely on the income from standardisation, which became its speciality. The worse the financial situation became at Kew, the greater the range of instruments that began to be standardised there. Prominent among the list of instruments tested at Kew in the last three decades of the nineteenth century were clinical thermometers, instruments quite unconnected with the observatory sciences hitherto practised at Kew, yet which brought in essential income thanks to the lucrative medical instrument trade.

This move towards specialisation at Kew in the last quarter of the nineteenth century mirrored a trend that also occurred at the Greenwich and Paris observatories at the same time. Mid-nineteenth-century Greenwich, with its own large Magnetic and Meteorological Department, in addition to its chronometer testing programme, itself had a diverse programme of work in addition to astronomy. Yet meteorology was a relatively minor department at Greenwich by the end of the century; by then, too, the nerve centre for French meteorological observations was a separate observatory – partly modelled on Kew – at Montsouris and not the old Paris Observatory, as had been the case when Le Verrier was director (see Chapter 4, Section 4.5). Kew did not just follow these trends. It was a major and active part of this changing dynamic in British national scientific institutions; indeed, events at Kew helped to cause some of these changes, as the tussles between Airy and Kew in the 1870s demonstrates. Until the 1870s, for all Airy's dislike of Kew as a centre for magnetic, meteorological and solar observations, there was little he could do about it. Only with the changed financial situation at Kew after 1871 (and after he had replaced Sabine as President of the Royal Society) did Airy have his chance to transfer the solar observations to Greenwich. By this time, however, even Airy was unable to seize the meteorological observations from Kew, as these were now firmly under the direction of the Meteorological Office. Neither Kew nor Greenwich could control the meteorological observations: a separate, specialist institution now oversaw them. Thus Kew became largely a specialist organisation in its own right: by the end of the 1880s, it was effectively a national standardisation laboratory. By 1900, different institutions specialised in just one of the observatory sciences carried out at Kew before 1871: Greenwich did astronomy (including solar physics), the Meteorological Office ran the meteorological observations and Kew was the undisputed centre for instrument standardisation.

We can draw two conclusions from this overall trend towards specialisation at Kew. First, it was encouraged by the ideological climate of *laissez-faire*, which persisted despite all the controversy over the Devonshire Commission in the 1870s. After 1871, Kew needed to make money from standardisation, as there was now no annual grant from the BAAS and little government money. At the same time, as shown in Chapter 5, Airy's moves to take possession of the Kew photoheliograph undercut the Devonshire Commission's proposal for a new, government-sponsored solar physics observatory that might rival Greenwich. Thus Airy was able to manipulate *laissez-faire* to his advantage: by appearing to save the taxpayer money, he could stop his rivals from usurping his position as 'national observer'. David Aubin's assertion that the mid-nineteenth century was a time of crisis for observatories, in which they initially had to take on an increasing range of sciences before being forced to specialise (Chapter 1, Section 1.1), seems to be borne out by the experience at Kew. Yet he backs up his assertion with too much reliance on the French experience of state-run observatories. More room needs to be given to the British story, in which *laissez-faire* was central to the 'crisis'. Secondly, the prominence of Kew Observatory in the overall move towards specialisation in the various national institutions carrying out 'observatory sciences' – astronomy at Greenwich, meteorology at the Meteorological Office and standardisation at Kew – means that Kew needs to be taken much more seriously when writing a narrative of the development of the observatory sciences in nineteenth-century Britain. The story is not simply about Greenwich. As Robert Smith has noted (see Chapter 1, Section 1.4), more studies are needed that compare Greenwich with other observatories.

Perhaps more precisely, we could say that more studies are needed of Greenwich as part of the wider world of observatory sciences in the nineteenth century.

3) How did standardisation develop at Kew in the context of the culture of the physical sciences between 1840 and 1900?

I have argued in Chapter 3 that by the late 1850s, standardisation at Kew was an essential service – to the London instrument trade and private devotees of science as well as government departments. The establishment of the Meteorological Department of the Board of Trade in 1854 certainly helped Kew, in the sense that the Department was a large and regular customer for standardised instruments for use aboard ships. Yet Kew was also an essential help to the Meteorological Department, in that it provided the instruments needed for Robert FitzRoy's weather reports. In the same decade, the standardisation service also became important to observatories and administrations across the British Empire; it was even recognised by foreign observatories and governments. After 1871, the financial constraints facing Kew not only compelled it to rely on standardisation as a source of income: Kew, in turn, became indispensable to its expanding customer base which, as described above, diversified into ever more types of instruments. By the early 1890s, in addition to the Meteorological Office, other government departments and the London instrument makers, clients for Kew's services included the medical instrument trade and the watch and chronometer industry. Moreover, the same service at Kew proved essential to the physics professors who managed the new university teaching and research laboratories that sprang up from the 1860s onwards. By the early 1890s, the prestigious Cavendish Laboratory and even the related Cambridge Scientific Instrument Company were clients for the service at Kew.

Thus by 1891, when Oliver Lodge proposed a national laboratory for testing instruments and determining standards, there was already a national standardisation laboratory that did a substantial part of the work of the institution that Lodge was calling for. This was admitted five years later in the BAAS report on the proposed laboratory, which noted that the work at Kew was of a type 'strictly consistent with a large portion of the work which would find a place in a national physical laboratory'.[13] As noted in Chapter 6 (Section 6.5), Kew was the largest standardisation laboratory in the British Isles and the one that did the widest range of work. Some work in electrical standardisation was done at the Cavendish Laboratory and in the Board of Trade's electrical standards laboratory, but these places were small and specialised. If anywhere was *the* place for general instrument standardisation, it was Kew Observatory.

7.4 Conclusions and suggestions for further research

It is clear from my findings in answer to the three questions above that Kew Observatory was an essential part of the culture of the physical sciences in the Victorian era – a part hitherto under-recognised by historians. Also under-recognised is its importance in the origins of the National Physical Laboratory. Indeed, the most striking aspect of the standardisation programme is the *continuity* between Kew and the NPL throughout the period. Right through the history of Kew from 1840 onwards, we can trace early ideas for what we can now recognise as a kind of national standardisation laboratory. Charles Wheatstone's 1842 prospectus for Kew suggested that it be used as a centre for comparing instruments (Chapter 2, Section 2.5). In 1848, Francis Ronalds suggested that Kew could be taken over by the government as a 'Proving House' for testing and comparing meteorological instruments (Chapter 3, Section 3.2). Even phrases similar to 'national physical laboratory' had long been in existence by the 1890s. For example, the phrase 'physical observatory' was first used by David Brewster in the 1830s (Chapter 2, Section 2.2) and in 1850 Roderick Murchison wrote to Herschel about Sabine's idea that a good use for the new Royal Society Government Grant might be to run 'a good national Physical Observatory' at Kew (Chapter 3, Section 3.2). Even Lodge's 1891 speech only used phrases like 'physical laboratory' and 'Physical Observatory': the exact phrase 'National Physical Laboratory' was only first used a year later (Chapter 6, Section 6.4).

Thus when the NPL began work in 1900, Kew Observatory, the 'nucleus' around which the NPL was built, already had a long history. As I have argued above under question 1, the NPL evolved fully within the prevailing *laissez-faire* ideology,

[13] Anon. (1896), p. 84.

as a modest 'extension' of Kew Observatory. This did not immediately change after Kew became the NPL. The early NPL's low staff salaries, and the expectation that it should be at least partly self-supporting through standardisation fees,[14] was a continuation of the same funding environment in which Kew had operated ever since the 1840s. Furthermore, even the apparently generous initial government spending on the NPL – £12,000 for initial capital expenditure, plus an ongoing grant of £4,000 per annum thereafter – was not entirely without precedent: even in the 1870s, Greenwich Observatory was receiving nearly £7,000 per annum from the government and the Meteorological Office £10,000.[15] Viewed in this context, the 'extension' of Kew Observatory in 1900 was modest indeed. With regard to the physical sciences – including the observatory sciences and standardisation – *laissez-faire* persisted to 1914. Only after 1914, with the exigencies of total war and the subsequent formation of the DSIR, would this situation begin to change.[16] From the arguments presented in this thesis in the framework of the above three questions, we might assert that the establishment of the NPL at Kew Observatory in 1900 was not an early triumph of the state over *laissez-faire*, but more one of the last triumphs of the *laissez-faire* system in the patronage of science.

This study raises a host of further research questions related to Kew Observatory itself – for example, the interaction of Kew Observatory with the scientific instrument trade, something that this institutional history has only touched upon. Most exciting of all, however, are the broader issues in the historiography of the physical sciences that this study has raised. It is clear from the preceding chapters that historians need to take Kew Observatory much more seriously as a substantial, active component in the story of the physical sciences in nineteenth-century Britain. For example, the narrative of Kew's transformation into the NPL has emphasised the need to move away from the heavily Cavendish-centred historiography of British physics around 1900.[17] At the same time, we can detect a clear need for a more balanced historiography of astronomy and the other observatory sciences, one less heavily centred on Greenwich than has hitherto been

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[14] Moseley (1978), esp. p. 249.
[15] Anon. (1875), pp. 49-50; also cited in Anderson (2005), p. 141.
[16] Hull (1999), esp. p. 480.
[17] This need has been noted by Hughes (2005), esp. p. 299, who has argued convincingly that much else was going on in British physics at the turn of the twentieth century and that the Cavendish Laboratory was not necessarily central to its development.

the case.[18] Secondly, this study has underlined the importance of researching the *unpublished* primary sources, not just the published documents. Unpublished sources are essential to discovering how the actors themselves, whatever their social standing or scientific prominence, saw the practice of science. Minutes and especially letters not intended for publication – including insightful off-hand comments, such as William Spottiswoode's crossed-out remark that Kew was 'a private establishment not a public one' (Chapter 5, Section 5.6) – can give a very different, yet much fuller picture of the workings of nineteenth-century science. Thirdly, the striking continuity between Kew Observatory and the NPL, both of which institutions had to work within an unchanged *laissez-faire* political environment, contrasts starkly with the idea of the NPL as a break from the *laissez-faire* past and therefore suggests a need to look for more continuities between the science of the nineteenth century and that of the twentieth. The simplistic, presentist picture of a haphazard Victorian science being unproblematically replaced by a twentieth-century model of professionalised and generously government-supported science – such as that portrayed by Russell Moseley for the NPL[19] – needs to be critically reassessed and revised. Above all, the new insights described under the three great questions above surely demonstrate the value of studying scientific institutions as a whole and not just individual aspects of them, as has hitherto been the case with Kew. We need more book-length histories of scientific institutions that challenge existing assumptions about these institutions.

[18] Smith (1991), p. 18.
[19] Moseley (1976); Moseley (1978).

Appendix

Chairmen of the Kew Committee, 1846-1900

British Association for the Advancement of Science

June 1846 – April 1850	John Frederick William Herschel
April 1850 – May 1850	Roderick Murchison
May 1850 – May 1853	William Henry Sykes
May 1853 – July 1871	John Peter Gassiot

Royal Society

July 1871 – June 1883	Edward Sabine
June 1883 – April 1889	Warren De La Rue
April 1889 - December 1899	Francis Galton

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