‘Imitable Thunder’: the role of gunpowder in seventeenth-century experimental science

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Abstract

The role of gunpowder as a military propellant has been widely studied. Less well understood, however, is its important role in seventeenth-century experimental science. Francis Bacon (1561-1626) called it 'imitable thunder', a designation indicative of its manifestation of nature's occult powers.

In the subsequent promotion of an experimental philosophy grounded on Bacon's demands for a union of theory and practice, gunpowder appears frequently in experiments, discussions and controversies among Bacon's followers. This thesis focuses on the transference of gunpowder from the battlefield to the laboratory. The Baconians re-valued and redefined it as an inquisitional material.

To get to grips with the complex nature of this transition, the approach taken here fuses intellectual history, materials history, and the reworking of historical experiments. This integration reflects the Baconian call for a union of theorising and experiment. It also highlights how common substances could be reconfigured as scientific materials.

Furthermore, this thesis demonstrates the diversity of Baconian endeavours to transfer gunpowder from the battlefield to the laboratory. There was little coherence among putative Baconians. While Bacon and Boyle saw gunpowder as a means to understand and appropriate the occult powers of matter, many fellows of the early Royal Society were more concerned to exploit gunpowder's explosive energies for more immediate fruits. For them, harnessing the power of gunpowder symbolised the usefulness of natural inquiry and hence a valued role for the nascent Royal Society itself.

Thus, locating gunpowder's role in early modern science illustrates the programmatic, inquisitional, and symbolic roles of an everyday, but hugely powerful material. Moreover, this focus on gunpowder offers further exploration of early modern Baconian cultures of experiment, as well as valuable insights into efforts to implement Bacon's project. Last but by no means least, gunpowder illustrates the benefits for historians of science of reworking historical processes and experiments.

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Author’s Declaration

This thesis is my own work, and explicit reference has been made to the contribution of others. This thesis has not previously been submitted for examination at the University of York or any other institution.

Introduction

> to investigate the nature of this awful ingredient, by which the fate of empires is decided in our days, cannot be indifferent to any body who takes delight in investigating natural causes.[1]

This thesis explains how Francis Bacon (1561-1626) and his followers in the early Royal Society sought to establish gunpowder as a tool for natural inquiry. The supporters of the Baconian method, which was characterised by a blend of scholarly theorising and practical investigation, were convinced of gunpowder's natural philosophical potential. It was employed profusely in their experiments, and it fulfilled a broad range of speculative and practical functions. The capacity of gunpowder to embody a wide range of experimental pursuits, and to tackle pressing questions in early modern natural philosophy, meant that the substance found itself playing an important and multifaceted role in the development of experimental philosophy in seventeenth-century England.

The subject of this thesis is a material substance. Gunpowder is a simple but potent mixture of three natural ingredients: saltpetre, charcoal, and sulphur.[2] John Bate in 1634 described the composition, poetically stating that 'the Saltpeter is the Soul, the Sulphur the Life, and the Coales are the body of it.'[3] The three components are usually mixed to a ratio of 75:15:10 or 6:1:1.[4] On ignition, this basic composition

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[1] John Ingen-Housz, "Account of a New Kind of Inflammable Air or Gass, Which can be Made in a Moment without Apparatus, and is as Fit for Explosion as Other Inflammable Gasses in Use for That Purpose; Together with a New Theory of Gun-Powder," *Phil Trans* 69 (1779), 376-418, on 380.

[2] Saltpetre is also known as 'nitre,' and now as 'potassium nitrate'. For a brief overview of the chemistry of gunpowder, see: Joseph Needham, *Science and Civilisation in China. Vol. 5 Chemistry and Chemical Technology, Part 7: Military Technology; The Gunpowder Epic* (Cambridge: Cambridge University Press, 1986), 108-11. For a more detailed exposition on gunpowder chemistry, see: Captain J. P. Morgan, "The Determination of the Explosive Force of Gunpowder," *Royal United Services Institution* 15 (1871), 312-37; Captain Noble and F. A. Abel, "Researches on Explosives – Fired Gunpowder," *Phil Trans* 165 (1875), 49-155; *idem.,* "Researches on Explosives. No. II. Fired Gunpowder," *Phil Trans* 171 (1880), 203-79; Oscar Guttmann, *The Manufacture of Explosives* (London: Whittaker and Co., 1895).

[3] John Bate, *The mysteryes of nature and art* (London: 1634), 55.

[4] This ratio normally correlates to saltpetre, charcoal and sulphur respectively. This composition is the standard one that would be used in most muskets. For different weapons, such as pistols or large artillery, the composition and grain size would vary. For a good contemporary source on gunpowder compositions, see: Nathaniel Nye, *The Art of Gunnery* (London: 1647). For example, Nye tells us that cannon require a coarser grain powder mixed to 4:1:1 for maximum efficacy, 7-9. It is not within the scope of this thesis to go into detail about the nature of gunpowder making. For a useful overview of

generates huge effects. In a compact space, such as a gun barrel, the powder will violently explode. As argued by John Ingen-Housz in the epigraph, the fact that such a simple mixture could unleash such massive power with the addition of just one spark was bound to rouse the interests of natural philosophers. Gunpowder was both awesome and awful. It inspired awe and admiration, but was simultaneously terrible and dread inducing. As such, commanded a profound respect from natural philosophers.[5]

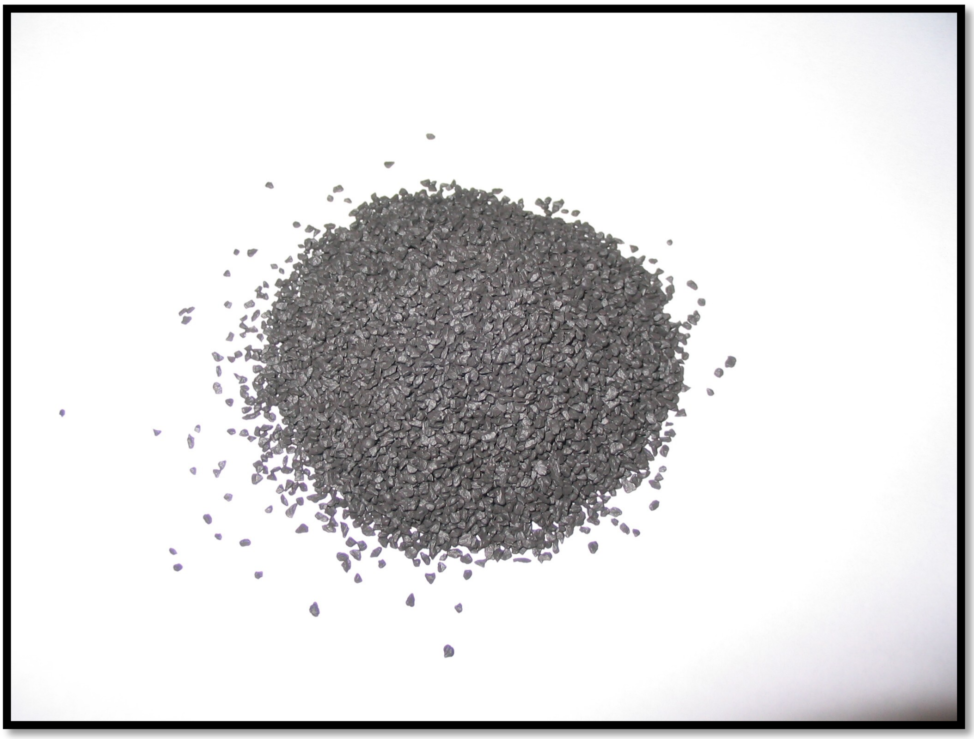

Figure 1: Loose gunpowder

the procedure, and the terminology associated with gunpowder, gunpowder-making, and gunnery, see: E. M. Patterson, "A Gunpowder Vocabulary," *Industrial Archaeology Review* 8 (1986), 215-16; Bert S. Hall, "The Corning of Gunpowder and the Development of Firearms in the Renaissance," in *Gunpowder: The History of an International Technology,* ed. Brenda J. Buchanan (Bath: Bath University Press), 87-120; Robert A. Howard, "Realities and Perceptions in the Evolution of Black Powder Making," in *Gunpowder, Explosives and the State: A Technological History,* ed. Brenda J. Buchanan (Aldershot: Ashgate, 2006), 21-41.

5 At this stage it is worth making a note on terminology. Throughout the thesis I will primarily employ the more correct term 'experimental philosophy'. In order to avoid excessive repetition, however, I also employ the word 'science'. In Chapter 2 I refer to 'chemistry' for simplicity, but I am aware that this term was not one that was used by the early moderns who sometimes preferred 'chymistry'. On terminology and the fact that chemistry and alchemy were not distinct disciplines in the early modern era, see: William R. Newman and Lawrence Principe, "Alchemy vs. Chemistry: The Etymological Origins of a Historiographic Mistake," *Early Science and Medicine* 3 (1998), 32-65.

Alchemists in ninth-century China discovered gunpowder; by accident rather than by design.[6] From the East, it gradually made its way to Europe. In the mid-thirteenth century English Monk Roger Bacon described gunpowder's effects, possibly after observing Chinese firecrackers.[7] In 1326 a council decree in Florence described cannons and cannonballs, and twenty years later at the Battle of Crécy (France) the first use of guns in European warfare was documented.[8] The mythology that grew to surround gunpowder's origins embraced the material as the product of chance, rather than genius. A prime example of a fabricated origin story is that Freiburg monk and alchemist Berthold Schwarz, or 'the Black Berthold', accidentally created the explosive concoction.[9] That such a simple chemical composition, one that was discovered accidentally no less, could have such devastating and useful powers, was of interest to natural philosophers. It was one of nature's most potent curiosities, and one well worth investigating.

The study of materials in the history of science can be analytically useful. For example, Anna Marie Roos successfully demonstrates that salts played a fundamental

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[6] On gunpowder's Chinese origins and discovery, see: Needham, *Gunpowder Epic,* 1-2. For a detailed account on the discovery of gunpowder in China and the nature of its journey to the battlefield, see: J. R. Partington, *A History of Greek Fire and Gunpowder* (Baltimore and London: The Johns Hopkins University Press, 1999 originally published 1960). A challenge to the common claim to Chinese origins for gunpowder is made by Asitesh Bhattacharya, "Gunpowder and its Applications in Ancient India," in *Gunpowder, Explosives and the State: A Technological History,* ed. Brenda J. Buchanan (Aldershot: Ashgate, 2006), 42-50. Bhattacharya bases this conclusion on the fact that ancient Sanskrit texts allude to projectile weapons, as well as the knowledge that the three necessary ingredients were available in India at the time.

[7] It is evident that Roger Bacon had observed gunpowder in the mid-thirteenth century, but he was not the inventor of it in Europe. On Roger Bacon's description of a gunpowder explosion see: Needham, *Gunpowder Epic,* 47-50; Partington, *Greek Fire and Gunpowder,* 64-87. A claim that Roger Bacon invented gunpowder was made by Colonel H. W. L. Hime, "Roger Bacon and Gunpowder," *Roger Bacon Essays,* ed. A. G. Little (Oxford: Clarendon Press, 1914), 321-35, on 334. The claim is thoroughly debunked by Lynn Thorndike, "Roger Bacon and Gunpowder," *Science* 42 (1915), 799-800. Bert S. Hall provides a critique on Partington's treatment of Roger Bacon and Albertus Magnus, a contemporary figure credited with writing down observations on gunpowder, "Introduction, 1999," in Partington, *Greek Fire and Gunpowder,* xxiii-xxv. Hall is primarily critical of Partington's faith in Hime's reconstruction of Bacon's supposed gunpowder formula. He demonstrates problems with the claim, including the fact that Hime's gunpowder recipe had not nearly enough saltpetre to produce an explosion.

[8] For a comprehensive timeline on the introduction and use of gunpowder, see: Stephen R. Bown, *A Most Damnable Invention: Dynamite, Nitrates, and the Making of the Modern World* (St. Martin's Press: New York, 2005), ix-xiv. On the early Florentine cannon and the documented use of guns at the Battle of Crécy: Partington, *Greek Fire and Gunpowder,* 101-08.

[9] Partington, *Greek Fire and Gunpowder,* 91-97. Partington scathingly describes the legend: 'Black Berthold is a purely legendary figure like Robin Hood (or perhaps better, Friar Tuck); he was invented solely for the purpose of providing a German origin for gunpowder and cannon, and the Freiburg monument with the date 1353 for his discovery rests on no historical foundation,' 96.

role in the emerging chemistry of the early modern period.[10] Jan Golinski has studied phosphorus, a material that fascinated the early Royal Society.[11] He argues that its novelty status made phosphorus instrumental in the developing public science espoused by the nascent institution. Ursula Klein and Wolfgang Lefèvre have studied materials in eighteenth-century science prolifically, demonstrating their significance and varying roles in the developing chemistry of the period.[12] They argue that the processes of identification and classification are singled out as central to contemporary ontologies of materials. In the aforementioned studies, we are not only provided with critical accounts of the significance of particular materials and the interactions surrounding them. These materials are also used to shed light on bigger and related issues in early modern philosophy.

By giving gunpowder the same sort of analysis we can enhance our understanding of: the nature of the theory/ practice divide in seventeenth-century experimentalism, the contrast between Bacon and Baconianism, and the significance of materials in the history of science. Gunpowder and its components were subject to many experiments and theoretical musings, but they were so much more than simple curiosities. The related experiments and discussions clearly had a high status and important role in the changing natural philosophy of the seventeenth century, and can reveal much about its nature. Thus it is highly unusual that gunpowder's relationship with early modern natural philosophy has not been the subject of more analysis.

Chemical materials such as gunpowder are valuable in the study of the history of science. They offer insight into a diverse range of themes and phenomena. Gunpowder had a presence both in the world of the natural philosopher and the typically unlearned artisan. Gunpowder has obvious social, militaristic, and technical facets, but it also commanded scientific interest both in terms of utility, and in experimental and theoretical reflections of matter. To genuinely meet Bacon's utilitarian requirements, science had to move out of the study and into the field, in the case of gunpowder, literally. In the case of Robert Boyle (1627-91) and the fellows of

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[10] Anna Marie Roos, *The Salt of the Earth: Natural Philosophy, Medicine, and Chymistry in England, 1650-1750* (Leiden, Boston: Brill, 2007).

[11] Jan V. Golinski, "A Noble Spectacle: Phosphorus and the Public Cultures of Science in the Early Royal Society," *Isis* 80 (1989), 11-39.

[12] Ursula Klein and Wolfgang Lefèvre, *Materials in Eighteenth-Century Science: A Historical Ontology* (Massachusetts: Massachusetts Institute of Technology, 2007).

the Royal Society however, gunpowder would then need to make a further move into the laboratory or experimental space—building on the knowledge acquired from the speculative and operative experiences gained along the way.

I argue that the Baconians brought gunpowder into the experimental world. For some, such as Boyle, this was a laboratory.[13] For Bacon this was a world of detailed practical observations that incurred detailed thought experiments. The Royal Society engaged in public experimentation. They all used experiment to pull gunpowder from the military sphere into the scientific one, in order to configure gunpowder as a means of research. They could use gunpowder to inquire into nature for knowledge, or with practical benefits in mind.

We are used to thinking about gunpowder as a source of blasting power, used primarily for military purposes. It can be difficult to divorce gunpowder from the military apparatus that gives its name to the substance. Yet the 'gun-' prefix corresponded to only one of gunpowder's many potential applications.[14] Kelly DeVries states that 'from the beginning of its known existence in Europe, gunpowder was considered an entirely separate entity from the device which used it to propel projectiles against an enemy.'[15] If we approach gunpowder first and foremost as a

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[13] The terms 'Baconian' and 'Baconianism' typically refer to the natural philosophers that took it upon themselves to conduct natural philosophy in the manner, or a variation of the manner, outlined by Bacon. The main work on Baconianism on the period post-Bacon's death and prior to the establishment of the Royal Society is: Charles Webster, *The Great Instauration: Science, Medicine and Reform* (London: Duckworth, 1975). On the Royal Society (and its fellows) and later, see: Rose-Mary Sargent, "Robert Boyle's Baconian Inheritance: A Response to Laudan's Cartesian Thesis," *Studies in the History and Philosophy of Science* 17 (1986), 469-86; Richard Yeo, "An Idol of the Market-Place: Baconianism in Nineteenth Century Britain," *History of Science* 23 (1985), 251-98; William T. Lynch, *Solomon's Child: Method in the Early Royal Society of London* (Stanford: Stanford University Press, 2001).

[14] Gunpowder's common applications, outside of the battlefield, included mining and fireworks. On gunpowder's use in mining see: R. Burt, "The international diffusion of technology in the early modern period: the case of the British non-ferrous industry," *Economic History Review* 44 (1991), 257-59; Graham Hollister-Short, "Gunpowder and mining in sixteenth- and seventeenth- century Europe," *History of Technology* 10 (1985), 31-66; *idem.,* "The Introduction of Powder," *Bulletin of the Peak District Mines Historical Society* 12 (1994), 148-49; Raffaelo Vergani, "The civil uses of gunpowder: demolishing, quarrying, and mining (15th-18th centuries). A reappraisal," (2009), trans. Gabriel Walton. Published in Italian in *Economia ed energia. Secc. XIII-XVIII. Atti della XXXIV Settimana di studi dell'Istituto internazionale di Storia economica* "F, Datini," Prato, April 15-19 2002, ed S. Cavaciocci, Florence, 2003, 865-78. Fireworks, normally made by gunners themselves, were another common way to utilise gunpowder. Early modern sources on fireworks include: Nye, *Art of Gunnery*, 79-97; Bate, *mysteryes,* 32-99. On the role of fireworks in early modern science and society the definitive source is: Simon Werrett, *Fireworks: Pyrotechnic Arts and Sciences in European History* (Chicago and London: University of Chicago Press, 2010).

[15] Kelly DeVries, "Gunpowder and early Gunpowder Weapons," in *Gunpowder: The History of an International Technology,* ed. Brenda J. Buchanan (Bath: Bath University Press, 1996), 121-36, on 123.

chemical material, as opposed to 'that powder which is in use for guns,'[16] we can see it in an illuminating new light. We can see another side to its persona: philosophical gunpowder.[17]

The Role of Gunpowder in Seventeenth-Century Experimental Philosophy

Taking its cue from Roos's book on salts,[18] this dissertation demonstrates the importance of a material through a series of case studies. Each case shows us a different way that gunpowder was employed and approached in the context of seventeenth-century Baconian experimental philosophy. Although there were shared commonalities among the early virtuosi their differences along with their diverse agenda are quite revealing. We will see, for example, how Bacon and Boyle each had distinct ideas concerning the employment of gunpowder for advancing knowledge, whereas a good many members of the early Royal Society exploited its status and notoriety to promote a programme of utility and social relevance. In exploring this wide-ranging series of experiments and discussions centred on gunpowder, we shall see how the Baconians envisioned it diversely as a natural philosophical tool. We also get a sense of the diverse manner in which the Baconian ideal was realised in the second half of the seventeenth century, and how some of the Baconians departed from the more demanding specifications of Bacon's programme for the sake of a more immediate payoff.

The central argument of this thesis is that gunpowder played an important role in the nascent experimental sciences of the seventeenth century owing to its reconfiguration as a tool for inquiry. It was able to function in programmatic, inquisitional, and symbolic capacities. The volume of gunpowder experiments in the context of the developing Baconian philosophy is enough to render gunpowder

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[16] Thomas Browne, *Pseudodoxia Epidemica, The Second Book, in Sir Thomas Browne's Works: Including his Life and Correspondence*, Vol. 2, ed. Simon Wilkin (London: Pickering, 1835), 344.

[17] Inspired by Werrett, *Fireworks*, who discusses 'philosophical fireworks' to refer to the alchemical and natural philosophical interest in fireworks in late-eighteenth century Russia, 200ff.

[18] Roos, *Salt of the Earth.* Roos offers a series of case studies pertaining to the role of salts in, for example, matter theory, natural history, medicine, and the development of chemistry. These case studies blend together seamlessly to produce a wide-ranging and compelling case for the formative role of salts in the development of early modern chemistry.

significant. When we consider in detail the gunpowder experiments—their motivations, functions, and impact—we see that gunpowder was an important part of the formation of the new experimental philosophy. It was a powerful example of what nature had to offer when studied according to the new sciences. Its powerful properties highlighted to its employers that gunpowder could do much more than bring down enemy soldiers. Gunpowder's power could potentially be harnessed to advance theoretical knowledge as well as extend a new range of practical uses.

The first aim of this thesis is to locate and define the role of gunpowder in seventeenth-century experimental science. We find gunpowder at the heart of high-level discussions, and sometimes in heated conflicts, among Bacon, Boyle, the Royal Society virtuosi and their adversaries. In each of the case studies that follow, gunpowder had something specific to offer its practitioners. More generally, gunpowder facilitated experimental inquiry into nature's most potent phenomena. Bacon and the Baconians employed gunpowder to deliver blows to opposing schools of scientific thought, which they perceived as incapable of explicating this common yet little understood material.[19] They sought to demonstrate that experiment would lead to a better understanding of one of nature's most powerful instances, which in turn could lead to major advancements in knowledge and technology. Furthermore, in its newfound capacity as philosophical material, gunpowder was intimately connected to theories of matter. Gunpowder was a potent manifestation of matter's capabilities, thus contributing to inquiries into the fundamentals of nature.

Secondly, I interpret the complex history of the gunpowder experiments of Bacon and his followers. In doing so, I aim to shed new light on the contrast between Bacon and Baconianism in the seventeenth century. Through his writings on the topic Bacon set the groundwork for a series of experiments with gunpowder amongst the followers of his method. I explore the nature of the experiments, and the motivations behind them. Comparing the gunpowder efforts of Bacon, Boyle, and the early Royal Society, highlights that there were different ideas concerning what it meant to be Baconian to the early modern experimentalists. The most revealing contrast is

[19] The natural philosophy taught in the universities in the early modern period was overwhelmingly scholasticism/ Aristotelianism; a speculative mode of inquiry based largely on the work of Aristotle and the 'ancients'. On scholasticism and the emergence of experimentalism, see: Steven Shapin, *The Scientific Revolution* (Chicago: University of Chicago Press, 1996), 141; Richard Jones, *Ancients and Moderns: a study of the rise of the scientific movement in seventeenth-century England* 2nd edn (St Louis: Washington University Press, 1961); Allen G. Debus, *Man and Nature in the Renaissance* (Cambridge: Cambridge University Press, 1978), 101-30.

between those who concentrated on what Bacon termed experiments of fruit or *experimenta fructifera*, that is, experiments seeking utility, and experiments of light or *experimenta lucifera,* those experiments designed for seeking knowledge.[20] In Bacon's understanding of inquiry, the two were intimately connected but ultimately some philosophers were more interested in one than the other. Charting the manifold uses of gunpowder in the following case studies offers a window through which the historian can observe the nature of the Baconianism as enacted by Boyle and the Royal Society. These case studies explore some of the reasons behind these often widely diverging interpretations of Bacon's proposals.

As a third and final aim, the thesis seeks to promote a methodology for conducting research on materials in the history of science that incorporates traditions of experimental archaeology. Reworking some of the experiments and practices at the heart of this thesis allows us to literally get to grips with the material in question. It shows us the diverse nature of gunpowder as a substance with many hats. One of the most important observations for this thesis was the result of reworked experiments. When we work practically with gunpowder in a laboratory setting we see just how many functions it embodies. We are reminded that gunpowder is a chemical material, and that gunnery is just one way in which this chemical material has been appropriated. Additionally, we are also reminded of the importance of the sheer physicality and demanding practical side of natural inquiry.

In the course of this thesis I am dealing with the uses of gunpowder in seventeenth-century Baconian natural philosophy. As such, here it is necessary to provide a brief overview of Bacon's vision for the reform of the sciences. Bacon's projections for a useful science would be built upon a 'marriage' of theory and practice.[21] This union of the operative and the contemplative is captured in Bacon's well-known maxim 'knowledge is power'. Bacon aimed to go beyond the scholastic

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[20] Francis Bacon, *Novum Organum,* in *The Oxford Francis Bacon,* Volume XI, ed. Graham Rees (Oxford: Clarendon Press, 2004), 157. *Experimenta fructifera* and *experimenta lucifera* are concepts laid out by Bacon in the *Novum Organum.* The former are experiments that lead to more immediate and practical gains, whereas the latter contribute to inquiry into knowledge of causes. It was the latter that Bacon prioritised, as only when nature and matter is properly understood, could the knowledge be applied to marvellous effect. Hereafter, *The Oxford Francis Bacon* will be abbreviated to *OFB.*

[21] For references to the Baconian method as a 'marriage' see: Paolo Rossi, "Bacon's Idea of Science," in *The Cambridge Companion to Bacon,* ed. Markku Peltonen (Cambridge: Cambridge University Press, 1996), 25-46, on 30; Sophie Weeks, "The Role of Mechanics in Francis Bacon's *Great Instauration,*" in *Philosophies of Technology: Francis Bacon and his Contemporaries,* ed. Claus Zittel *et al.,* (Leiden and Boston: Brill, 2008), 133-96, on 137; Benjamin Farrington, *Francis Bacon: Philosopher of Industrial Science* (London: Lawrence and Wishart, 1951).

methods of learning that were based on speculation and book learning, and thus were inherently incapable of making any practical improvements to the condition of mankind. Practical observation combined with scholarly theorising, thought Bacon, was the key to revealing nature's secrets. This knowledge in turn could be applied to the production of works.

Baconian inquiry demanded a collaboration of practical mechanical knowledge and scholarly intellect, which would meet in experiment.[22] The mechanical arts and experiment offered the Baconian investigator the opportunity to bring nature's hidden processes to the surface. An absolutely essential requirement in getting nature to reveal its hidden powers was the manipulation of material stuff. Thus operation must, if inquiry is to be systematic, take its rightful place along with contemplation. Operation is the core of a Baconian conception of experiment. If genuine knowledge is to be had then matter has to be reconfigured. If that is not done no amount of contemplation can reveal nature's secrets.[23] It is a major claim of this thesis that experiment is an essential component in Baconian induction, the approach used by Bacon to establish nature's axioms.[24] This method is 'applied to all stages of knowledge, and at every phase the whole process has to be kept in mind'.[25] As Michel Malherbe describes it:

> Knowledge starts from sensible experience, rests upon natural history which presents sense data in an ordinate distribution, rises up from lower axioms or propositions to more general ones, tries to reach the more

[22] On Bacon's projected experimental method and goals for natural philosophy: Rossi, "Bacon's Idea of Science"; Michel Malherbe, "Bacon's Method of Science," in *Cambridge Companion to Bacon,* ed. Markku Peltonen (Cambridge: Cambridge University Press), 75-98; Weeks, "Mechanics," 134-35. Weeks presents a detailed account of the role of mechanics in Baconian inquiry, the ultimate goal of which was to reach natural magic that would utilise knowledge of forms to produce marvels and works. She argues that '[m]echanics is indispensable in the pursuit of magic because it is essentially experimental,' 135.

[23] An alternative reading presents Bacon's experiment as the 'torture' of nature: Carolyn Merchant, "'The Violence of Impediments': Francis Bacon and the Origins of Experimentation," *Isis* 99 (2008), 731-60, on 732-33 n 3; *idem.,* "Francis Bacon and the 'vexations of art': experimentation as intervention,' *British Journal for the History of Science* 46 (2013), 551-99. Arguing fervently against this reading, is: Peter Pesic, "Wrestling with Proteus: Francis Bacon and the 'Torture' of Nature," *Isis* 90 (1999), 81-94; *idem.,* "Proteus Rebound," *Isis* 99 (2008), 304-17.

[24] A more detailed account of Baconian induction can be found in: Mary Hesse, "In Defence of Francis Bacon: A Criticism of the Critics of the Inductive Method," *Studies in the History and Philosophy of Science* 4 (1973), 241-78.

[25] Malherbe, "Bacon's Method," 76.

> fundamental laws of nature (the knowledge of forms) and, from there, by a practical deduction, derives new experiments or works.[26]

These 'practical deductions' are essential in the overall scheme of Baconian induction, and as we can see from the foregoing, inquisitional success relies on a fruitful union of hand and mind.

Gunpowder experiments were used to generate both knowledge and works. Harnessing its energy for a variety of practical uses was of course an interest for the early moderns, but following Bacon they also recognised that it could give light and direction to inquiry. Bacon saw experiments of light as more noble than experiments of fruit, but understood that even they would terminate in utility as the most important result of the knowledge generated.[27] Gunpowder's utility was obvious, but Bacon encouraged his followers to look beneath the surface. Employing gunpowder in light bearing experiments was important in recasting gunpowder as a vehicle of inquiry. To show gunpowder's ability to shed light on important natural philosophical questions would also allow the early moderns to distance the material from the unsurprisingly horrendous, often superstitious, and generally negative associations that it sometimes incurred.

Gunpowder Scholarship: war and science

Gunpowder has attracted considerable scholarship owing to its centrality in military affairs from the medieval period onwards. This thesis, however, is concerned with the natural philosophical applications of gunpowder. There are only a handful of historical studies that venture into this territory. Alfred Rupert Hall's influential *Ballistics in the Seventeenth Century* (1952) considers some of the Royal Society's gunpowder experiments as part of his study claiming that there was not much synthesis between science and military practice in the early modern period.[28] More

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[26] Malherbe, "Bacon's Method," 76.

[27] Bacon, *OFB,* XI, 157.

[28] Alfred Rupert Hall, *Ballistics in the Seventeenth Century: a study in the relations of science and war with reference principally to England* (Cambridge: Cambridge University Press, 1952). See also his associated paper: *idem*., "Gunnery, Science, and the Royal Society," in *The Uses of Science in the Age of Newton*, ed. John G. Burke (Berkeley: University of California Press, 1983), 111-41. Hall's study does however go much wider than gunpowder to consider internal and external ballistics. An alternative viewpoint is provided by Catherine France, *Gunnery and the Struggle for the New Science (1537-1687)*, unpublished PhD thesis (University of Leeds, 2014). She demonstrates cogently that rather than gunnery being used as an attempt to gain patronage as Hall would argue, work on ballistics

recent studies have begun to build a counter-argument to Hall's thesis. *The Heirs of Archimedes* (2005), edited by Brett D. Steele and Tamera Dorland, is an excellent volume containing chapters concerned with the connections between science and the 'art of war'.[29] They focus mostly with the ways in which science benefited military practice, arguing that scientific ingenuity advanced various fields of military technology. In the third section of the book, on the manufacture of gunpowder, we see that by the late-eighteenth century, chemistry, sometimes state sponsored, did help powder makers improve their methods.

For example, the contribution to *The Heirs of Archimedes* from Brenda Buchanan, a main authority on gunpowder in early modern England, discusses 'the 'art and mystery' of making gunpowder.'[30] She explores the development of English gunpowder manufacturing, paying attention to the rules of the workmen, and to the role of the Board of Ordnance in advancing military science from 1660. She argues that gunpowder making moved from being an artisan practice shrouded in mystery to a more industrialised scientific process in the mid-eighteenth century. Buchanan's own excellent edited volumes, *Gunpowder: The History of an International Technology* (1996) and *Gunpowder, Explosives and the State: a technological history* (2006) are also concerned with the development of gunpowder making and aspects of its military applications.[31] They span the development of gunpowder technology with a wide geographical scope.

There are many more good accounts on the history of gunpowder, some touching on scientific considerations, even if only briefly. Richard Crozier has provided a history of guns, gunpowder, and saltpetre.[32] Jack Kelly's *Gunpowder: Alchemy, Bombards, & Pyrotechnics* (2004) is a biographical account of gunpowder

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goes hand in hand with the emerging theory and practice relationships of early modern science, and that the work on ballistics had genuine programmatic aims.

29 Brett D. Steele and Tamera Dorland (eds), *The Heirs of Archimedes: Science and the Art of War through the Age of Enlightenment* (Cambridge, Mass: Massachusetts Institute of Technology, 2005).

30 Brenda J. Buchanan, "'The Art and Mystery of Making Gunpowder': The English Experience in the Seventeenth and Eighteenth Centuries," in *The Heirs of Archimedes: Science and the Art of War through the Age of Enlightenment*, eds. Brett D. Steele and Tamera Dorland (Cambridge, Mass: Massachusetts Institute of Technology, 2005), 233-74.

31 Brenda J. Buchanan (ed.), *Gunpowder: The History of an International Technology* (Bath: Bath University Press, 1996); *idem*. (ed.), *Gunpowder, Explosives and the State: a technological history* (Aldershot: Ashgate, 2006).

32 Richard D. Crozier & The Faversham Society, "Guns, Gunpowder and Saltpetre: A Short History," *The Faversham Papers* 58 (1998), 1-91.

and explosives.[33] He argues that gunpowder and pyrotechnics were fundamental in the making of the modern world. He briefly considers early modern scientific interactions with explosives, claiming that gunpowder affected how some scholars thought about the world, and particularly about fire.[34] One of the most useful biographical accounts of gunpowder is Robert Douglas Smith's *Rewriting the History of Gunpowder* (2010).[35] This practical account of gunpowder's history details the trials of the Medieval Gunpowder Research Group in its endeavours to investigate medieval gunpowder technology by re-creating it. In this work we get a sense of what it may have been like to make and work with gunpowder in the past, and the particular challenges and nuances that accompanied it. It demonstrates the practicality of gunpowder and the complexities of handling it, that few other studies are able to grasp.

From the standpoint of the history of science, gunpowder has also been of some interest. James Riddick Partington's well-known *A History of Greek Fire and Gunpowder* (1960) considers the chemistry of its eponymous subjects, as well as their applications.[36] Indeed Bert Hall's introduction to the 1999 edition of the book describes Partington's effort as 'very much a chemist's history of gunpowder'.[37] Yet although a more 'scientific' account, it is still concerned with gunpowder's origins and procurement, as opposed to making any developed claims on the impact of gunpowder on early modern science. By far the most detailed work solely devoted to gunpowder is Joseph Needham's aptly named *The Gunpowder Epic* (1986).[38] Part of his mammoth *Science and Civilisation in China* series, Needham delivers an in-depth study of the Chinese origins and uses of gunpowder through to the black-powder age of military technology. He also goes further than other studies in considering its major contribution to a specific topic in early modern science. In the final chapter on peaceful and industrial uses of gunpowder, he argues that late-

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33 Jack Kelly, *Gunpowder. Alchemy, Bombards, & Pyrotechnics: The History of the Explosive that Changed the World* (Massachusetts: Basic Books, 2004).

34 Kelly, *Gunpowder,* 109-17. Kelly's discourse on gunpowder and fire pertains to the theories of the 'aerial nitre' and 'flamma vitalis' which we shall encounter in chapters 2, 3, and 5.

35 Robert Douglas Smith, *Rewriting the History of Gunpowder* (Nykøbing, Denmark: Middelaldercentret, The Medieval Centre, 2010). Although very useful, this book is in limited publishing/circulation.

36 Partington, *Greek Fire and Gunpowder*.

37 Bert S. Hall, "Introduction," in *Greek Fire and Gunpowder,* xv-xxxiv, on xxvii.

38 Needham, *Gunpowder Epic*.

seventeenth century engines using gunpowder's energy as a source of motive power were instrumental in the development of the steam engine.[39]

Getting much closer to the issues taken up in this dissertation, and recognising some of the things that gunpowder could contribute to experimental knowledge production, is Robert Frank in *Harvey and the Oxford Physiologists* (1980).[40] Frank's subject is respiration and the air, as studied by William Harvey and the Oxford Group in the mid-seventeenth century. Within his wider analyses, Frank recognises the important role of gunpowder, and its oxidising component saltpetre, in generating knowledge about respiration. He analyses Robert Boyle's and Robert Hooke's (1635-1703) experiments with gunpowder *in vacuo* that studied the necessity of the air to respiration and combustion.[41] He considers what it was that made gunpowder an important conduit for research, and the properties it brought to the vacuum-pump experiments. On a similar topic, Douglas McKie's work looks exclusively at the Boyle and Hooke vacuum experiments, inclusive of their work on gunpowder and saltpetre.[42] He uses these experiments to explore the developing chemical knowledge and method of the period, in particular, pertaining to combustion and respiration.

The above historiography takes us closer to a natural philosophical analysis of gunpowder in the early modern period. It was inevitable that natural philosophers should eventually incorporate gunpowder and its marvellous properties. It had become one of the tri-partite symbols of technological advancement, along with the printing press and mariner's compass. This model of technological 'progress' has caught the attention of Roy S. Wolper.[43] He argues that although gunpowder was by some early moderns considered a symbol of technological advancement, many struggled to reconcile this with the fact that it was so horrendously destructive. He gets to the heart of the paradox of gunpowder. It was an incredibly powerful substance and to have brought it under, to some extent, human control, to exploit its

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39 Needham, *Gunpowder Epic,* 525-79. This claim will be discussed in Chapter 5.

40 Robert G. Frank, *Harvey and the Oxford Physiologists* (Berkley: University of California Press, 1980).

41 Frank, *Oxford Physiologists,* 115-39, 221-74. Frank's work is more concerned with saltpetre than gunpowder, but is nonetheless a very useful account of how both materials could be incorporated into the field of research in respiration and combustion.

42 Douglas McKie, "Fire and the Flamma Vitalis: Boyle, Hooke and Mayow," in *Science, Medicine and History: Essays on the Evolution of Scientific Thought and Medical Practice written in honour of Charles Singer*, Vol. 1, ed. E. Ashworth Underwood (Oxford: Oxford University Press, 1953), 469-88.

43 Roy S. Wolper, "The Rhetoric of Gunpowder and the Idea of Progress," *Journal of the History of Ideas* 31 (1970), 598-98.

energy in combat, fireworks, and mining, was a remarkable achievement. Yet there was no escaping that its primary employment was to destroy. When we consider the horrific connotations of gunpowder, as Wolper has done, we can see why the early moderns were so keen to keep gunpowder's origin story as one of discovery rather than invention. Although Wolper does not venture into the ways that gunpowder was scientifically useful, the points he raises about notions of progress and gunpowder's inherent challenges are valuable. His account, emphasising that gunpowder holds a complex position in early modern considerations of progress, highlights the importance of the substance not only to the early modern state, but also to philosophers of nature.

The crucial but complex role of gunpowder can be further explored in David Cressy's recent *Saltpeter: The Mother of Gunpowder* (2013).[44] Cressy's focus is saltpetre, not gunpowder—and this is an important distinction to make. Saltpetre was known for its role in gunpowder, but it had a natural philosophical life of its own outside of this. Cressy's interest in saltpetre is mostly derived from its essential role in making gunpowder. He argues that saltpetre had a central role in the formation of the early modern world, showing that the substance had several overlapping spheres of influence—military, political, economic, and scientific. Cressy reminds us of the necessity of gunpowder and its high status in our period of study. That saltpetre and gunpowder had such extensive networks was, I argue, important in informing the decision of some of the Baconian scholars to study the materials. As a symbol of technological advancement and simultaneously a state necessity, gunpowder was a medium through which early experimentalists could prove their relevance and utility. There were few chemical substances more socially and politically relevant than gunpowder in the seventeenth century.

An excellent example of the recent attention given by historians to gunpowder and related subjects is Simon Werrett's *Fireworks* (2010).[45] Again, gunpowder is not the main focus, but it is not possible to research the history of fireworks without some consideration of the substance that makes them work. Further, as an historian of science, Werrett offers an approach more appropriate for comparison with this thesis.

[44] David Cressy, *Saltpeter: The Mother of Gunpowder* (Oxford: Oxford University Press, 2013).

[45] Werrett, *Fireworks.* See also: *idem.*, "Watching the Fireworks: Early Modern Observation of Natural and Artificial Spectacles," *Science in Context* 24 (2011), 167-82. Werrett also argues that audience engagement with pyrotechnic spectacle had a strong philosophical element, as fireworks could imitate natural phenomena and stimulate philosophical engagement.

He argues that through fireworks, collaboration between the arts and natural philosophy was facilitated. Fireworks are a means to study the locations of early modern scientific practice, and the elaborate and vital, but often occluded, interactions between natural philosophers and artisans. Most relevant to this dissertation is Werrett's second and third chapters concerned with the impact of fireworks on English natural philosophy.[46] He documents the increasing natural philosophical interest in pyrotechnics in the early modern era. Pyrotechnics were able to imitate natural effects, and produce great spectacle. They brought gunners, who made court fireworks, together with philosophy, as fireworks became part of magical and experimental procedures. Importantly, Werrett argues that the study of pyrotechnics could combat the accusations of religious enthusiasm that were often levied against the makers of fireworks. By shedding light on their natural causes, early modern natural philosophers explained these apparently miraculous phenomena and so some of the ignorant wonder and superstition could be neutralised.

An important piece of work on gunpowder in the history of science explores the role of the chemical revolution in transforming understandings of gunpowder. It picks up where I will leave off, with the Royal Society's endeavours to explain gunpowder's force in the very early years of the eighteenth century. Seymour H. Mauskopf looks at explanations of gunpowder in what is typically referred to as the 'chemical revolution'.[47] He argues that the chemical revolution starting in the late-eighteenth century and the development of the thermochemistry of Antoine Laurent Lavoisier were fundamental in transforming understandings of the detonation of gunpowder, which hitherto had been explained by means of a very different set of constantly evolving scientific ideas. Mauskopf's paper, though excellent, ignores the efforts of the seventeenth-century Baconians. Whilst, as we shall see, there was no overwhelming or radical changes made to gunpowder in this period, they did lay the groundwork for the aerial explanations of the chemical revolution that provide the starting point of Mauskopf's analysis. The efforts of Bacon and some of his followers were clearly focused on the nature of gunpowder's expansive energy on ignition. In proposing a historical thread connecting the experiments of the earlier period with the chemical revolution, this study offers a surprising background to Mauskopf's study.

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46 Werrett, *Fireworks,* 47-101.

47 Seymour H. Mauskopf, "Gunpowder and the Chemical Revolution," *Osiris* 4 (1988), 93-118.

The Baconians sowed the seeds of the more radical changes in gunpowder theory that occurred in the eighteenth and nineteenth centuries.

In extending our focus to wider themes in the study of early modern science, we should consider the literature concerning the interactions of craft practice and scholarly knowledge, and what has become a significant theme in early modern studies, viz., the relationship between theory and practice in the emergence of the new science. Gunpowder contributes to these developing studies by showing how practical observations and investigations of a material substance informed the production of knowledge for Bacon and his followers. Ursula Klein's and E.C. Spary's *Materials and Expertise in Early Modern Europe* (2010),[48] uses various materials as a way to investigate the connections between artisans and the developing experimental sciences in the early modern period. The essays in *The Mindful Hand* (2007) explore, in a wide variety of contexts, how early modern craft practices and manual labours contributed to the production of knowledge.[49] Pamela Smith's *The Body of the Artisan* (2004),[50] and Deborah Harkness's *The Jewel House* (2007),[51] also focus on the relationships between the production of knowledge and the everyday practices encountered in trades. These studies show how craft practices informed scientific method and knowledge, and how theory and practice came together with reference to craft or artisan technologies in the emerging experimental philosophy.

The literature relating to gunpowder, as we have just seen, is mostly focussed on its origins, manufacture, and procurement—all with an overwhelmingly military gloss. Naturally, there is a great deal to be said about these issues and it would be foolish to claim that military uses were only a minor part of gunpowder's history. However, the story of a philosophical gunpowder not only offers another aspect of the history of this substance. It also greatly expands our understanding of the material

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48 Ursula Klein and E. C. Spary (eds), *Materials and Expertise in Early Modern Europe: Between Market and Laboratory* (Chicago and London: University of Chicago Press, 2010). On the theory and practice relationship, see also: Pamela O. Long, "Power, Patronage, and the Authorship of *Ars:* From Mechanical Know-how to Mechanical Knowledge in the Last Scribal Age," *Isis* 88 (1997), 1-41. Long challenges Edgar Zilsel's view of the artisan being apart from elite culture, and explores the patronage of artisans and their elite connections.

49 Lissa Roberts, Simon Schaffer and Peter Dear (eds), *The Mindful Hand: inquiry and invention from the late Renaissance to early industrialization* (Amsterdam: Royal Netherlands Academy of Arts and Sciences, 2007).

50 Pamela H. Smith, *The Body of the Artisan: Art and Experience in the Scientific Revolution* (Chicago: University of Chicago Press, 2004).

51 Deborah E. Harkness, *The Jewel House: Elizabethan London and the Scientific Revolution* (New Haven & London: Yale University Press, 2007).

nature of experiment and of the significant interplay between theory and practice in the early modern period. Despite the large and diverse body of gunpowder experiments conducted in the seventeenth century, so far there is no study devoted to gunpowder's place in early modern experimental philosophy. This thesis should go some way to addressing this gap and make a contribution not only to the existing gunpowder literature, but also to the literature dedicated to the rise of early modern experiment.

The success of the aforementioned recent studies that focus specifically on aspects of gunpowder (in Cressy's case, gunpowder's majority ingredient and in Werrett's case, one of the primary applications of gunpowder) means that this is a good time to produce a work that is dedicated to early modern gunpowder itself.[52] This thesis, I argue, complements the work of Cressy and Werrett, as it provides another take on the significance of gunpowder and its related procedures in early modern natural philosophy.

We have seen above that some scholars have commented on gunpowder in the history of science. But in the main, the standard account of Hall is concerned principally with external ballistics and its relationships with mechanics and physics, and when it does treat explosives it has little to contribute on their role in the emergence of an experimental philosophy. Moreover, it remains connected to the military sphere, as does the work of Steele and Dorland, and Buchanan.[53] The latter studies do consider to some extent the impact that science had or did not have on the procurement and manufacture of gunpowder and gunpowder weapons. However, none of the works consulted consider in any significant way the importance of gunpowder as a scientific subject in its own right. Their primary interest lies in the gunpowder experiments that were conducted with military interests in mind. There were of course many experiments in this vein, but I argue that if we consider gunpowder as an experimental material, a substance that was studied for many reasons—military and otherwise—then we gain a fuller understanding of its potential for seventeenth-century natural inquiry.

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[52] Cressy, *Saltpeter*; Werrett, *Fireworks.*

[53] On the relationship between the Board of Ordnance and the Royal Society, both founded in 1660, see: Buchanan, "Art and Mystery," 254-64. Steele and Dorland, *Heirs of Archimedes,* look mostly on gunnery/ballistic development within the military sphere as opposed to any external scientific or philosophical influences. Hall, *Ballistics,* focuses on the relationship between science and war, asking how much the former affected the latter.

Cressy, Werrett, and Frank all look at aspects of gunpowder's natural philosophical uses, but they contextualise gunpowder within a much wider historical setting.[54] I focus exclusively on gunpowder experiments. This allows us to trace the evolution of gunpowder as a laboratory material throughout the seventeenth century. We see not just how it was used to address one or two specific questions in natural philosophy, but rather, we see how it addressed several major issues. We will see how different scholars in diverse locations and for very different reasons interpreted and employed gunpowder in the novel setting of the laboratory.

My approach to explicating the meaning and use of early modern gunpowder requires a fusion of intellectual history and materials history. This integration consciously reflects the Baconian integration of theorising and experiment. This approach offers a highly productive analytical framework that allows the historian to examine the historical transference of a common substance into a scientific material. The aim here is to delineate how gunpowder was re-valued and redefined as a laboratory chemical material. This integration of materials and intellectual history has necessitated the reworking of experiments to bring together the material and theoretical components. In combination, these normally independent approaches work together here to explain the revaluation of a common but powerful material into a laboratory and effectively a philosophical substance.

Roos has shown in detail how salts, materials normally regarded in commercial or industrial roles, had their own powerful persona in the world of alchemy and chemistry.[55] Her work explores the formative role of salts in early modern chemical theories of matter, natural history, and medicine. She demonstrates how a wide-ranging and increasingly sophisticated understanding of salts should be studied to shed light on evolving approaches to chemistry and natural philosophy. Golinski used phosphorus not only to comment on the interests and priorities of the Royal Society, but also on the status of chemistry among the fellows and the developing public face of natural philosophy. He argued that the novelty status of phosphorus made it an invaluable tool in garnering public support for the nascent

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[54] Cressy, *Saltpeter,* 26-29; Werrett, *Fireworks,* 73-101; Frank, *Oxford Physiologists,* 115-39, 221-74.

[55] Roos explains how much of the historiography of salts focuses on its commercial significance, 'concentrating on its production, consumption and trade,' *Salt of the Earth,* 4. The historiography of gunpowder, as I argue above, is similar in nature.

institution.[56] The work of Roos and Golinski, which integrates studies of chemical materials with wider themes and research in the history of science, has contributed significantly to the approach taken here. However, there is one significant difference between phosphorus and gunpowder.

In contrast to phosphorus, which begins life in the laboratory and moves outwards into industrial use, gunpowder is already in daily use when it moves into the laboratory. Gunpowder's route from the field to the laboratory bears a striking resemblance to Bacon's contemporary William Gilbert (1554-1603) who through a highly elaborate series of experiments in tandem with systematic and consummate theorising on a commonly available substance, made the loadstone a laboratory entity.[57] He drew on craft knowledge and technique to conduct natural philosophical inquiries into magnetism. The protagonists of this thesis took a common material with spectacular properties and inquired into it using the developing methods in natural philosophy that stressed the importance of both theory and practice.

In order to assess how gunpowder, a material substance, was employed in scientific pursuits, it is necessary to adopt a methodology that mirrors that of its early modern proponents and consequently combines theory and practice. As the practical observations and empirical studies of gunpowder were essential to its theoretical significance and interpretation, studying it practically can illuminate new avenues of inquiry. In collaboration with the Royal Armouries Museum (Leeds),[58] several carefully selected experiments were chosen for reworking.[59] Moreover, in order to get to grips with the tricky process of gunpowder making, saltpetre making in particular, I participated in on-going experiments with the Medieval Gunpowder Research Group, at The Medieval Centre in Denmark, to rework early modern processes of saltpetre making.[60] The methodology of reworking is presented in detail in chapter 3.

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[56] Golinski, "Phosphorus," 39.

[57] William Gilbert, *De Magnete (1600),* trans P. Fleury Mottelay 1893 (New York: Dover, 2013); Edgar Zilsel, "The Origins of William Gilbert's Scientific Method," *The Journal of the History of Ideas* 2 (1941), 1-32.

[58] The Royal Armouries, Armouries Drive, Leeds, UK.

[59] My use of the term 'reworking' as opposed to 'replication' is explained in Chapter 3.

[60] Middelaldercentret (The Medieval Centre), Ved Hamborgskoven 2, Sundby, L. 4800; Nykøbing-Falster, Denmark.

By taking an approach that emphasises materials, it will also be possible to comment more widely on the context of early modern gunpowder experiments. Aided by the reworking of experiments, we will explore gunpowder in experimental spaces where both theory and practice were required to generate knowledge and works. This thesis will contribute to on-going research on the relationship between theory and practice as it featured in early modern experimental science. Focussing on the synthesis of scientific theory and gunpowder during the early modern period provides an analysis that will yield new insights into the knowledge-power fusion, which characterised the rise of early modern science.

Chapter Outline

The thesis is divided into three main parts: the first deals with gunpowder and theorising; the second with the coming together of theory and practice; and the third with gunpowder and utility. This structure consciously echoes the Baconian programme and interpretations of it. Gunpowder could be used for theory and utility, but to produce either of these, it had to be studied in a union of theory and practice.

Chapter 1 argues that Francis Bacon employed gunpowder strategically in his projected reform of natural philosophy. Gunpowder had symbolic, inquisitional, and programmatic roles for Bacon. He used gunpowder to expound his own natural philosophy whilst delivering a devastating blow to scholasticism. Bacon was uninterested in improving the manufacture or procurement of gunpowder. Rather, he utilised gunpowder to serve his own natural philosophical goals. He saw gunpowder as one of the great works of nature; emblematic of the marvellous powers that lay hidden within matter. He aimed to neutralise its seemingly magical effects in order to show that great works were achievable if the correct methods are employed. Bacon wanted to reconfigure gunpowder as a site of knowledge. Owing to the futility of scholasticism, gunpowder stood alone as an example of a marvel, yet one discovered not systematically, but by chance. With Bacon's projected method, gunpowder, an already powerful manifestation of nature's possibilities, could soon find itself by other marvels that lay far beyond both human ability and human imagination.

The second chapter argues that Boyle brought gunpowder into the laboratory to configure it as a key component in his philosophising of chemistry, which was the core of his implementation of the Baconian method. He used gunpowder to contribute to an inquiry into fundamental causes. Gunpowder was now to be contemplated as well as simply utilised for its manifest power. Bacon introduced the idea of gunpowder being used for theorising, but Boyle fully, and literally, brought it into the laboratory and out of its usual domain. We will see how Boyle used gunpowder in explicating and exploring his corpuscular theory of matter. He planned to mechanise the hidden processes underlying gunpowder. His experiments aimed to reduce explanation to corpuscular structures. On that model he could explain why the ingredients of gunpowder do little separately but in combination they do a great deal. To do this he had to pull gunpowder into the laboratory. This simple but fundamental shift illustrates well Boyle's Baconian credentials.

In Chapter 3 we move from the theoretical world of gunpowder experiments into the sites where theory and practice combined. Using the process of making saltpetre, this chapter explores how theory and practice came together in the world of gunpowder research. We further see how the artisan-scholar relationship, a crucial component of the Baconian programme, played out. This chapter firstly presents a unique four-stage methodology for the replication or reworking of past experiments and processes. As a second aim, I consider the interactions surrounding gunpowder's majority ingredient, saltpetre. To do this, I draw on my experience in reworking early modern processes of saltpetre making. I show that reworking experiments gives us insight into the tacit knowledge that does not survive in our written sources.

Chapter 4 argues that a heated conflict over gunpowder in 1670 between the Royal Society and their virulent opponent Henry Stubbe, highlights the centrality of gunpowder to natural philosophy in that time. Moreover, having experienced first-hand the challenges of saltpetre making (Chapter 3), we are better prepared to understand the challenges and complexities of gunpowder making that was at the heart of the conflict. I argue that the Royal Society's decision to commission a 'Baconian history' of gunpowder tells us that gunpowder was to form an important part of its public persona. It wanted to demonstrate its relevance and utility, so it chose one of the most common, useful, and revered substances known at the time. The high status of gunpowder was used as a justification for experimental pursuits. Secondly, I argue that the stakes were much higher than the knowledge of gunpowder making. Both sides used gunpowder strategically in order to present their respective ideas of what the Baconian method should be. In this chapter we see that even in 1670, gunpowder had an important but contested status in natural philosophy. Its utility, and its ability to generate knowledge, was undeniable. Yet gunpowder brought particular challenges to the table, and these challenges are brought to the surface in this chapter.

The final chapter looks at the internal dynamics of the Royal Society's gunpowder experiments. I argue that gunpowder received a comparative lack of attention from the putative Baconians of the Royal Society. Their ignoring of gunpowder is made evident and glaring precisely because of gunpowder's prominent place in the publications analysed in Chapter 4. The material played a prominent role in the early Society's attempts to establish its public face and persona. Yet inside the lecture halls of the institution, the fellows did not quite know what to do with gunpowder. I argue that the case of gunpowder demonstrates the contrast between the vision of Baconianism presented by Bacon and Boyle (and the often neglected Hooke) and the more vulgar Baconianism enacted by the Royal Society. Secondly, I explore the reasons why gunpowder did not play a more prominent role in the emergent Royal Society in its founding decades. Based on earlier efforts, the Royal Society's lack of attention is indeed surprising and raises important historical questions relevant to its development. I argue that a blend of internal factors stemming from the nature of the Society's Baconianism, and pressing external factors, meant that the institution was not well-placed to continue to give gunpowder the high priority it had in Sprat's promotional efforts.

PART ONE: GUNPOWDER AND THEORISING

Chapter 1

Francis Bacon's Strategic Use of Gunpowder

> It is as if before the discovery of artillery someone had described the thing by its effects and put it in this way: that something had been discovered which would knock down and overthrow walls and the greatest fortifications from a long way off. This would surely have set people thinking about the many and various ways in which the powers of catapults and siege-engines could be multiplied by means of weights, gearing, and suchlike devices for ramming and smashing. But the idea of a fiery wind so suddenly and violently expanding and blasting forth would hardly have struck a man's imagination or fancy — which is to be expected when he had seen nothing resembling it, except perhaps in earthquakes, or lightning which, as magnalia naturae and beyond imitation, would have been dismissed out of hand.[1]

Introduction

This chapter argues that Francis Bacon employed gunpowder deliberately and strategically in his projected reform of natural philosophy. He drew frequently upon the example of gunpowder when explicating important aspects of his work, placing the substance in symbolic, inquisitional, and programmatic roles. Bacon did something with gunpowder that almost none of his contemporaries or predecessors had dared.[2] He took gunpowder out of its most obvious context—warfare—and reconfigured it as an essential tool for scientific inquiry. Gunpowder, for Bacon, was much more than the originator of the awesome blasting power found in artillery, mines, and fireworks. It was symbolic of the marvellous powers that lay hidden in nature, and it was an invaluable medium for studying these powers. Gunpowder was able to demonstrate Bacon's desired protocols of inquiry, as well as functioning as a source of potential knowledge.

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1 Bacon, *Novum Organum, OFB,* XI, 166-67.

2 A rare example of gunpowder being brought into a more philosophical environment pre-Bacon, is in Leonardo da Vinci's design for a gunpowder operated weight-lifting machine in 1508. The design ignited a small charge of gunpowder above a piston with an attached weight. On ignition, the gunpowder explosion caused the doors in the device to shut and create a vacuum that raised the piston and the weight below. On this design, see: Needham, *Gunpowder Epic,* 552-53.

Bacon's novel approach to gunpowder, as will be shown throughout the remainder of the thesis, was picked up enthusiastically by the followers of his method in the mid-late seventeenth century—none more so than Robert Boyle. Boyle fervently seized the idea that gunpowder could give direction to inquiry. The correspondents of the Hartlib Circle and the virtuosi of the early Royal Society, the subjects of later chapters, relished Bacon's emphasis on gunpowder as a tool for inquiry but focussed on the aspect of his programme that is generative of works, seeking new and exciting ways to study and exploit gunpowder's energy. Bacon's recasting of gunpowder as philosophically valuable was a crucial moment in defining gunpowder's role in seventeenth-century science.

Bacon studied gunpowder often but he did not advance any practical improvements. For this reason, Bacon features only sparsely in gunpowder's practice-oriented historiography.[3] Likewise, gunpowder does not feature in the Baconian secondary literature, bar the oft-quoted statement proclaiming that gunpowder, the compass, and the printing press were symbolic of mechanical achievement.[4] Werrett is one of few commentators who have recognised 'the importance [Bacon] placed on pyrotechnic arts in his discussions.'[5] Although interested primarily in fireworks, Werrett rightly connects gunpowder's effects to Bacon's natural philosophy. He observes that fireworks symbolised progression and the potential prosperity of the Baconian method. However there is much more to be said regarding Bacon's use of gunpowder. I argue that by bringing together the most important passages in which Bacon discusses gunpowder, we can see precisely what he envisioned for the material, and why it was important to him. Bacon was not interested in improving gunpowder, either in performance or procurement. Rather than serving gunpowder, Bacon utilised gunpowder to serve his own philosophical programme.

Firstly, I argue that Bacon understood gunpowder as an example of a *magnale* or great work of nature, and that it was his aim to restore gunpowder's status as a site

3 Examples of the wider gunpowder historiography making mention of Bacon include: Needham, *Gunpowder Epic,* 68 note e; Partington, *Greek Fire and Gunpowder,* 209. Both point to Bacon's mention of the presence of gunpowder in ancient India.

4 Bacon, *Novum Organum*, *OFB,* XI, 162.

5 Werrett, *Fireworks,* 167.

of marvellous effects.[6] As such, gunpowder took on a symbolic role for Bacon. Gunpowder was emblematic of matter's hidden potencies. In absence of the experimental method, however, these powers would remain beyond human ability and human imagination. He perceived that only by practical investigation into nature's causes, could matter truly be understood and harnessed.

As a second aim, Bacon sought to reconfigure gunpowder as a tool for inquiry. Gunpowder was, Bacon believed, a potent instantiation of his theory of matter based on configurations of motions. Bacon explains gunpowder in these terms, and uses gunpowder to render the theory intelligible. He envisaged matter as a labyrinth, and gunpowder could be used to navigate this labyrinth, leading the Baconian investigator closer towards the elusive knowledge of forms.[7] Bacon used gunpowder deliberately to show the inadequacy of the scholastic matter theory, and the superior efficacy of his own. Furthermore, as the scholastics had little interest in the empirical investigation of matter itself, gunpowder served as a direct illustration of the power and fundamental importance of matter.

In presenting gunpowder as a vehicle for theorising about fundamental natural philosophical issues, Bacon could neutralise it. Successfully explaining gunpowder's properties would remove it from the suspicions associated with magic and the realm of occult qualities. Gunpowder was miraculous, but it absolutely could not be seen as supernatural. It had various applications, and Bacon could turn gunpowder from something overtly practical to something with invaluable intellectual prowess. His theorising of gunpowder could demonstrate that natural causes, even the most common and unpleasant, could produce far more desirable magical effects.

Gunpowder as a Great Work

> Printing, a gross invention; artillery, a thing that lay not far out of the way; the needle, a thing partly known before; what a change have these three made in the world in these times; one in the state of learning, the

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[6] The *Magnalia* are listed in: Bacon, *Magnalia Naturae, The Works of Francis Bacon,* ed. James Spedding, Robert Leslie Ellis, and Douglas Denon Heath, Vols. 1-7 (London: Longman, Green, Reader and Dyer, 1859-64), Vol. III, 167-68. Hereafter this addition will be abbreviated to *SEH.*

[7] Weeks, "Mechanics," 138-40. Weeks discusses the analogy to both mechanics and matter as a labyrinth inclusive of complications, dead ends, and various routes leading towards the ultimate goal. See also: Peter Pesic, "The Clue to the Labyrinth: Francis Bacon and the Decryption of Nature," *Cryptologia* 24 (2000), 193-211.

> other in the state of war, the third in the state of treasure, commodities, and navigation. And those, I say, were stumbled upon and lighted upon by chance. Therefore, no doubt the sovereignty of man lieth hid in knowledge; wherein many things are reserved, which kings with their treasure cannot buy, nor with their force command; their spials and intelligencers can give no news of them, their seamen and discoverers cannot sail where they grow. Now we govern nature in opinions, but we are thrall unto her in necessity; but if we would be led by her in invention, we should command her in action.[8]

Bacon's first aim for gunpowder was to restore its status as a *magnale*. Attaining or inventing *magnalia* was the goal of Bacon's reform of the sciences.[9] He believed that his own method would lead to knowledge of forms, and that knowledge of forms would bring the motions of matter under human control.[10] Lisa Jardine maintains that forms are at the same time 'essential definitions of natural qualities, and *laws* or practical rules for producing such qualities'.[11] The knowledge of forms must be applied practically. Bacon thought that if natural philosophers really understood matter, then they would be able to manipulate it to make inventions and produce marvellous effects on demand. In Bacon's ontology, nature was full of unlocked potential whose benefits were currently beyond the human imagination, 'beyond our wildest dreams,' as Sophie Weeks puts it.[12] As we saw in the epigraph, gunpowder, prior to its chance discovery, lay far beyond human thought. As a rare example of an actual *magnale*, it signalled what matter could be made to do.[13]

With marvellous, useful and astonishing properties, gunpowder fulfilled a symbolic role in Bacon's *great instauration.* The discovery of gunpowder, along with the printing press and mariner's compass, had made a huge impact on the world, inducing 'innumerable changes, insomuch that no empire, no sect, no star seems to have exerted greater power and influence in human affairs than these mechanical discoveries.'[14] He wanted to demonstrate that although gunpowder had become an

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[8] Bacon, *Mr. Bacon in Praise of Knowledge,* in *The Letters and Life of Francis Bacon,* ed. James Spedding, Vols 8-14 (London: 1861-74), Vol VIII, 123-26.

[9] Malherbe, "Bacon's Method of Science," 76-77, claims that the main aim of Bacon's method was to 'answer the question of invention.'

[10] Weeks, "Mechanics," 114.

[11] Lisa Jardine, *Francis Bacon: Discovery and the Art of Discourse* (Cambridge: Cambridge University Press, 1974), 114-15.

[12] Weeks, "Mechanics," 192.

[13] Bacon, *Novum Organum, OFB,* XI, 166-67.

[14] Bacon, *Novum Organum, OFB*, XI, 162.

everyday occurrence, and although it was basic and somewhat unpleasant to handle, it was sufficient to produce huge effects and make real changes in the world. And yet its actualisation was owing to nothing more than chance.

Gunpowder, however, was only the beginning. It was symbolic of the inventions that could be attained if only the Baconian method was employed. As a great work, it was an example of the potential benefits of his mode of inquiry, and a means of simultaneously undermining competing natural philosophies. Bacon used gunpowder to contrast the marvels accruing from chance discovery with the complete failure of the scholastic tradition, for all its sophisticated methods, to generate a single marvel or useful effect. He used gunpowder strategically; he presented it as a symbol of what his natural philosophy could do, and what scholastic philosophy could not do.

The Discovery of Gunpowder

Bacon was aware of gunpowder's presence in ancient India, as explained below. Yet in the *New Atlantis,* when depicting the technologically and philosophically advanced fictional utopia *Salomon's House* in *Bensalem,* the narrator (a member of Salomon's House) proclaims 'your monk [Berthold Schwarz] was the inventor of ordnance and gunpowder.'[15] Salomon's House erected statues of important inventors; and of course the purported inventor of gunpowder would be more than deserving of being immortalised in stone. Despite its massive legacy, however, gunpowder was not strictly an invention. It was discovered by accident.[16]

Gunpowder came into the world as a ready-made *magnale*. It was not invented through knowledge of forms. As common as gunpowder was, in Bacon's time there was no real knowledge of its forms or causes. Bacon suggested that 'if gunpowder had been discovered, not by good luck but by good guidance, it would not

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15 Bacon, *New Atlantis, SEH,* III, 165-66. In spite of this proclamation, Bacon was aware of the presence of gunpowder or something similar in ancient India, as explained below. For more on the *New Atlantis,* see: Stephen A. McKnight, "The Wisdom of the Ancients and Francis Bacon's New Atlantis," in *Reading the Book of Nature: the other side of the scientific revolution*, eds. Allan G. Debus and Michael Thomson Walton (Sixteenth century journal publishers, 1998), 99-101; Bronwen Price (ed.), *Francis Bacon's New Atlantis: New Interdisciplinary Essays* (Manchester: Manchester University Press, 2002); William Eamon, *Science and the secrets of nature* (Princeton: Princeton University Press, 1994), 290-91.

16 Gunpowder's chance discovery is also mentioned in: Weeks, "Mechanics," 142-144; *idem. Francis Bacon's Science of Magic,* unpublished PhD dissertation (University of Leeds, 2007), 171-73; Werrett, *Fireworks,* 67.

have stood alone, but been accompanied by a host of noble inventions of a kindred sort.'[17] Bacon thought that his method would give rise to similarly powerful effects.

For such a powerful phenomenon to be discovered accidentally was hugely significant for Bacon. He used this chance discovery deliberately to attack the barren scholasticism, which he argued was incapable of producing works.[18] Unfortunately, chance was erratic and its findings were far too rare. In *Thoughts and Conclusions,* Bacon lamented that 'chance without doubt is a useful originator of things, but scatters her blessings on mankind only after tedious and tortuous wanderings.'[19] Nevertheless, gunpowder demonstrated that an unsystematic, random manipulation of materials was more effective than the most sophisticated methods that the scholastics had to offer. Bacon therefore argued that through employing the correct methods to gain knowledge of forms, *magnalia* comparable to gunpowder could be made deliberately. In his terms:

> Hence all the discoveries which we regard as more noble have (if you think about it) been brought to light not by minute elaborations and extensions of the arts but entirely by chance. And nothing anticipates or gets ahead of chance (whose custom is to work only over long ages) except the discovery of forms.[20]

Chance discoveries were not commonplace. Bacon urged scholars not to wait around for accidental discoveries. They had to use his method, or else be subject to the vicissitudes of time.[21] If something so powerful and useful could be discovered accidentally, then what could be discovered via systematic inquiry?[22]

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[17] Bacon, *The Masculine Birth of Time,* in *The Philosophy of Francis Bacon,* ed. Benjamin Farrington (Liverpool: Liverpool, University Press, 1964), 71.

[18] Paolo Rossi, "Bacon's Idea of Science," in *The Cambridge Companion to Bacon,* ed. Markku Peltonen (Cambridge: Cambridge University Press, 1996), 25-46, on 35.

[19] Francis Bacon, *Thoughts and Conclusions on The Interpretation of Nature, in The Philosophy of Francis Bacon*, ed. Benjamin Farrington (Liverpool: Liverpool University Press, 1964), 73.

[20] Bacon*, Novum Organum, OFB*, XI, 302-03.

[21] Malherbe, "Bacon's Method of Science," 76, stresses the importance for Bacon to make discoveries systematically, and the challenges associated with this. A prominent challenge to invention was the finding of things currently beyond human imagination precisely because they are beyond human imagination. It is hard to invent what one cannot foresee or envisage.

[22] Weeks, "Mechanics," 143, explains that Bacon conceived of gunpowder and such chance discoveries as existing, prior to discovery, near the 'surface' of nature (hence why it was able to be discovered accidentally). She quotes Bacon 'the rule is that what discoveries lie on the surface exert but little influence. The roots of things, where strength resides, are buried deep,' Bacon, *Cogita et visa,* in Farrington, *Philosopher of Industrial Science*, 93, cited in: Weeks, "Mechanics," 143.

Gunpowder is symbolic because it illustrates that even the chance uncovering of matter's potential has produced effects hitherto unconceivable.[23] Gunpowder's power was such that it resembled thunder and lightning. It demonstrated the marvels possible if only we understood nature: 'So that these times may justly bear in their motto not only plus ultra—further yet—in precedence of the ancient non ultra—no further; and "Imitable Thunder" in precedence of the ancient "Inimitable Thunder"'.[24] Gunpowder was Bacon's 'imitable thunder.'

Bacon also claimed that 'the wind made by the nitre mixed in gunpowder, that explodes and inflates the flame, not only imitates but exceeds all other winds, except those in thunderstorms.'[25] What nature produced only spontaneously, man could now produce on demand. Gunpowder generated noise as loud as thunder, and flashes as bright as lightning. The ancients could go no further with their methods, but with the correct methods natural philosophy had much to explore and much to achieve.[26] Gunpowder's massive physical power indicated how far nature could be pushed.

Bacon's effort to restore gunpowder as a *magnale* and object of study is evident in its inclusion in the *New Atlantis*.[27]

> We have also engine-houses, where are prepared engines and instruments for all sorts of motions. There we imitate and practise to make swifter motions than any you have, either out of your muskets or any engine that you have; and to make them and multiply them more easily, and with small force, by wheels and other means: and to make them stronger, and more violent than yours are; exceeding your greatest cannons and basilisks. We represent also ordnance and instruments of war, and engines

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[23] Antonio Pérez-Ramos, *Francis Bacon's Idea of Science and the Maker's Knowledge Tradition* (Oxford: Clarendon Press, 1988), 99, writes that 'Baconian science does not limit itself to the ordering of what *actually* exists in a correlation of alleged causes and effects. Rather, it envisages the fantastic projection of what is potentially amenable to existence once man gets operative insight into what exists in the present constitution of things. The Baconian practitioner, therefore, has to be provided with categories that would enable him to think and produce a *novum* in a way totally alien to the Aristotelian beholder.'

[24] Bacon, *De Augmentis, SEH*, IV, 311. Bacon was responding to Virgil (*De Aeneid*, Book VI, 590) 'Madman! to mimic the storm – clouds and inimitable thunder" cited in: Francis Bacon, *The Major Works,* ed. Brian Vickers (Oxford: Oxford University Press, 1996), 616, n 184.

[25] Bacon, *The History of the Winds, SEH*, V, 195.

[26] Werrett, *Fireworks,* 77. Werrett also takes Bacon's discussion of the 'imitable thunder' as demonstrative of the capacity of the new philosophy to surpass that of the scholastics. For a comparison of Bacon's natural philosophy to Aristotle's, see: William M. Dickie, "A Comparison of the Scientific Method and Achievement of Aristotle and Bacon," *The Philosophical Review* 31 (1922), 471-94.

[27] Bacon, *New Atlantis, SEH,* III, 119-66.

> of all kinds: and likewise new mixtures and compositions of gun-powder, wildfires burning in water, and unquenchable.[28]

The description of Bensalem's engines of war recalls Bacon's lament that if gunpowder had been discovered systematically, it would be surrounded by similarly important inventions. Gunpowder and related bodies in Bensalem were stronger, and the operator had more power over them. Its inclusion in the desiderata of the *New Atlantis* of 'instruments of destruction, as of war and poison,'[29] makes it clear that Bacon expected his successors to study gunpowder and other related phenomena.

Gunpowder's inherent challenges

Gunpowder's ubiquity was at odds with its marvellous effects. Yet Bacon drew attention to gunpowder's common and basic nature, and made its lowly status a central component of its philosophical persona. Gunpowder was a simple mixture of just three ingredients. The mixture can be messy, filthy, and unpleasant. Yet this simple concoction produced huge powers on ignition. Bacon makes the case, using gunpowder, for studying the everyday materials under our feet. Gunpowder is listed along with silk, the magnet, sugar and paper as examples of bodies evidencing that 'noble intentions may be lying at our very feet, and yet mankind may step over without seeing them.'[30] John Channing Briggs correctly notes that gunpowder is an example of a body deriving from 'easily ignored, lowly sources.'[31] Such common bodies can be useful and significant because they encourage the mind to extend its sense of what is possible and go beyond our pre-conceived ideas and expectations. Although important in early modern society, the ubiquity of these materials resulted in their becoming 'ordinary.'[32] According to Bacon, however, the most commonplace substances can produce miracles if matter's motions are sufficiently understood and manipulated.

Gunpowder also presented moral challenges to the Baconian investigator. War and destruction were integral components of gunpowder's public image. It had a

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[28] Bacon, *New Atlantis, SEH*, III, 163.

[29] Bacon, *New Atlantis, SEH*, III, 167.

[30] Bacon, *Novum Organum, OFB*, XI, 112-13.

[31] John Channing Briggs, "Bacon's Science and Religion," *The Cambridge Companion to Bacon,* ed. Markku Peltonen (Cambridge: Cambridge University Press, 1996), 172-99, on 185.

[32] Briggs, "Bacon's Science and Religion," 185.

massive destructive efficacy, and this association was difficult to combat. The *Daedalus* fable highlights the paradox of gunpowder, a substance integral to early modern culture yet very dangerous:

> The passages which follow concerning the use of mechanical arts are plain enough. Certainly human life is much indebted to them, for very many things which concern both the furniture of religion and the ornament of state and the culture of life in general, are drawn from their store. And yet out of the same fountain come instruments of lust, and also instruments of death. For (not to speak of the arts of procurers) the most exquisite poisons, also guns, and such like engines of destruction, are the fruits of mechanical invention; and well we know how far in cruelty and destructiveness they exceed the Minotaurus himself.[33]

Bacon was not opposed to gunpowder being applied in warfare per se. Indeed as we have seen, instruments of destruction are one of his *desiderata*. In the right hands, such instruments are necessary and valuable to human society.

He does make it clear however that there are moral choices to be made. Musing on the possibility of a silent gunpowder, Bacon called it ‘a dangerous experiment if it should be true: for it may cause secret murders,’[34] echoing Giambattista Della Porta who was similarly reluctant to reveal the secret of his own recipe for silent gunpowder ‘lest wicked men should take occasion to do mischief by it.’[35] This is the only occasion on which Bacon directly confronts gunpowder’s capacity to take human life, intriguingly adopting similar arguments to those modern opponents of silencers. Bacon’s philosophy was supposed to benefit humankind.[36]

Bacon also had to rid gunpowder of superstitious associations. *Magnalia* would be the fruits of Baconian natural magic.[37] However, Bacon’s magic was an ability to perform wonders based on knowledge of forms or causes. Bacon was fully aware of the significant problems with the tradition of Renaissance magic, and hence he sought to reform it.[38] His own brand of magic would produce miracles, in the

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[33] Bacon, *De Sapienta Veterum, SEH*, VI, 735.

[34] Bacon, *Sylva Sylvarum, SEH,* II, 392-93.

[35] Giambattista Della Porta, *Natural Magick* 1658 (New York: Basic Books, 1957), 292.

[36] Rossi, “Bacon’s Idea of Science,” 27.

[37] Sophie Weeks, “Francis Bacon and the Art-Nature Distinction,” *Ambix* 54 (2007), 117-45, on 117; *idem.*, *Francis Bacon’s Science of Magic*, 2-3.

[38] On Bacon’s natural magic see: Paolo Rossi, *Francis Bacon: From Magic to Science*, trans. Sacha Rabinovich (London: Routledge and Keegan Paul, 1968), who argues that magic was transformed by Bacon into Science; Weeks, *Francis Bacon’s Science of Magic*, convincingly argues that Bacon’s

sense of things deserving of wonder, but these miracles would be intelligible. Renaissance magic had traditions of both demonic and natural magic, but the former category tainted the latter. Stuart Clark provides an excellent overview on Renaissance natural magic, and explains Bacon's approach as 'recycling […] what had become a particularly popular scientific vocabulary in the cause of fundamental reform.'[39] Magical traditions by Bacon's time had become so immersed in nonsense and so plagued by fraud and suspicion that they muddy the waters for genuine inquirers. Bacon did not want to be tarred by this same brush.

Gunpowder was an example of natural magic. It allowed Bacon to demonstrate that magic could produce wonders whilst being at the same time completely explicable in terms of cause and effect (knowledge of forms): true knowledge overrides all superstitious and imaginary explanations. Bacon connected gunpowder to magic as follows: 'As for the Weapons, it hardly falleth under Rule and Observation; yet we see even they have Returns and Vicissitudes. For certain it is, that Ordnance was known in the City of the Oxydrakes in India; and was that which the Macedonians called Thunder and Lightning and Magick.'[40] The huge effects of gunpowder, unintelligible on the battlefield, resulted in its being perceived as magical. It was the failure to explicate occult causes that made effects seem miraculous, as traditionally if the cause is not intelligible or sensible, it renders the effect mysterious and supernatural. Bacon has no role for the supernatural yet his programme aimed at miraculous things.

Occult properties were an oft-chastised aspect of the scholastic philosophy, as they discouraged the study of causes. Brian Copenhaver uses the example of the torpedo fish to show how certain effects attributed to occult properties, typically considered magical, were 'de-mystified' by early modern natural philosophers.[41] According to Copenhaver, studying so-called occult phenomena and finding ways to explain them led to the 'decline of magic.'[42] These fish could stun those who came

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programme aimed to renovate a magic which had become corroded, superstitious, and problematic, rather than move from magic to science as Rossi suggests.

[39] Stuart Clark, *Thinking with Demons: the idea of witchcraft in early modern Europe* (Oxford: Oxford University Press, 1997), 214-32, on 224. On Bacon's view of the problems of natural magic that was viewed as suspicious and fraudulent, see: Rossi, *Magic to Science,* 10.

[40] Bacon, *Of the Vicissitudes of Things, SEH*, VI, 516.

[41] Brian P. Copenhaver, "A Tale of Two Fishes: magic objects in natural history from antiquity through the scientific revolution," *Journal of the History of Ideas* 52 (1991), 373-98.

[42] Hutchison, "Occult Qualities."

into contact with them, a property which natural philosophers struggled to understand. However, the emergent natural philosophies of the early modern era maintained that if their properties could be explained, then they would no longer be occult. Hutchison attributes the 'de-mystification' to the decline of Renaissance natural magic, and the emergent systems of inquiry in the seventeenth century.[43] Like Hutchison, Ron Millen argues that occult properties, rather than being banished by the early moderns, were incorporated as something to be explained.[44] He maintains that the 'difference between [occult qualities] and so-called manifest qualities lost its significance.'[45]

Gunpowder was Bacon's equivalent to the torpedo fish. Other authors, such as Agrippa and Pliny, referred to the torpedo fish as an example of occult or magical properties, whereas Bacon referred to gunpowder. Evolving theories of matter in the seventeenth century provided natural philosophy with explanations of occult causes. Theories of matter would look to invisible (hidden but not inexplicable) effects that, though not directly sensible, were present and the cause of specific occult effects.[46] For Bacon, occult powers were the hidden appetites of matter.[47] Matter's appetites, according to Bacon's ontology, were especially visible in gunpowder. For Bacon to remove gunpowder from occult associations, and to challenge the scholastic doctrine of the occult in general, he would need to make gunpowder's causes manifest and intelligible. To restore gunpowder as a *magnale* and to make it marvellous and non-occult, Bacon had to overcome all of the inherent challenges and associations that accompanied the material.

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[43] Keith Hutchison, "What Happened to Occult Qualities in the Scientific Revolution?," *Isis* 73 (1982), 233-253, on 398.

[44] Ron Millen, "The Manifestation of Occult Qualities in the Scientific Revolution," in *Religion, Science, and Worldview: Essays in Honour of Richard S. Westfall,* ed. Margaret J. Osler and Paul Lawrence Farber (Cambridge: Cambridge University Press, 1985), 185-216, on 216. Millen fundamentally agrees with Hutchison but goes further in suggesting that the scholastics were also engaged in this process of investigation. Also on occult properties, see: John Henry, "Occult Qualities and the Experimental Philosophy," *History of Science* 24 (1986), 335-81. Henry argues that the appeal to occult principles in matter was a way of understanding God's presence.

[45] Millen, "Occult Qualities," 216.

[46] Clark, *Thinking with Demons*, 228-32.

[47] On Bacon's matter as appetitive, see: Guido Giglioni, "Mastering the Appetites of Matter. Francis' Bacon's *Sylva Sylvarum,*" in *The Body as Object and Instrument of Knowledge: Embodied Empricism in Early Modern Science,* eds. Charles T. Wolfe and Ofer Gal (Netherlands: Springer, 2010), 149-67; Weeks, "Art-Nature Distinction," 7-8.

Gunpowder in Inquiry

Bacon's second aim with gunpowder was both programmatic and inquisitional. He aimed to reconfigure it as a tool of inquiry. Bacon saw in gunpowder a rare opportunity to delve into the hidden powers of matter that do not often make themselves present on the surface. Gunpowder was more than a military propellant, and importantly, gunpowder need not be commonplace, horrendous, or superstitious. Bacon used gunpowder as a source of potential knowledge. When theorising about matter, he drew regularly upon gunpowder. It was a potent instantiation of matter's hidden appetites in conflict with each other. In recasting gunpowder in this light-giving capacity, Bacon sought to de-mythologise it. He proved that gunpowder was worthy of study outside the context of artillery and destruction, and that its power was in accordance with the natural configurations of matter. Gunpowder could be used as a thread to navigate nature's labyrinth.

De-mythologising Gunpowder

As mentioned above, Bacon's attempt to de-mythologise gunpowder is especially evident in his discourse on the mysterious silent gunpowder. Bacon drew on references to a type of gunpowder that 'produces percussion without sound,' to 'discharge a piece without noise.'[48] This silent gunpowder appears to have been a well-known myth in the early modern era. Thomas Browne was among those pondering the 'white powder...discharged without report.'[49] Bacon and Browne understood silent gunpowder to be a white powder, which contrasts with Della Porta's silent gunpowder made by weakening the saltpetre with 'glew and butter of gold.'[50]

Silent gunpowder was conceptually interesting to Bacon. His suggestions regarding it were not entirely about producing the mute substance. He aimed to tackle this myth head on. Either he would uncover the recipe and produce the substance, or he would prove that the substance existed only in legend. The experiment further offered the opportunity to generate knowledge about how such a substance would operate or why it would not operate. Bacon described the powder as a 'conceit' that

48 Bacon, *Historia Soni et Auditus*, *SEH,* VII, trans. Sophie Weeks.

49 Browne, *Pseudodoxia Epidemica, Works of Browne*, II, 343-44.

50 Della Porta, *Natural Magick*, 292.

'runneth abroad' and seemed unconvinced by its existence.[51] Nevertheless, he began the experiment by explaining how silent gunpowder might work:

> It is certain that nitre, which is white, has the greatest power as regards an explosion, however in such a way that the swiftness of the ignition/catching fire greatly promotes percussion and sound; however a rapid ignition is caused above all from charcoal which is black, therefore if its composition is made up of sulphur and nitre and from a small bit of camphor, it can occur that the ignition is slower and the percussion not so jolting and sharp; and therefore there could be a great diminution/ loss of sound, but also together with a loss in the strength of the percussion.[52]

The silent gunpowder of legend was white in colour, so Bacon's first task was to consider the ingredients of gunpowder in appearance and function. The obvious ingredient to omit would be the black charcoal, which Bacon suggests may be replaced by camphor. He understood that the role of charcoal, which is highly flammable, is to provide speed to the ignition process. The problem now, was that the camphor would not give the swift reaction necessary to produce the desired effects. This mixture may produce quieter gunpowder, but it would lack power. Silent gunpowder, realised Bacon, would surely not be very good.

Returning to this matter of great interest in the *Sylva*, Bacon proposes that the silent gunpowder is 'not unpossible.'[53] Here he tackled the issue in more detail, delving further into the causes of the huge noise of artillery. The sound of guns firing is produced not by gunpowder, but by the percussion as the energy produced by the gunpowder is forced out of the barrel and clashes with the air outside. Bacon wrote that 'if the air pent be driven forth and strike the air open, it will certainly make a noise.'[54] He conjectured that there might be a way of 'discharging the pent air before it cometh to the mouth of the piece and to the open air.' [55] He then rejected this possibility, claiming that it would simply 'make more divided sounds: as if you should make a cross barrel hollow through the barrel of the piece […] both at the nose and the sides.'[56]

[51] Bacon, *Sylva Sylvarum*, *SEH,* II, 392-93.

[52] Bacon, *Historia Soni et Auditus, SEH,* VII, 662, trans. Sophie Weeks.

[53] Bacon, *Sylva Sylvarum, SEH,* II, 392-93.

[54] Bacon, *Sylva Sylvarum, SEH*, II, 392-93.

[55] Bacon, *Sylva Sylvarum, SEH,* II, 392-93.

[56] Bacon, *Sylva Sylvarum, SEH,* II, 392-93.

Deducing that the weapons, and not the powder, are the key to producing or removing the sound upon firing, Bacon proposed an experiment that could potentially lead to a modified weapon that would dampen the sound on ignition:

> But I conceive that if it were possible to bring to pass that there should be no air pent at the mouth of the piece, the bullet might fly with small or no noise. For first, it is certain that there is no noise in the percussion of the flame upon the bullet. Next, the bullet in piercing through the air maketh no noise, as hath been said. And then if there be no pent air that striketh upon open air, there is no cause of noise; and yet the flying of the bullet will not be stayed. For that motion (as has been oft said) is in the parts of the bullet, and not in the air. So a trial must be made by taking some small concave of metal, no more than you mean to fill with powder, and laying the bullet in the mouth of it, half out in the open air.[57]

The proposed experiment would fashion a semi-spherical device that would be filled with gunpowder, and a musket ball that would sit half-buried in the powder.[58] As the ball would not be discharged down the barrel, then the possibility of the clash in air-pressure would be removed and the sound diminished.

Bacon generated both potential practical gains and intellectual gains in this experiment. He thought carefully about the causes of noise and the salient effects of air on silent gunpowder. He realised that this was a fruitless endeavour as the cause of the noise of artillery is in the barrel of the weapon; he diverted attention away from gunpowder and towards the gun. Gunpowder's horrendous nature is as much to do with the physical instruments in which it is employed, as the gunpowder itself. De-mythologising the silent gunpowder of legend is an important case study in neutralising gunpowder. Bacon implied that gunpowder in and of itself need not be destructive. Furthermore, removing at least one type of gunpowder (the silent kind) from legend contributed to the effort to remove gunpowder from the world of occult properties.

Bacon realised that gunpowder could have applications beyond being a source of blasting energy. The effects that gunpowder is best known for arise when gunpowder is compacted and confined. Bacon observed:

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[57] Bacon, *Sylva Sylvarum, SEH,* II, 392-93.

[58] I envisage this as a stoned fruit, such as a peach, cut in half with the stone remaining in one half. The skin would be the metal semi-sphere, the flesh the powder, and the stone the musket ball.

> The force of this wind is compressed in machines made by man, as guns, mines, and powder magazines when they blow up. But whether a great quantity of gunpowder fired in the open air would likewise by the commotion of air raise a wind that would last for many hours, has not yet been tried.[59]

The fact that no attempt had yet been made to work with gunpowder outside of the confined spaces wherein it is normally compacted tells us that gunpowder, in Bacon's view, had more to offer to the inquirer. He hinted that outwith artillery, mining, and fireworks, gunpowder could still be useful. The silent gunpowder and the passages divorcing gunpowder from its customary home on the battlefield show that gunpowder's potential was not fully actualised. However, in theorising on why gunpowder could not operate silently, Bacon was forced to consider precisely how gunpowder worked, and how it worked in relation to artillery. Bacon confined silent gunpowder to mythology, but in the process, shed some light on why firing gunpowder makes a noise.

Gunpowder and Matter Theory

Gunpowder was employed by Bacon to comment directly on matter theory. Gunpowder could not only help explicate Bacon's ontology of motions, but it could also challenge the ineffective scholastic doctrine of matter. Bacon drew upon the fable of Dædalus who invented the labyrinth and the 'clue' to solving/navigating it.[60] The labyrinth represented both the complicated nature of matter, and of mechanics, whose forces were equally complex and difficult to explicate, yet whose powers were self-evident.[61] Experiments and artificial bodies could act as clues to the labyrinth of nature. They offered the chance to gain insight into natural processes. To really understand it, it was necessary to look to mechanics for examples of how nature operated.

It is worth restating Maxwell Primack's argument that 'unlike Aristotle, Bacon is not concerned to investigate the forms of different types of individual substances […] For him the prime objective of scientific investigation is the discovery of the forms of *properties* – yellowness, heat, cold, and the like. Bacon's

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[59] Bacon, *The History of the Winds, SEH*, V, 195.

[60] Bacon, *De Sapienta Veterum, SEH*, VI, 735.

[61] Weeks, "Mechanics," 138-40.

terms for such properties is "simple nature."'[62] Bacon studied gunpowder and other bodies specifically, but it was not necessary with the goal of studying individual things. Rather, he demonstrated interest in the causes of bodies like gunpowder owing to what they represented. He was studying the properties or simple natures of gunpowder, rather than the material itself. As a ready-made example of nature's *magnalia,* gunpowder was an ideal subject to act as a clue to unravelling nature's secrets.

Gunpowder, and mechanical bodies in general, represented a version of nature that had been 'bound' by human effort.[63] Considering Bacon's approaches to the artificial and to natural aids to human welfare helps to explain why gunpowder and mechanical contrivances could be used in inquiry. The 'art-nature distinction,' and whether Bacon did or did not collapse it, has been the subject of debate. William Newman argues that Bacon clearly distinguished between art and nature, and is critical of Paolo Rossi whom he claims proposes that Bacon collapsed the distinction.[64] Rossi, as explained by Weeks, in fact wrote that Bacon saw art and nature as being different in the cause, but not necessarily in the effect.[65] The more convincing approach taken by Weeks, using a detailed interpretation of Bacon's definitions of both art and nature, argues that Bacon did collapse the distinction.[66]

Matter, for Bacon, existed in two main states. Nature in its actual condition, following the path of least resistance, is 'nature free'. It takes art to manipulate matter to form 'nature bound' which represents the potential of matter.[67] Some bodies, such as gunpowder, require mechanical effort, or a binding of matter, to be formed.[68] Artificial and natural bodies are the same basic stuff, or motions, but artificial bodies are merely those that do not form naturally owing to the 'lazy' nature of free matter. To utilise Weeks's metaphor of 'enfolded matter,' the 'folds' contain 'the power to

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[62] Maxwell Primack, "Outline of a Reinterpretation of Francis Bacon's Philosophy," *Journal of the History of Philosophy* 5 (1967), 123-32, on 131-32.

[63] Weeks, "Mechanics," 138-40.

[64] William Newman, *Promethean Ambitions: Alchemy and the Quest to Perfect Nature* (Chicago: University of Chicago Press, 2005), 256-57.

[65] Rossi, *From Magic to Science*, 26; Weeks, "Art-Nature Distinction," 117-18.

[66] Weeks, "Art-Nature Distinction."

[67] Weeks, "Art-Nature Distinction," 130-36.

[68] Weeks, "Art-Nature Distinction," 133-34, explains the three categories of natural bodies as envisaged by Bacon. These include natural bodies, artificial bodies, and intermediates that can be produced either naturally or mechanically.

bring into being all potential worlds.'[69] Gunpowder, and mechanical arts, are emblematic of this 'unfolding.' 'Nature Bound' unleashes matter's hitherto unrealised potential. Gunpowder is a potent example of this.

Artificial bodies, the result of mechanics, owing to their ultimate reliance on natural forces, can be revelatory of nature's inner processes. For Bacon 'the history of Arts is of most use, because it exhibits things in motion, and leads more directly to practice [...] it takes off the mask and veil from natural objects, which are commonly concealed and obscured under the variety of shapes and external appearance.'[70] Artisans see a side to bodies that scholars do not. They have a transformative practical ability to rearrange matter to produce works.[71] With the projected Baconian knowledge-practice relationship, Bacon suggested the arts which may most usefully be explored are the ones 'which exhibit, alter, and prepare natural bodies and materials of things; such as agriculture, cookery, chemistry, dyeing, the manufacture of glass, enamel, sugar, gunpowder, artificial fires, paper, and the like.'[72] When nature's motions are bound, as in properly conducted experiments, they manifest in such a way that the human mind is given indirect access to the fundamental powers of matter, that are otherwise so complicated and intertwined that the mind is overwhelmed.

Gunpowder was highly compatible with Bacon's theory of matter. To assess precisely how gunpowder made manifest Bacon's ideas of matter it is first necessary to understand the basic principles in Baconian matter theory. Baconian matter is a complex and important subject, and has been explained in detail by Graham Rees.[73] Bacon adopted a bi-quaternion theory of matter resting on ideas of conflict between

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[69] Weeks, "Art-Nature Distinction," 124.

[70] Bacon, *Preparative Towards a Natural and Experimental History, SEH*, IV, 257.

[71] That is not to say that Bacon thought that manual workers were equal to scholars. As Farrington, *The Philosophy of Francis Bacon,* 53-54, explains, 'It is a complete mistake to think that he put the craftsman on the same level as the scientist. The purpose of the whole operation was to facilitate the emergence of science out of craft knowledge. The scientist, however, must be humble enough to understand that no degree of cleverness could compensate for the ignorance of particular facts. The most attractive theories must abide the test of experiment.'

[72] Bacon, *Preparative, SEH*, IV, 257.

[73] Graham Rees, "Francis Bacon's Semi-Paracelsian Cosmology," *Ambix* 22 (1975), 81-101; *idem.,* "Francis Bacon's Semi-Paracelsian Cosmology and the Great Instuaration," *Ambix* 22 (1975), 161-73; *idem.,*"Matter Theory: a unifying factor in Bacon's natural philosophy?" *Ambix* 24 (1977), 110-25; *idem.,"*Bacon's Speculative Philosophy" in *The Cambridge Companion to Bacon,* ed. Markku Peltonen (Cambridge: Cambridge University Press, 1996), 121-45.

bodies of opposing quaternions. All bodies fall into the categories of sulphur and mercury.

	SULPHUR QUATERNION	MERCURY QUATERNION
TANGIBLE SUBSTANCES (WITH ATTACHED SPIRITS)	Sulphur (subterranean)	Mercury (subterranean)
	Oil and oily inflammable substances (terrestrial)	Water and "crude", non-inflammable substances (terrestrial)
PNEUMATIC SUBSTANCES	Terrestrial fire (sublunar)	Air (sublunar)
	Sidereal fire (matter of heavenly bodies)	Ether (medium of heavenly bodies)

Figure 2: Bacon's bi-quaternion matter theory. Reproduced from Rees.[74]

In Bacon's view, bodies in the same sub-category would fight with their opposite in the other quaternion for dominance.[75] Bodies are produced on the principles of conflict and compatibility. This should not be confused with the Paracelsian sympathy and antipathy of which Bacon was highly critical.[76] Bacon's matter theory was an ontology of simple motions, which as discussed earlier, have appetites. Motions arise out of appetitive atoms and give rise to bodies as they intertwine with one another.[77] Within this tangle of motions there are manifold potentialities that can be accessed if the motions can be sufficiently recomposed.[78] As explained by William M. Dickie, 'just as a limited number of letters go to make up the infinite variety of words, so simple natures go to make up the infinite variety of natural phenomena.'[79]

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74 Table reproduced from: Rees, "Matter Theory,"113.

75 Rees, "Matter Theory," 114.

76 Rees, "Semi-Paracelsian Cosmology," 97-98, explains that the Paracelsian or alchemical sympathy and antipathy doctrine represented part of the natural magic tradition whereby 'natural objects possessed by virtue of their substantial forms inherent inclinations akin to friendship and enmity towards other natural objects', whereas Bacon saw bodily interactions across quaternions as resulting from configurations of motions which in some cases found a 'match' with each other that made them compatible or incompatible.

77 For a detailed exposition on Bacon's theory of matter as atoms and motions, see: Weeks, "Art-Nature Distinction," 123-27. See also: William M. Dickie, "'Form' and 'Simple Nature' in Bacon's Philosophy," *Monist* 33 (1923), 428-37.

78 Weeks, "Art-Nature Distinction," 125-26.

79 Dickie, "Aristotle and Bacon," 479.

Gunpowder's processes on ignition manifested Bacon's idea that matter is made up of conflations of motions in cooperation or conflict. Newman discusses processes of nature on the macro and micro levels,[80] and this can help us understand approaches to gunpowder. The effects of gunpowder at the macro-level are a massive onslaught on the senses, but these effects reflect the processes of the combining and conflicting of motions at the micro-level that we cannot sensibly perceive. Gunpowder's sensible effects drew attention to what was happening beneath the surface.

Instances with Special powers

Gunpowder's role in inquiring into matter is at its clearest in what Bacon refers to in the *Novum Organum* as *Instances with Special Powers*.[81] These instances were intended to assist inquiry into knowledge of forms, utilising practical examples to render them more intelligible.[82] Gunpowder's inclusion in the ISPs is significant and strategic. Bacon uses gunpowder to take his audience to the heart of matter. As gunpowder's effects are solely owing to matter's motions conspiring and conflicting, it highlights the possibility that recombining these motions in novel configurations will produce hitherto unimaginable effects. Gunpowder's motions are no different from the motions at work in all processes, but they are harnessed in a particular way that gives them power and impact. Gunpowder demonstrates that such reconfigurations could be applied in other processes to produce *magnalia*.

Rees describes the ISPs as a fruitful yet woefully understudied resource in Bacon scholarship. They comprise almost half of the *Novum Organum*, and seventy per cent of Book II, according to Rees's calculations, yet they have been 'forgotten' by scholars.[83] Rees utilises these instances in the study of what he terms 'Bacon's

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[80] Newman, *Promethean Ambitions*, 267.

[81] Following Rees, these will hereafter be abbreviated to ISPs. The ISPs are located in Book II of the Novum Organum: Bacon, *Novum Organum, OFB*, XI, 273-447. They are discussed in detail by Rees, *OFB,* XI, lxxvii-xcii.

[82] Rees, *OFB,* XI*,* lxxvi-lxxvii.

[83] Rees, *OFB,* XI, lxxvii. For more on ISPs: Jardine, *Bacon and the Art of Discourse*, 124-26, discusses the ISPs briefly over two pages, noting that these instances are where some of Bacon's 'most interesting observations about scientific procedure' are located; Lisa Jardine and Michael Silverthorne, "Introduction," in *Francis Bacon: The New Organon,* eds. Lisa Jardine and Michael Silverthorne (Cambridge: Cambridge University Press), vii-xxviii, on xxi-xxv; Clark, *Thinking with Demons*, names two chapters after the ISPs, which he calls 'prerogative instances.' The chapters are titled

speculative philosophy,' arguing that a 'necessarily selective study of ISPs will encourage others to explore a seam whose exploitation may with perseverance make our understanding of Bacon richer, broader, deeper.'[84] I aim to use gunpowder to draw attention to the ISPs, and underline their significance in Bacon's programme.

That the ISPs provide concrete ways of envisioning nature's processes is important. They give the intellect something real to grasp, in contradistinction from the abstractions employed by the scholastics. Bacon wanted 'to teach and instruct the intellect not to batten on and embrace abstract things.'[85] His philosophy would 'slice into nature, and discover the virtues and acts of bodies […] it is no wonder that [his] text is everywhere shot through and illustrated with reflections and experiments on the nature of things by way of exemplifying [his] art.'[86] Gunpowder presented a valuable chance to 'slice into nature.' It is a substance that most would find easy to envisage, thus was ideal in explicating the ontology of motions. The ISPs explain gunpowder's motions on various levels, presenting a series of case studies exploring different aspects of gunpowder's powers. They use gunpowder strategically to guide the reader through the labyrinth, leading to the final instance dealing with the all-important Baconian natural magic.

Instances of an ultimate state provide examples of extremities of nature. Its inclusion in these instances make it clear that Bacon considers gunpowder to be a great work.

> For they point quite openly to the real dividing lines of nature, to the measures of things, to that How Far a nature may do or suffer anything, and afterwards to the transitions of one nature into another. Examples of this are gold in weight; iron in hardness; the whale in animal size; the dog in scent: the firing of gunpowder in rapid expansion, and other things of the kind.[87]

It is no surprise that gunpowder is selected as an example. These instances demonstrate nature at an extreme. Gunpowder shows how far matter can be pushed if its motions are correctly configured. Its power is interpreted as its 'rapid expansion',

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'prerogative instances (1)' and 'prerogative instances (2),' although they do not actually provide discussions of the ISPs themselves.

[84] Rees, *OFB,* XI*,* xcii.

[85] Bacon, *Novum Organum, OFB*, XI*,* 443.

[86] Bacon, *Novum Organum, OFB*, XI*,* 443.

[87] Bacon, *Novum Organum, OFB*, XI, 310-11.

which deals with air, wind and fire expelled on ignition as the result of the conflict of motion.

Gunpowder is a potent example of the view that all bodies are concatenations of motions, which if sufficiently opposed, can produce huge effects. This is clear in the *crucial instances*. Bacon's *crucial instances*, broadly speaking, were instances whereby the experimenter could decide between two or more competing theories or explanation. They functioned in much the same way as what we now refer to as the Newtonian *experimentum crucis.*[88] Bacon probed the reasons behind gunpowder's motions that caused its extreme expansive effects.[89]

> Let the nature under investigation be the rapid and powerful expansive motion of gunpowder into flame which, as we see in large mines and artillery pieces, causes such enormous masses to be blown up and such huge weights discharged [...] this motion is provoked [...] by the compound appetite of the raw spirit rushing away from the surrounding fire, and bursting from its embrace as from a prison.[90]

The full passage on gunpowder in the *crucial instances* is interspersed with the competing explanation for gunpowder as expounded by the scholastics, which we shall return to soon.

Bacon clearly presented his own explanation for gunpowder's effects. He saw gunpowder as having a 'compound appetite,' referring to several motions tangled together and in conflict with each other. The analogy of gunpowder breaking free from a prison on the moment of ignition is a telling one. This underlines Bacon's idea that unfolding, or unleashing matter's motions could release matter's full potential. The bodies we see and sense are only apparently stable, but should these motions be

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[88] Isaac Newton's *experimentum crucis* demonstrated that light was inherently refrangible. For more on the Newtonian 'crucial experiment', see: Ronald Laymon, "Newton's *Experimentum Crucis* and the Logic of Idealization and Theory Refutation," *Studies in the History and Philosophy of Science* 9 (1978), 51-77; A. E. Shapiro, "The Gradual Acceptance of Newton's Theory of Light and Colour, 1672-1727," *Perspectives on Science* 4 (1996), 59-140. For an alternative reading, with more emphasis on the practical dimension and replication of the crucial experiment, see: Simon Schaffer, "Glass Works: Newton's Prisms and the Uses of Experiment," in *The Uses of Experiment: Studies in the Natural Sciences,* ed. David Gooding, Trevor Pinch and Simon Schaffer (Cambridge: Cambridge University Press: 1989), 67-104. On Bacon's crucial instances, see: Claudia Dumitru, "Crucial Instances and Crucial Experiments in Bacon, Boyle, and Hooke," *Society and Politics* 7 (2013), 45-61. Dumitru argues that there was a tension owing to the fact that Bacon presents the *crucial instance* as if the experimenter is dealing with two developed hypotheses, one of which is definitely correct.

[89] Bacon, *Novum Organum, OFB*, XI, 318-39.

[90] Bacon, *Novum Organum, OFB*, XI, 332-35.

untangled the hidden powers of matter will be released, and perform spectacular effects. Knowing how to bind or oppose matter's motions was the key to operative power.

Whereas the *crucial instances* look at ignited gunpowder and its expansion after ignition, the *instances of wrestling* dig deeper to look at the conflict between gunpowder's constituents. *Instances of wrestling* is one of the most important ISPs. It is one of what Rees calls the 'big four' and it is in fact the largest of these.[91] Among other things, *instances of wrestling* tackle the idea of the bi-quaternion theory of competing and cooperating forces. They deal with different types of motions and the interactions between motions. Gunpowder appears as an example of 'motion of Hyle', which occurs when a body 'long[s] for a new sphere or dimension, and hanker[s] after that willingly and without hesitation, and sometimes (as with gunpowder) with devastating force.'[92] This motion pertains to the desire and urgency of bodies to expand their domain and hence the swiftness with which such a body acts, with massive effects on surrounding bodies.

Gunpowder's effects on other bodies is a result of the 'motion of hyle' coming to dominate whilst supported by other motions. In Bacon's ontology motions wrestle with each other for dominance, as seen in the following example:

> When you put powdered sulphur alone in a gun with a round and fire it, the round is not discharged; and in this motion of the Greater Congregation beats motion of Hyle. But when you put in gunpowder, motion of Hyle in the sulphur prevails, helped by the motions of Hyle and of Flight in the nitre [...] For Instances of Wrestling (which point to the Ascendancies of virtues, and by what proportions and reckonings they get the upper hand or give way) should everywhere be inquired into with keen and unflagging diligence.[93]

The 'motion of hyle' combines with the 'motion of flight', which occurs when 'bodies, provoked by antipathy, bolt and scatter hostile bodies, and cut themselves off or refuse to get mixed up with them.'[94] This combination is enough to overcome the 'motion of the greater congregation' which 'carries bodies to the masses of their

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91 Rees, *OFB,* XI, lxxxiv. In Rees terms, the 'big four' instances are the four instances which are largest in terms of word count: instances of wrestling, multi-purpose or *polychrest* instances, crucial instances, and summonizing instances.

92 Bacon, *Novum Organum, OFB*, XI, 388-89.

93 Bacon, *Novum Organum, OFB*, XI, 414-15.

94 Bacon, *Novum Organum, OFB*, XI, 398-99.

connaturals—heavy ones towards the globe of the Earth, light towards the heights of the heavens.'[95] Sulphur alone would not desire to change dimensions and so does not produce a reaction when used alone in a gun. However, gunpowder aided by nitre can successfully change dimensions, and owing to the nitre which reacts violently with fire, escape from its current state. The motions of the nitre are so violently opposed to the addition of fire that they have no choice but to furiously ascend. The case of gunpowder combines several motions in conflict with each other in a complex reaction.

We find out how gunpowder's conflicting motions are able to impart such huge physical force in *instances of the race-track,* which measure motions over time:

> the comparative measures of motions – and not just of the thing itself but of the outstanding usefulness I mentioned a moment ago – shows itself splendidly in underground mines charged with gunpowder, where a tiny amount of powder destroys and blows up vast masses of earth, masonry and the like. Now the cause of this is certain: that the powder's motion of dilation which produces the shock is much swifter by a long way than the motion of gravity which could put up some resistance, so that the first motion is over before the opposing motion has begun, and at the start the resistance is a mere nothing. Hence too it happens that in all missiles it is not a heavy blow but a sharp and swift one that carries them furthest [...] Now this is one of the main props in experiments in magic which I shall speak of soon, namely where a small mass of matter overpowers a much greater one and reduces it to order. This, I say, can happen if one motion by speed steals a march on another before the latter can get itself moving.[96]

The ability of one motion to overtake another depends on its reaction speed. If a body, such as gunpowder, expands fast enough then there is little time for nearby bodies to resist or fight back. In this instance we move from dealing internally with gunpowder—the reaction of gunpowder's appetites on ignition—to dealing with gunpowder's effects on other bodies. The explosion of the ignited gunpowder directly brings down huge masses, displaying its true destructive capacity. It is the ability of gunpowder's motions to overtake the motions of other bodies, and so generate a large effect by a relatively small cause, that makes gunpowder an example of magic. Bacon used gunpowder to present magic as a natural conflation of motions which is non-

[95] Bacon, *Novum Organum, OFB*, XI, 392-93.

[96] Bacon, *Novum Organum, OFB*, XI, 378-81.

superstitious. Gunpowder offered an opportunity for Bacon to assess how bodies interact with each other when their motions are opposed.

Instances of the race-track illustrate the extraordinary ability of gunpowder to overcome the combined resistance of other motions and this provides a paradigm example of Baconian magic. As a notable magical instance, gunpowder occupies a prominent place in the final ISP: *magical instances*.[97] Magic for Bacon occurred when 'the material or efficient cause is small or slight compared with the magnitude of the work or effect produced, so that even when they are common, they still seem like miracles—some at first glance, others too after closer consideration.'[98] All magical instances have a similar quality: they are deemed miraculous owing to the huge effects produced by small causes. Gunpowder was the perfect illustration of this essential principle of natural magic. There are three ways in which Baconian magical effects could be produced. The first is 'self-multiplication as in fire and in what they call specific poisons, and in the motions passed on and intensified from one gear-wheel to another.'[99] The second is 'excitation or inducement in another body, as in the loadstone which excites countless needles without any loss or of its virtue, or in yeast in the like.'[100] The third example of magic occurs by 'one motion stealing a march on another—as I have said before of gunpowder, and artillery and mines.'[101] Just as in *instances of the race-track*, gunpowder's magical effect owes to its ability to overcome competing motions, resulting from the swiftness, or velocity, of its reaction.

It was demonstrated earlier that gunpowder reproduced natural processes in nature such as thunder and lightning. Within the magic tradition, art can perform functions on demand which nature would do by chance. Bacon explains precisely how magic is able to achieve this ability so that it is not viewed as superstitious. Gunpowder is a medium through which he can do this, considering it is something already interpreted as a marvellous effect. The ISPs draw on gunpowder throughout, building up the *magical instances.* Detailed explanations, based on Bacon's theory of matter, are given in the *Novum Organum,* so as to remove any ambiguity. Gunpowder

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97 Bacon, *Novum Organum, OFB,* XI, 440-43.

98 Bacon, *Novum Organum, OFB,* XI, 440-43.

99 Bacon, *Novum Organum, OFB*, XI, 442-43.

100 Bacon, *Novum Organum, OFB*, XI, 442-43.

101 Bacon, *Novum Organum, OFB*, XI, 442-43.

shows that magic is not superstitious, but rather the result of a natural configuration of natural motions.

Gunpowder offered a real insight into how matter worked. Its huge force meant it was an ideal material to study, and so gunpowder appeared in several ISPs looking at the conflict of motions on different levels: the motions of its individual constituents with each other, the motions when the ingredients are ignited, and the combined motions in conflict with external bodies once ignited. Bacon's use of gunpowder to inquire into matter does appear outside of the ISPs. At this stage it will be useful to consider other examples of Bacon explaining gunpowder in order to underline the necessity of gunpowder to the Baconian doctrine of motions. I have noted that he explains how nitre has 'a great aversion to flame, which causes that wonderful blast and explosion.'[102] This means that it had a sort of antipathy, so when put in contact with flame, reacted violently in explosive fashion. It is worth exploring this point further.

When compacted in gun barrels, or cavities in mines, gunpowder does not just take fire, but explodes. This is what separates it from other flammable substances and allows such a unique insight into matter's hidden processes. Bacon wrote in the *Cogitationes* how the motions of gunpowder collaborate and conflict to produce this effect:

> But the truth of the matter is this. You will find that the motion here inquired is double and compound. For besides the motion of kindling, which is principally in the sulphur of the powder, there is another stronger and more violent. This proceeds from the crude and watery spirit, produced mostly from the nitre, and in some degree from the charcoal of willow wood which is not only expanded (as vapours usually are by heat), but also (which is the chief point) flies and bursts away from the heat and inflammation with the utmost rapidity and violence, and thereby likewise makes a passage or opening for the inflammation. Therefore men should be admonished and entreated by this example, not to seize some one point in the inquisition of causes and thereupon lightly pronounce, but to look about them and fix their considerations stronger and deeper.[103]

The sulphur is the flammable ingredient, providing the carrier for the fire and heat upon ignition. Yet stronger is the nitre with a 'crude and watery spirit.' The nitre is in the mercury quaternion and clashes with sulphur in the sulphur quaternion. It is the

[102] Bacon, *History of Life and Death, SEH*, V, 274.

[103] Bacon, *Cogitationes, SEH*, V, 435-37.

charcoal that helps enhance the ignition process, and as the main flammable ingredient gives gunpowder its necessary swiftness. The passage ends with a not-so-subtle dig at the scholastics who Bacon criticises for not looking deep enough for knowledge of gunpowder's, and other bodies', causes.

Disputes over Matter Theory

Gunpowder's inquisitional role is double. It was used not only to explicate Bacon's own matter theory, but also to challenge competing theories. Gunpowder became a site of disagreement and resolution concerning matter theory. Whilst not denying the influence of social factors in influencing knowledge generation, I argue that a close understanding of the subject (gunpowder) itself is revelatory. Not just any substance could play this role. For the reasons described above, gunpowder had an intimate relationship with Bacon's theory of matter, which made it ideal in solving the dispute over matter theory. It is gunpowder's properties and behaviours that compelled Bacon, and as we shall see in the next chapter, Boyle, to use it in expounding theories of matter.

Bacon remarks in his investigation into 'the cause of motion in fire-arms' that 'the explanation of so powerful and noble a motion is imperfect, and deficient in the most important part.'[104] In the *crucial instances* Bacon directly used gunpowder to confront scholasticism.[105] *Crucial instances* were meant to help the inquirer in deciding between competing explanations. Gunpowder is just one example employed in this passage, but it is an important one. I am in agreement with Rees that the *crucial instance* of gunpowder, in no uncertain terms, presents a direct attack on the scholastic matter theory.[106] The example of gunpowder strengthened Bacon's convictions whilst denying those of the scholastics.

In the above passage Bacon provides a scholastic explanation that posits that gunpowder's effects owe to the 'motion [being] provoked by the bodies simple

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[104] Bacon, *Cogitationes, SEH,* V, 435-37.

[105] Rees, *OFB*, XI, 564-65, in his commentary on the *Novum Organum,* interprets the *crucial instances* as particularly important, claiming that 'Bacon's natural philosophy cannot be epitomized, simplified, or put in a nutshell. But if I were asked to identify the single passage which best exemplified his originality, breadth and complexity, I would choose this one.'

[106] Rees, *OFB,* XI, 564-565. Rossi, "Bacon's Idea of Science," 27-31, discusses Bacon's problems with the scholastic philosophy in general.

appetite to expand once it has been detonated.' [107] He subsequently provides another account of gunpowder's effects. This explanation, to briefly repeat what was cited earlier, suggests that gunpowder's actions derive from the 'compound appetite of the raw spirit rushing away from the surrounding fire.'[108] It is the scholastic explanation that Bacon rejects. He criticised the 'schoolmen' who 'philosophize sweetly if they claim that flame is put by its elemental form under a certain necessity of taking up more space than it did while in powder form, and that this motion is the result.'[109] The scholastics attribute gunpowder's expansion to a necessity of its form, but Bacon saw the expansion differently. He wrote that 'they forget that though flame is indeed generated, it is still possible for its generation to be checked by a mass such as can compress and choke it, so that the question cannot be reduced to the necessity they speak of.'[110]

If we consider that the flame of gunpowder could be suppressed or smothered before it ignites, then this expansion cannot be a necessary attribute:

> But this necessity does not hold if the solid mass suppresses the flame before it is generated. And we see that flame in the instant of its birth is soft and gentle and needs room to play and try itself out. So such violence cannot be ascribed just to flame alone. But this much is true: that the generation of this kind of flatulent flames or fiery winds arises from the conflict of two bodies whose natures are totally at odds; one of the two-the nature flourishing in sulphur-is extremely inflammable, while the other – the raw spirit inherent in nitre – shrinks from flame. The upshot is tremendous conflict: the sulphur inflames itself as much as it can (for the third body, i.e. willow charcoal does little more than incorporate and conveniently unite the other two), and the spirit of nitre bursts out as much as it can, and dilates at the same time (for this is what air, all crude bodies and water do when heat dilates them), and, by its flight and bursting out, it fans the flame of sulphur on all sides as if by invisible bellows.[111]

There are no ambiguities regarding Bacon's bi-quaternion ontology within this passage. He followed his explanation of why the scholastic interpretation is inadequate with a re-iteration of his own theory. It is important that Bacon used

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107 Bacon, *Novum Organum, OFB*, XI, 332-35.

108 Bacon, *Novum Organum, OFB*, XI, 332-35.

109 Bacon, *Novum Organum, OFB*, XI, 332-35.

110 Bacon, *Novum Organum, OFB*, XI, 332-35.

111 Bacon, *Novum Organum, OFB*, XI, 332-35.

gunpowder to undermine an entire theory of matter. Gunpowder was not just employed piecemeal and on an ad hoc basis to explain specific effects in nature. Theories of matter were the basis for understanding nature. He was not the only natural philosopher to use gunpowder to perform such a function. The Baconian *crucial instances* perform a similar function to Boyle's *Origin of Forms and Qualities.*[112] Boyle, as we shall see, also used an experiment with gunpowder to challenge chemical and scholastic theories of matter and so insinuate his own corpuscular views. Bacon influenced Boyle in this regard even though, as we shall see, they disagreed on the nature of matter.

Conclusion

In this chapter I have argued that gunpowder occupied a prominent place in Bacon's natural philosophy. As a rare example of an actualised *magnale,* gunpowder invited philosophical scrutiny, especially for one whose programme appropriated the aims of the magical traditions. By undertaking a close study of gunpowder, Bacon could emphasise the potencies that lay deep within nature. Gunpowder symbolised the unimaginable possibilities to be had from his systematic and experimental method of inquiry. At the same time he used the material to emphasise the failings of a barren scholasticism that still dominated the universities. He used the powerful example of gunpowder, a material often cited in the early modern period as one of the most important and change-inducing inventions, to argue that accident had done more for the world than scholasticism ever could hope to do. For these reasons alone, Bacon's work on gunpowder should be given recognition for its role in his programmatic aim of reforming natural philosophy.

Moreover, by reconfiguring gunpowder as a tool of natural inquiry, Bacon transformed common perceptions of the substance. He drew often on the example of gunpowder to inquire into nature's hidden but potent occult motions. Owing to its mammoth sensible properties, gunpowder was the ideal material through which Bacon could explore the conflicts of motions that he believed happened deep within nature. This important inquisitional role for gunpowder allowed Bacon to suggest that what was destructive and dangerous in the wrong hands, was also in the right

[112] Robert Boyle, *Origin of Forms and Qualities* (1666)*,* in *The Works of Robert Boyle,* 14 Vols, Vol. 5, ed. Michael Hunter and Edward B Davis (London: Pickering & Chatto, 1999-2000).

circumstances intellectually productive. The ability of gunpowder to provide insight into fundamental issues in natural philosophy more than compensated for its better-known horrendous applications.

Further weight is added to Bacon's work on gunpowder when we consider the profound influence that it had on the followers of his experimental method in the seventeenth century. Boyle was especially enthusiastic about the material, and used it frequently in his own chemical implementation of the Baconian programme. Bacon and Boyle both used gunpowder in resolving important disputes concerning matter, and both saw gunpowder as a window on nature's hidden processes. The ways in which they interpreted these processes, however, were at odds, as we shall see in Chapter 2.

Chapter 2

Robert Boyle: gunpowder philosophised

> And though it be very true that man is but the Minister of Nature, and can but duely apply Agents to Patients (the rest of the work being done by the applied body themselves), yet by his skill in making those Applications, he is able to performe such things as do not only give him a Power to Master Creatures otherwise much stronger than himselfe; but may enable one man to do such wonders, as another man shall think he cannot sufficiently admire. As the poor indians lookt upon the Spaniards as more than Men, because the Knowledg they had of the properties of Nitre, Sulphur and Charcoal duely mixt, enabled them to Thunder and Lighten so fatally, when they pleased. And this Empire of Man, as a Naturalist, over the Creatures, may perchance be to a Philosophical soul preserved by reason untainted with vulgar Opinions, of a much more satisfactory kind of power or Soveraignty then that for which ambitious Mortals are wont so bloodily to contend.[1]

Introduction

The previous chapter demonstrated how Bacon strategically used gunpowder as a tool for inquiry in his projected reform of science. In this chapter we will see how Robert Boyle appropriated gunpowder in his implementation of a Baconian experimental philosophy. Boyle agreed with most parts of Bacon's vision, especially the most fundamental point that natural philosophy should combine operation and contemplation. His project was not utilitarian, but it did have the production of works, via experimentally acquired knowledge, as the end goal.[2] The work of Rose-Mary Sargent has done a great deal to delineate the impact of Bacon on the development of Boyle's natural philosophy, but it fails to sufficiently acknowledge

[1] Robert Boyle, *Some Considerations touching the Usefulness of Experimental Natural Philosophy* (1663), *Works,* III, 212. See also: Robert Hooke, G*eneral Scheme, The Posthumous Works of Robert Hooke* (Richard Waller: London, 1705), on 3. Hooke uses the same phrase, 'agents to patients.'

[2] Sophie Weeks and Chris Kenny, "Bacon, Boyle and the Birth of Experimental Philosophy," draft manuscript. Weeks and Kenny provide an in-depth discussion of the nature of Boyle's Baconianism. They convincingly show that Boyle's philosophy had to combine theory and practice as per the fundamental Baconian goal, and emphasize that Boyle's philosophy, like Bacon's was to be productive of works.

that the endpoint of Boyle's programme was to be works.[3] Boyle's many engagements with gunpowder pursued the experimental knowledge that he hoped would ultimately generate works on the same level of significance as the explosive material.

To realise his interpretation of Baconian natural philosophy, Boyle turned to chemistry. As explained by Antonio Clericuzio, Boyle saw chemistry as the key to understanding nature.[4] The discipline had the desirable empirical element that facilitated practical inquiry and the manipulation of basic natural materials. It offered an insight into matter and a Baconian fruitfulness that in Boyle's mind, scholasticism lacked. Boyle promoted a philosophical chemistry; chemistry rendered philosophical owing to a method that married contemplation and operation as according to the Baconian tradition. Gunpowder would serve in Boyle's overall project to make chemistry essential in the implementation of a Baconian style of natural inquiry. Like his predecessor, Boyle recognised in gunpowder the potential to reveal knowledge about matter. Whereas Bacon's flirtations with gunpowder were largely theoretical, however, Boyle actualised his conjectures by placing gunpowder under close chemical scrutiny.

In this chapter I argue that Boyle altered the function of gunpowder. He did this by relocating it from the battlefield to the laboratory where he made it serve as a revelatory philosophical material, capable of bringing matter's occult powers to the surface. Gunpowder made an important contribution to seventeenth-century experimental philosophy as an indispensable tool in the arsenal of one of the century's most famous scientific minds. In Boyle's laboratory, gunpowder was a

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[3] Sargent, "Boyle's Baconian Inheritance," 481. Sargent claims 'For Boyle, as for Bacon, the justification for the *pursuit of science* was its usefulness to man's material and spiritual well-being, but *within science* they referred to hypotheses and experiments as not being useful directly to the well-being of man but as useful directly as a means of acquiring truth.' See also: *idem., The Diffident Naturalist: Robert Boyle and the Philosophy of Experiment* (Chicago: University of Chicago Press, 1995); *idem.,* "Learning from Experience: Boyle's Construction of an Experimental Philosophy," in *Robert Boyle Reconsidered,* ed. Michael Hunter (Cambridge: Cambridge University Press, 2003), 57-78.

[4] Antonio Clericuzio, "A Redefinition of Boyle's Corpuscular Philosophy," *Annals of Science* 47 (1990), 561-89; *idem.,* "From van Helmont to Boyle: A Study of the transmission of Helmontian chemical and medical theories in seventeenth-century England," *The British Journal for the History of Science* 26 (1993), 303-34; *idem., Elements, Principles and Corpuscles: A Study of Atomism and Chemistry in the Seventeenth Century* (Netherlands: Springer, 2001). On Boyle's chemistry, see also: Marie Boas Hall, *Robert Boyle and Seventeenth-Century Chemistry* (Cambridge: Cambridge University Press, 1957).

regular fixture for almost his entire career.[5] Gunpowder was not a random curiosity, a phase, or a passing interest for Boyle. The epigraph to this chapter tells us why.

Boyle clearly states in the epigraph that gunpowder should be given over to a natural philosophical treatment. That potent mixture so useful and necessary in seventeenth-century England was in Boyle's mind, underexploited. The simple procedure of bringing together three ingredients and kindling them (applying agents to patients) initiated processes in matter at the insensible level. These processes resulted in a powerful manifestation of matter's hidden powers and capabilities. Through practical skills art could activate phenomena typically associated with magic and natural meteorological forces. Gunpowder was perhaps the most profound example of the impressive power that could be obtained over nature when it is understood practically.

Hitherto the marvellous power of gunpowder was confined to its common or vulgar uses. Boyle contrasted these practical applications of gunpowder to the philosophical knowledge that it could generate. Under the right kind of philosophical scrutiny, gunpowder could be a source of knowledge and a means of natural inquiry. In the chemical laboratory gunpowder's uses would not be terminated in its outward properties. Rather, it would contribute to an inquiry into fundamental causes. Boyle was telling us that gunpowder is now to be contemplated as well as simply utilised for its manifest power.

When subject to chemical experiments, the explosive gunpowder takes on a different persona. This awesome substance, when stripped of the effects most commonly associated with it, is transformed into a laboratory material. Chemical analysis opened up a new world of uses for gunpowder. It could be used in the research of matter as well as in the physical application of matter's powers. Boyle's corpuscular philosophy explained the fundamental interactions of matter responsible for all chemical changes. When gunpowder interacts with fire it ignites violently. In the laboratory, Boyle could see what happens when it is combined with other

[5] Gunpowder begins to appear regularly in Boyle's works from around 1660, and he is still writing about its simultaneous wonder and terror a quarter of a century later, in the years leading up to his death in 1691. Boas-Hall, *Boyle and Seventeenth-Century Chemistry,* 1, cites gunpowder as an example of the chemistry that late seventeenth-century scholars, such as Boyle, concerned themselves with.

materials. This was not necessarily to make practical gains, but to see what these chemical changes tell us about matter's sub-phenomenal processes.

It is a crucial point that Boyle's chemical studies of gunpowder were far removed from the martial or blasting uses of it. This relocation to the laboratory was not just physical. It generated a new way of experiencing and interpreting gunpowder. The realisation that simply moving gunpowder to another location can transform perceptions of it occurred to me during the reworking of two of Boyle's experiments with gunpowder. When gunpowder is studied using chemical apparatus and materials, a new range of effects—both physical and theoretical—are unleashed. The laboratory was a different world and therefore opened up unconsidered possibilities for gunpowder. The difference between the reflective environment of the laboratory and the commonplace applications of gunpowder on the outside are important. It was only in the former environment that Boyle could philosophise gunpowder and make it an inquisitional tool to generate knowledge and works in the Baconian style. This is the sort of power that Bacon envisaged in his *great instauration* and it is expressed succinctly in Boyle's concept of a 'more satisfactory kind of power.'[6]

Following a brief outline of Boyle's experimental philosophy, the first major section in this chapter looks at Boyle's 'philosophising of the everyday.' It argues that Boyle philosophised gunpowder, which by his time had become familiar and common. The second section argues that Boyle saw in gunpowder both manifest and inquisitional powers. The re-location to the laboratory sought to accommodate both of these, but it was the inquisitional powers that would give rise to the manifest powers. Boyle as a Baconian sought power over nature through experimentally produced knowledge by means of its hidden forces and motions. Finally, I argue that a major question for Boyle was the expansion of gunpowder when fired. He wanted to understand the capacity of matter to expand to such an awesome degree. For this reason, gunpowder was analogous to the air, and intricately connected to Boyle's studies on the air's expansion. It is a further hope that re-examining Boyle on air should also contribute to the vexed question of the nature of early modern

[6] Boyle, *Usefulness, Works,* III, 212.

experiment—especially as the air-pump has been at the centre of discussions on his role in establishing early modern experimental life.[7]

Boyle confined gunpowder into an inquisitional space. Its outward uses were important but it had to be made to do something for the development of natural philosophy. At the heart of this chapter is the re-housing of the everyday within the chemical laboratory. This gave novelty to Boyle's implementation of the experimental programme. Further, focussing on this process of translation between environments is a novel approach from a historiographical perspective. It sheds some new light on Boyle's experimental life, pertaining to how he made materials philosophical.

This approach is in contrast to the sociological approach established by Shapin and Schaffer.[8] They explore the fact that experiment in the seventeenth century was neither the obvious nor only way to generate knowledge. Yet they give little attention to the ways Boyle used experiment to make materials philosophical and his efforts to make novelties emerge from the everyday—a process that Bacon referred to as the superinduction of forms. Boyle conducted experiments because they promised to reveal the behaviours of matter and truths about nature. Sargent describes experimental philosophy as 'a method of discovery […] clearly meant to disclose truths about the world's hidden processes.'[9] Like the air, one of Boyle's most famous topics of inquiry, and as he himself notes a substance of vast importance; gunpowder too was common but important. It mattered. Boyle was interested in these materials for what they might reveal under chemical analysis. The social influence on experiment cannot be denied, but it is useful to think more practically about precisely what experiment did for Boyle given its Baconian provenance.

Little has been written on Boyle's gunpowder experiments. Certainly there are no studies focussing exclusively on Boyle's relationship with gunpowder. Rather, some of the more high-profile experiments have made their way into works concerned with a broader subject matter. Douglas McKie and Robert G. Frank have

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[7] Shapin and Schaffer, *Leviathan and the Air-Pump.*

[8] Shapin and Schaffer, *Leviathan and the Air-Pump.* See especially: Chapter V 'Boyle's Adversaries: Experiment Defended,' 155-224.

[9] Sargent, *The Diffident Naturalist*, 31.

both expressed interest in Boyle's experiments with gunpowder *in vacuo.*[10] Both discuss gunpowder in the context of the developing physiology of the seventeenth century, acknowledging that the material raised important questions about the air and combustion. Werrett, concerned primarily with fireworks, offers a more dynamic, albeit brief, approach to Boyle's work on gunpowder.[11] He argues that fireworks were seen as problematic in the mid-late seventeenth century owing to their spectacle and associations with popery. By explaining gunpowder mechanically, argues Werrett, Boyle could 'explain away spectacle' and combat arcane alchemical theories of matter.[12] His argument that gunpowder and its products could have such a wide-reaching impact, and neutralise seemingly magical, alchemical or seditious phenomena, is valuable. To show gunpowder's worth in natural philosophy, it had to be divorced from dubious occult or alchemical sympathies.

As well as contributing to the gunpowder historiography with a hitherto untold story about how Boyle utilised the material, this chapter contributes to the continuing debates on Boyle's chemistry and laboratory practice. Malcolm Oster explores Boyle's engagement with craft practices as part of his programme for reforming chemistry.[13] He explains that Boyle saw value in manual and craft labour for his natural philosophy, yet argues that Boyle would have experienced the world of craftsmen as 'foreign territory, both literally and metaphorically.'[14] I argue that Boyle had to make craft practices relatable and comprehensible in order to incorporate them, as he did, in his natural philosophy. There were boundaries between the world of the craftsman and the world of the scholar, and Boyle would need to somehow negotiate these in order to enact the Baconian marriage of theory and practice and of scholar and artisan.

In this chapter I show that Boyle had to metaphorically deconstruct or translate outside processes or materials, such as gunpowder, so he could cross these boundaries between the world and the laboratory, and theory and practice. If we take

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[10] McKie, "Fire and the *Flamma Vitalis,"* 477-88; Frank, *Oxford Physiologists*, 252-53.

[11] Werrett, *Fireworks*, 81-83.

[12] Werrett, *Fireworks,* 83.

[13] Malcolm Oster, "The Scholar and the Craftsman revisited: Robert Boyle as Aristocrat and Artisan," *Annals of Science* 49 (1992), 255-76. Oster's paper is a response, or 'revisit', to: A. R. Hall, "The Scholar and the Craftsman in the Scientific Revolution," in *Critical Problems in the History of Science,* ed. Marshall Clagett (Madison: University of Wisconsin Press, 1959), 3-23.

[14] Oster, "The Scholar and the Craftsman," 256.

methodological influence from Bruno Latour as an alternative to Shapin and Schaffer, we learn more about these boundaries.[15] Latour, as we shall see, used the laboratory of Louis Pasteur (1822-95) to demonstrate how materials and processes were adapted to the laboratory environment. For Boyle, the laboratory was the place where gunpowder could be used in an inquisitional capacity, not the battlefield or gunpowder factory.

The work undertaken in this chapter can also contribute more widely to the literature on laboratory studies of specific materials. Michael Hunter and Harriet Knight have studied Boyle's work on the blood, another everyday phenomenon necessary to human life and worthy of inquiry.[16] Like blood, salts, and phosphorus, gunpowder was transferred into early modern laboratories to gain philosophical status.[17] In studying a well-known substance, Boyle could certainly gain attention. Golinski attributes some of the appeal of phosphorus to its novelty status, although, as he notes, the objectors to alchemy viewed novelties as arcane and superfluous.[18] Gunpowder, by contrast, drew attention to socially and politically relevant subjects. Chemistry could be advanced on two fronts: through its valuable practical implications and through its power to produce novel effects from familiar and common substances.

When we understand the necessity of rehousing of materials to make them serve philosophical purposes, we increase our understanding of how Boyle aimed to restore chemistry. Gunpowder provides a practical case study on how Boyle endeavoured to reform chemistry by combating its associations with unlearned empirics and the more bizarre and fraudulent baggage surrounding alchemy. Furthermore, by submitting familiar substances to chemical operations, he adhered to the Baconian imperative to focus on everyday (as well as extraordinary) materials with a view to exploiting their inquisitional powers. Boyle was determined that chemistry can and should study these materials; not because he was interested in

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[15] Bruno Latour, "Give me a Laboratory and I will move the World," in *Science Observed: Perspectives on the Social Study of Science*, ed. Karin D. Knorr-Cetina and Michael Mulkay (London: Sage, 1983), 141–70, on 145-46.

[16] Michael Hunter and Harriet Knight (eds.), "Unpublished Material relating to Robert Boyle's Memoirs for the Natural History of Human Blood," *Robert Boyle Project Occasional Papers* 2 (London: University of London, 2005).

[17] Roos, *Salt of the Earth,* 47-107*;* Golinski, "Phosphorus."

[18] Golinski, "Phosphorus," 26.

materials per se, but because of what they could be made to reveal under experimental conditions.

Boyle's Experimental Philosophy

The process of philosophising gunpowder had to fit into Boyle's wider programme of experimental philosophy.[19] For this reason it is necessary to provide a brief overview of Boyle's programme before launching into his gunpowder experiments. According to Hunter, it was in the late 1650s that 'Boyle emerged as an original voice in natural philosophy'.[20] He became involved with the Hartlib Circle in the previous decade and began establishing his programme. Based on an analysis of Boyle's work diaries, Hunter describes 1651 as a turning point when Boyle became more interested in 'underlying theoretical principles' of natural philosophy.[21] From this period, Boyle's sympathies leaned increasingly toward chemistry. As shown by William R. Newman and Lawrence M. Principe, involvement with American chemist George Starkey was particularly influential on Boyle's chemistry-inclined ways of thinking and working.[22] Correspondence with Benjamin Worsley and Kenelm Digby, both natural philosophers of a chemical persuasion, further pulled Boyle into that chemical world.[23]

For Boyle, like Bacon, theorising and hands-on experience had to be united into a single enterprise in order to generate genuine knowledge of nature's hidden

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19 For more detailed accounts on Boyle's method and natural philosophy, see: Michael Hunter, *Boyle: Between God and Science* (Newhaven and London: Yale University Press, 2009), especially chapters 5-11; Marie Boas-Hall, *Robert Boyle on Natural Philosophy* (Bloomington: Indiana University Press, 1965); Sargent, "Learning from experience," 66-74; *idem., The Diffident Naturalist*.

20 Hunter, *God and Science*, 104.

21 Hunter, *God and Science,* 76-77.

22 William R. Newman and Laurence M. Principe, *Alchemy Tried in the Fire: Starkey, Boyle, and the Fate of Helmontian Chemistry* (Chicago: University of Chicago Press, 2002). See also: *idem., Gehennical Fire: The Lives of George Starkey, an American Alchemist in the Scientific Revolution* (Chicago: University of Chicago Press, 2003).

23 Hunter, *God and Science*, 70-86. Hunter describes 1649-52 as a 'turning point' for Boyle, as this was when he became immersed in the experimental and chemical method of philosophy. He had been acquainted with Worsley for at least two years by this point, and Hunter describes Worsley as a 'mentor' in chemical matters. For more on Worsley, see: Thomas Leng, *Benjamin Worsley (1618-1677): Trade, Interest and the Spirit in Revolutionary England* (Suffolk: The Boydell Press, 2008). On Digby, see: Wyndham Miles, "Sir Kenelm Digby, Alchemist, Scholar, Courtier, and Man of Adventure," *Chymia* 2 (1949), 119-28.

powers so that they could be practically applied.[24] All Boyle's work, whether chemical or mechanical, required hands-on manipulation and the production and perception of novel effects. It is these effects that are produced in the laboratory, elicited purely through human interference. Operative interference was Boyle's way of bringing skill to bear on the everyday and the basis of magical power, minus the bizarre jargon and wild theorising of its usual practitioners.

Chemistry was essential in Boyle's implementation of the Baconian philosophy, and it is what made Boyle's approach to Baconianism novel. Newman states that 'it is clear that [Boyle's] extensive reading in the chemical literature of his time allowed him to supplement and modify the views of his English forebear [Bacon].'[25] Clericuzio has shown that in the seventeenth century, chemistry evolved from a mere 'practical art' into a valid discipline in its own right, and that it was Boyle's 'primary way of penetrating into nature.'[26] He further argues that Boyle's chemistry was not made subordinate to mechanical philosophy, and that the corpuscular theory of matter at the core of Boyle's natural philosophy, was based on chemical, rather than just mechanical, properties.[27]

Yet in Boyle's time, the reputation of chemistry was not pristine. Boyle sought to transform it into the science of the fundamentals of matter and its powers. Principe has argued that Boyle tried to 'elevate [chemistry's] status by insisting upon its usefulness to natural philosophy.'[28] Boyle wanted to show that natural philosophy needed this practical analytical component that we find in chemistry, and that the dubious associations of chemistry could be negated by upgrading its methods and

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[24] Weeks and Kenny, "Birth of Experimental Philosophy." Hunter describes 'the Boylean programme' as one 'which would at the same time be experimentally based, intellectually rigorous, theistic and practical,' *God and Science*, 120.

[25] Newman, *Promethean Ambitions*, 272.

[26] Clericuzio, "Sooty Empirics," 339-44; *idem.,* "Redefinition of Chemistry," 561, 564-68.

[27] Clericuzio, "Redefinition of Chemistry," 573-83. Clericuzio argues that corpuscles for Boyle held chemical properties rather than just mechanical ones. Boyle's famed corpuscular philosophy departed from the chemical principles of matter yet was based on an understanding of chemical qualities and how they are produced. Also on chemical and mechanical properties: William R. Newman, "Boyle's Debt to Corpuscular Alchemy," *Robert Boyle Reconsidered* ed. Michael Hunter (Cambridge: Cambridge University Press, 2003), 108-118; On non-mechanical powers in experimental philosophy, see: John Henry, "Robert Hooke, the Incongruous Mechanist," *Robert Hooke: New Studies,* eds. Michael Hunter and Simon Schaffer (Woodbridge: Boydell, 1989), 149-80; *idem.,* "Boyle and Cosmical Qualities," in *Robert Boyle Reconsidered* ed. Michael Hunter (Cambridge: Cambridge University Press, 2003), 119-38.

[28] Lawrence M. Principe, *The Aspiring Adept: Robert Boyle and his Alchemical Quest* (Princeton: Princeton University Press, 1998), 33.

theories in accordance with Baconianism. As argued by Oster, whose account is more emphatic of the nature and importance of practical interventions in nature, Boyle showed that chemistry could demonstrate mechanical principles that would make chemical phenomena intelligible.[29]

Boyle's approach to chemistry was built upon his earlier exposure to alchemy. Principe explains that Boyle did not reject alchemy but rather used it in the development of his chemical method.[30] He did not accept the discipline as it was, however. It had to be modified. Boyle said that 'though [he has] a very good opinion of Chymistry it self, as 'tis a practicall art; yet as 'tis by Chymists pretended to containe a systeme of Theroeticall Principles of Philosophy, I fear it will afford but very little satisfaction to a severe enquirer, into the Nature of Qualities.'[31] The practitioners of chemistry were accompanied with associations of secrecy, and often were regarded not as scholarly, but as 'unlearned empirics.'[32] Boyle admired the practical dimension of chemistry, but for the most part, he felt it lacked the speculative qualities necessary to generate truths.

To make chemistry fit the Baconian programme, Boyle had to overcome these obstacles. Peter Alexander maintains that 'Boyle feared criticism from fellow natural philosophers because of his interest in chemistry which was unfashionable at the time'.[33] Not only was it unfashionable, the nature of the discipline, as it was then,

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[29] Oster, "The Scholar and the Craftsman," 275.

[30] Principe, *Aspiring Adept*, 219. On Boyle's approach to alchemy, and his retained interest in traditional alchemical pursuits such as transmutation, see also: *idem., "*Boyle's Alchemical Pursuits*,"* in *Robert Boyle Reconsidered,* ed. Michael Hunter (Cambridge: Cambridge University Press, 2003), 91-105; Antonio Clericuzio, "From van Helmont to Boyle: A Study of the transmission of Helmontian chemical and medical theories in seventeenth-century England," *The British Journal for the History of Science* 26 (1993), 303-34, on 317-19; William R. Newman, "Robert Boyle, Transmutation, and the History of Chemistry before Lavoisier: A Response to Kuhn," *Osiris* 29 (2014), 63-77, in response to Thomas S. Kuhn, "Robert Boyle and Structural Chemistry in the Seventeenth Century," *Isis* 43 (1952), 12-36. Kuhn claimed that Boyle's aspirations towards transmutation were a step back in chemical development and Newman shows the productive influence of traditional alchemy on Boyle's works.

[31] Boyle*, Origin of Forms, Works*, V, 301.

[32] Principe, *Aspiring Adept*, 33. As shown by both Principe and Clericuzio, "Sooty Empiricks," 342-43, Boyle distinguished between the 'vulgar chymists' (who whilst had practical expertise, did not provide hypotheses or explanations of their efforts) and the 'Adepts' who were more thorough in their investigations and explications. See also: Clericuzio, "Carneades and the Chemists: A study of *The Sceptical Chymist* and its impact on seventeenth-century chemistry," in *Robert Boyle Reconsidered* ed. Michael Hunter (Cambridge: Cambridge University Press, 2003), 79-90.

[33] Peter Alexander, *Ideas, Qualities and Corpuscles: Locke and Boyle on the External World* (Cambridge: Cambridge University Press, 1985), 9-10; Boas Hall, *Boyle on Natural Philosophy,* 81-93.

was problematic for Boyle's own agenda.[34] Boyle had to refashion chemistry in accordance with his Baconian ideals and corpuscular matter theory. He had to distinguish his own use of chemistry from that of the dubious 'vulgar chymists' who sought immediate practical gains and shrouded themselves in arcane beliefs.

The practical nature of chemistry offered the desired Baconian insight into nature's inner workings. Sargent tells us that chemistry was the best discipline through which Boyle could explore his corpuscular theories.[35] This is because chemistry provided a practical way to explore nature. It involved breaking down materials and studying them in controlled environments in transparent glass vessels in which they could be carefully studied. As explained by Boas-Hall, 'chemistry, it seemed to Boyle, came as near to dealing directly with the fundamental structure of matter as anything could do, and therefore chemistry must be an integral part of natural philosophy.'[36] Boyle saw chemistry as able to accommodate both theory and practice by allowing the practitioner to closely scrutinise and manipulate materials in the designated environment of the laboratory. Most importantly, chemistry is a science that directly illustrates the transformative capacity of the magical ethos that novel properties emerge purely through knowing how to apply actives to passives. That principle was retained in spite of jettisoning the suspect image and baggage of the magical traditions.

It was also important for Boyle to distance himself from the *tria prima* theory of matter traditionally adopted by the chymists.[37] The *tria prima* was a Paracelsian principle based on the notion that all bodies could be reduced to the principles of salt, sulphur, and mercury. Boyle did not believe in sympathies and antipathies, nor did he believe that all matter could be reduced to these three principles or substances.[38] Likewise, despite agreeing with Bacon on the most fundamental procedures for natural philosophy, Boyle disagreed entirely with Bacon's matter

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[34] Clericuzio, "Sooty Empirics," 329.

[35] Sargent, "Learning from Experience," 61.

[36] Boas Hall, *Boyle on Natural Philosophy*, 85.

[37] On the chymical *tria prima,* see: Clericuzio, "Sooty Empiricks," 330-37; Allen G. Debus, "Fire Analysis and the Elements in the Sixteenth and the Seventeenth Centuries," *Annals of Science* 23 (1967), 127-47; *idem., Man and Nature in the Renaissance* (Cambridge: Cambridge University Press, 1978), 20-26; *idem., The Chemical Philosophy,* 2 Vols (New York: Science History Publications, 1977), 51-60; Owen Hannaway, *The Chemists and the World: The Didactic Origins of Chemistry* (Baltimore: Johns Hopkins University Press, 1975).

[38] For more on Boyle's approach to the *tria prima,* see: Sargent, "Learning from Experience," 62-64.

theory. The latter's matter was appetitive, whereas Boyle's was passive. Boyle's theory required divine intervention, whereas Bacon's was more worrisome as it could be self-sufficient. Atomic or mechanical theories of matter were more accommodating of a deity that could set the mechanism in motion.[39]

Boyle's matter theory was corpuscular. This theory is explained in depth in *The Origin of Forms and Qualities* (1666).[40] Corpuscularianism conjectured that all matter was made up of the same basic stuff, which is 'extended, divisible and impenetrable.'[41] Boyle conceived of matter as being made up of tiny particles, called corpuscles, which arranged in particular combinations give rise to the qualities that we actually experience. To account for the large range of bodies that we experience from these apparently uniform particles, Boyle turned to motion.[42] The particles or corpuscles of matter are endowed with qualities of motion or rest, and motion is the fundamental power in the union and separation of corpuscles, whose combination, separation and recombination explains the phenomenal qualities we sense and the hidden properties of bodies.

In corpuscularianism, 'bulk, figure, rest, situation, and texture' are simply effects that modify the operation of the part of matter owing to the motion the corpuscles have upon each other. Boyle uses the example of sulphur, which is highly flammable yet 'would never be kindled, unless some actual fire, or other parcel of vehemently and variously agitated Matter should put the Sulphureous Corpuscles into a very brisk motion.'[43] He called the size and shape of matter accidents because they can be altered by interaction with other corpuscles.

It is only when motion drives corpuscles or clusters together that they produce new properties by virtue of their chemical interactions. *Prima Naturalia*, says Boyle, are particles of matter which are not sensible, and which are whole and undivided with a determinate shape. Then *minima naturalia* are clusters of corpuscles with a tiny bulk and 'close and strict adhesion'.[44] These little clusters are

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[39] On matter theories and the role of religion, see: Steven Shapin, *The Scientific Revolution* (Chicago: University of Chicago Press, 1996), 43-45.

[40] Boyle, *Origin of Forms*, *Works,* V, 281-491.

[41] Boyle, *Origin of Forms*, *Works*, V, 301.

[42] Boyle, *Origin of Forms*, *Works*, V, 305-07.

[43] Boyle, *Origin of Forms*, *Works,* V, 305-07.

[44] Boyle, *Origin of Forms*, *Works*, V, 326.

insensible, although they cannot be divided by nature back into *prima naturalia*. *Minima naturalia* have their own bulk and shape which when connecting to other clusters will necessarily alter by their position and cohesion.[45] When enough of these corpuscles are put in motion they cause sufficient alteration so as to generate a change that affects the senses to such an extent that we experience a new body. For example, air put into a great motion is called wind and is colder to the senses than the ambient air.[46] All phenomenal qualities for Boyle were relative to the hidden textures of corpuscular arrangements. By getting materials to interact chemically, corpuscles generate properties that they would not otherwise have, thus all properties of bodies are the product of a relational interaction among invisible corpuscles. Boyle could see that chemistry was of all the sciences the one most suited to intervene in corpuscular arrangements and thus induce novel properties. Few substances evidence such a dramatic rearrangement of corpuscles as gunpowder.

It is important that Boyle was using gunpowder to champion a new method and discipline over what had gone before. He claimed that he aimed not at 'raising or abetting a Faction in Philosophy, but at the Discovery of the Truth.'[47] Gunpowder was used in pursuing this truth. More importantly, he let his experiments show what chemistry, as a transformative art, could do. Revelation and transformation meet in the Baconian slogan 'knowledge is power.' When it comes to matter theory, transformation is more easily understood through some version of atomism whereby tiny particles combine and recombine to build up bodies and their resultant properties. This led to Boyle getting rid of occult powers and sympathies, yet like Bacon, he wanted to retain the goals of magic and alchemy. Gunpowder, although an everyday phenomenon, was one of the powerful secrets of matter that Boyle thought his approach could unravel.

Philosophising the Everyday

By Boyle's time, gunpowder was defined by its common and vulgar uses. To gain an understanding of the substance, however, Boyle had to translate or re-house

45 Boyle, *Origin of Forms, Works*, V, 326.

46 Boyle, *Origin of Forms, Works*, V, 326-27.

47 Boyle, *Origin of Forms, Works*, V, 285.

it within the chemical laboratory. Under chemical analysis, Boyle would manipulate gunpowder into revealing nature's processes. A crucial part of Boyle's chemical project was the use of laboratory techniques to philosophise the everyday. In one of Boyle's earliest published works he called upon medical practitioners to give up their secrets to natural philosophy.[48] This clearly tells us that from a very early stage Boyle's programmatic intentions were to appropriate everyday arts and render them philosophical.[49] Gunpowder is a profound example of how basic or common materials could be made to serve as inquisitional tools when explored in the correct methodological framework.

In this section I focus on the theoretical process and implications of re-housing gunpowder in Boyle's laboratory. I consider how gunpowder is a powerful example of an everyday phenomenon philosophised. It could only be philosophised via experiment. Experiment is a revelatory process and this was a good reason to bring substances into the laboratory. However, matter will only reveal its hidden qualities under duress. Transposed in the laboratory, gunpowder was subjected to systematic revelatory operations. Boyle wanted to promote the virtues of chemical experiments to reveal hidden potencies, but he knew that this would happen only under certain conditions.

Ubiquitous Gunpowder

Bacon demanded that scholars pay attention to the underappreciated everyday phenomena, and Boyle used gunpowder to make a similar point. It was important to understand the everyday. The most famous instance of Boyle's philosophising of common materials is the air. Despite its necessity to human life,

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[48] Boyle, *An Invitation to a free and generous Communication of Secrets and Receits in Physick* (1655), *Works,* I, 1-14. Hunter argues that this work was part of Boyle's efforts on 'public spirited activity' and railed against the 'social exclusivity' of knowledge that could be of benefit to the wider world, *God and Science,* 61. Principe provides an alternative reading, arguing that owing to this work being written at such an early stage in Boyle's career, it cannot be taken seriously as a statement of intention, and that Boyle's attitude towards secrecy was more complex and actually permitted some exceptions in the case of alchemy, *Aspiring Adept,* 148-49.

[49] Oster, "The Scholar and the Craftsman," 262 ff. Oster has shown how Boyle sought to make craft knowledge part of his programme, and the influence of his own background and later interaction with the Hartlib Circle in informing his approach to the manual trades.

the air was not sufficiently given over to natural inquiry until the 1640s.[50] Neglect of the everyday was a key point in Boyle's critique of the scholastics and the vulgar chemists. The failure to analyse common substances was a failure indeed. He lamented that 'with all this labour and toile of the Brain they are at last known, prove impertinent and useless to the making out with satisfaction, or so much as tolerably, the ordinary *Phaenomena,* which nature every day presents the world with.'[51] This is an utter oversight, claimed Boyle. We should not think 'that the most familiar Objects in the World, and that seem likely to afford the least Discoveries' have been well enough explored and explained.[52]

The huge power of gunpowder was at odds with its commonplace occurrence. In the early modern period, defence was a constant and pressing concern. In England, which experienced a dramatic Civil War in the mid-seventeenth century, the constant need for gunpowder was all too obvious.[53] Yet Boyle, like Bacon, wanted to remind his audience that this material used on a daily basis was indeed a wonder of nature. Bacon reminded his readers of this through his endeavours to reinstate gunpowder as a *magnale*; Boyle did this by drawing attention to its philosophical potential.

> When a Gunner or a souldier employs Gun-powder, it is not necessary that he should consider, or so much as know, of what and of how many ingredients (much less of what kind of Atoms) it is made, and the proportion and manner wherein they are mingled; but the Notice Experience gives him of the power of that admirable Concrete, as it is made up and brought to his hands, suffices to enable him to perform things with it, that nothing but their being common and unheeded can keep from being admir'd.[54]

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[50] Frank, *Oxford Physiologists.* Chapters 5, 6, and 8 cover the experiments of Boyle and others on the air and respiration.

[51] Boyle, *Origin of Forms*, *Works,* V, 283.

[52] Boyle, *Usefulness, Works,* VI, 517-18.

[53] On the specific challenges faced by mid seventeenth-century England in procuring saltpetre and gunpowder in the midst of civil war, see: Cressy, *Saltpeter,* 88-120. Cressy shows how the country both imported saltpetre and made state-supported efforts to ensure that supplies of the vital materials did not dwindle; Brenda Buchanan, "Art and Mystery," 240-42. Buchanan demonstrates the complexities of, and methods of, producing good quality gunpowder, which had become an essential commodity for the early modern world.

[54] Boyle, *Certain Physiological Essays, Works*, II, 24.

Gunpowder was used everyday by powder makers and soldiers who performed wonders with it on demand. These practitioners had only the bare knowledge of how to bring the three ingredients together, so their tacit knowledge was crucial. It was practical experience that was required to perform these huge effects. The description of gunpowder as 'common and unheeded' shows that Boyle perceived gunpowder to be so common that people had not seen fit to investigate its causes. In response, Boyle heralded the way to an understanding of gunpowder that would combine scholarly knowledge with practical knowhow.

Boyle proposed that natural philosophers should discover the ingredients and corpuscular structures that give gunpowder its peculiar powers. Despite gunpowder being simultaneously common, marvellous, and necessary to the early modern state, scholars had failed to really explicate its causes or do anything philosophically valuable with it. By Boyle's time, gunpowder was more or less taken for granted. As a potent example of what specific corpuscular arrangements could do when manipulated by human hands, it was an oversight not to have studied it properly. This material that was used so often and so well by manual workers could be of value to Boyle, but to make it philosophical, he had to bring it into his own territory—the laboratory.

Gunpowder in the Laboratory

Boyle was the seventh son of his family; free of the familial and political obligations of his older brothers.[55] He was at leisure to pursue his natural philosophy. In 1668 he moved in with his sister Katherine, Lady Ranelagh, in London. In this house he had his own laboratory, possibly in the basement.[56] A designated space to conduct his research was essential to Boyle. To study natural philosophy, all of his chosen topics of study had to somehow be transferred to his laboratory.

The early modern laboratory has been given a sociological analysis by Shapin who argues that the sites of knowledge production were important in

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[55] On Boyle's family and background see: Hunter, *God and Science,* 10-27.

[56] Steven Shapin, "The House of Experiment in Seventeenth-Century England," *Isis* 79 (1988), 373-404, on 379-70.

securing the validity of knowledge.[57] He further claims that to gain acceptance for the knowledge produced in the laboratory, the production of that knowledge had to be publically witnessed.[58] Shapin's account tells us about the social codes and forces that would surround the more public laboratory setting in Boyle's time. Yet he does not give much due to the practical activities and requirements of the laboratory.[59] Maurice Crosland delivers a more practical account of experimental locations.[60] He considers the equipment, layout and significance of the physical space necessary to experiment. To be considered a laboratory, a space had to have certain equipment and features, such as a furnace and chemical apparatus.[61] A laboratory was, literally and mentally, a distinct space.[62] Yet to really comprehend it, we cannot afford to dwell on just the theoretical or just the practical elements of the laboratory. We must pursue an understanding of both elements, and how this distinct inquisitional space was used.

Boyle did not do fieldwork, so everything had to take place within the laboratory. This was an environment contrary to the one that gunpowder and other materials normally found themselves in—a contrast that will be shown to be very stark in Chapter 3. Crosland says that 'the most basic feature of a laboratory is isolation from the everyday world'.[63] It was a dedicated space to produce knowledge but to do this, materials and ideas from the outside had to be transposed inside. Oster maintains that Boyle struggled to meet the ideal of incorporating craftsmen fully into the experimental process, as they were often unwilling to share the knowledge upon

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57 Shapin, "House of Experiment," 391-99.

58 Shapin, "House of Experiment," 387-88. He notes that there were social codes that let others visit laboratories, even in private residences, such as Boyle's. Yet Boyle would on occasion excuse himself from receiving visitors.

59 Shapin focuses on the social dynamic as opposed to the laboratory's operative aims and practices. He also questions Boyle's practical involvement in his own experiments: Steven Shapin, "The Invisible Technician," *American Scientist* 77, 554-63.

60 Maurice Crosland, "Early Laboratories c. 1600-c. 1800 and the Location of Experimental Science," *Annals of Science* 62 (2005), 233-53, on 239-45.

61 Crosland, "Early Laboratories," 238.

62 For more on the practical space of early modern laboratory, see: Owen Hannaway, "Laboratory Design and the Aim of Science: Andreas Libavius versus Tycho Brahe," *Isis* 77 (1986), 585-610; Peter J. Morris, *The Matter Factory: A History of the Chemistry Laboratory* (London: Reaktion Books, 2015), chapters 1 and 2. An archaeological approach to the early modern laboratory, demonstrating excavated evidence on the layout and instrumentation, is presented by: Marcos Martinón-Torres, "Inside Solomon's House: An Archaeological Study of the Old Ashmolean Chymical Laboratory in Oxford," *Ambix* 59 (2012), 22-48.

63 Crosland, "Early Laboratories," 239.

which their livelihood depended, and the intense investment and familiarity with their trades made it difficult for them to offer any real descriptions of their efforts to the unacquainted.[64] It may have been the case that it was not simple to incorporate craft processes into a Baconian experimental philosophy, but this is why, I argue, Boyle made materials and processes undergo this process of translation.

Boyle was not quite so divorced from practice as Oster and Shapin might suggest.[65] He had to be involved in laboratory practice, it was not enough just to 'embrace the activities of the artisan in his writings' and use the laboratory as a place 'to sift mechanical knowledge.'[66] In contrast with Oster's more philosophical and literary take on Boyle's incorporation of craft skills and practices, I maintain that his 'embracing' of craft activities necessarily involved a process of appropriation, translation and re-interpretation of those practices in conformity with Baconian protocols.

An apt comparison to gunpowder's laboratory translation can be made to Barbara Orland's study of milk.[67] She argues that eighteenth-century chemists endeavoured to 'transform milk into a chemically defined object.'[68] My approach to Boyle's use of gunpowder is similar to Orland's study in some senses. Like milk in the hands of eighteenth-century chemists, gunpowder raised a range of questions under Boyle's scientific analysis, and its ties to particular practical applications remained ever-present. By contrast, I emphasise the procedure of the transition into the laboratory. I argue that for Boyle, working before the chemical revolution of the eighteenth century, the philosophising of gunpowder required radical physical and conceptual transformations.

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[64] Oster, "The Scholar and the Craftsman," 266-67. The craftsmen who had spent years learning and perfecting their trade would have an intimate knowledge of it. Their understanding of their craft would be a tacit one that far exceeds words and a simple understanding of what to do in order to produce their products. Chapter 3 in this thesis tackles practically embedded tacit knowledge, and its implications for Baconian scholars, in greater detail.

[65] Shapin argues that Boyle did not often get his hands dirty in the laboratory, but rather a great deal of Boyle's experimentation was conducted by his technicians and assistants, "Invisible Technicians," 557.

[66] Oster, "The Scholar and the Craftsman," 271.

[67] Barbara Orland, "Enlightened Milk: Reshaping a Bodily Substance into a Chemical Object," in *Materials and Expertise in Early Modern Europe: Between Market and Laboratory,* eds. Ursula Klein and E. C. Spary (Chicago and London: University of Chicago Press, 2010), 163-97.

[68] Orland, "Enlightened Milk," 164.

To better comprehend the place of gunpowder in Boyle's laboratory, it is more analytically useful to turn to the work of Latour. He argues that there were boundaries between the laboratory and the wider world in which it was situated. Yet these boundaries are 'precisely what laboratories are built to destabilize or undo'.[69] Latour analysed the ways in which Pasteur's laboratory functioned as a place where outside phenomena could be translated into the world of the laboratory scientist before being re-translated for application in the outside world. Pasteur brought anthrax from the farm into a laboratory. Not only did he physically transport anthrax. He also translated the substance into his own terms. Thus, Latour argues, the very act of transposing the material brought about a conceptual shift. The disparity between outside and inside the laboratory no longer held good because the inside was made relevant to the outside.[70] The work done inside the laboratory would, if successful, generate knowledge that could be applied outside. In Pasteur's case, this was to solve the anthrax problem and treat the afflicted animals. But the laboratory is the location that the phenomena have to go through to get these results, as they need to be translated into the scientist's own terms and environment to be comprehended.

Pasteur worked on a laboratory on site, on the farm. Yet as argued by Latour, 'no two places could be more foreign to one another than a dirty, smelling, noisy, disorganized nineteenth-century animal farm and the obsessively clean Pasteurian laboratory.'[71] Scientists learn from the external world to move to the internal, translating what happens outside into their own terms on the inside. Boyle did the same. He took gunpowder from the field where it was used practically on a daily basis, and translated it into a phenomenon that now belongs in the internal world of the laboratory. Isolating it in this way allows it to fulfil a speculative role that in turn will lead to its new-and-improved practical ones. Gunpowder had to go through Boyle's laboratory in order for his understanding of it to be transformed, before putting this knowledge to use back on the outside. In Baconian terms, *experimenta lucifera* had to be generated in the laboratory before the *experimenta fructifera* could

[69] Latour, "Give me a Laboratory," 143.

[70] Latour, "Give me a Laboratory," 143-44.

[71] Latour, "Give me a Laboratory," 145.

be applied elsewhere. In the familiar setting of the laboratory, these common or 'outside' materials would unveil philosophical functions.

The difference between gunpowder's laboratory applications and its better known military ones was made clear during the reworking of two of Boyle's gunpowder experiments, which will be discussed below. The reworked experiments took small amounts of gunpowder and treated them with other chemicals and procedures to reach particular effects. No explosions, deafening bangs, pillows of smoke, or unpleasant sulphurous odours—the phenomena normally present after gunpowder is ignited. They look internally at the substance behind the huge effects, and unlock a variety of sensory experiences that we would not normally associate with gunpowder. Using chemistry, Boyle opened up a new way of conceptualising the substance that is miles away from the quotidian explosive that we are used to. It would not suffice to observe explosions or gunpowder making. It had to be chemically scrutinised in order to fulfil the inquisitional role that Boyle had in mind. He wanted to know what was behind gunpowder's explosive force: not only for the sake of understanding gunpowder, but also for understanding the powerful arrangements of matter that could produce such forces.

In the early modern period gunpowder was often described in relation to its physical handling and powerful effects. It is also the case that the substance was the prerogative of manual workers who made, sold, and used it. Unlike phosphorus, for example, gunpowder did not have its origins and meaning solely within the world of scientific curiosity. As a rarity and curiosity, phosphorous was noble topic of study for scholars but it was not in widespread common use on the 'outside' as gunpowder was, until after it had acquired laboratory significance.[72] Both substances were discovered by alchemists but gunpowder quickly found its way outside the alchemical world owing to its ability to quickly generate fire and explosions. It was clearly a candidate for a new generation of offensive and defensive weapons. Yet gunpowder did already have one foot in the laboratory, as the three ingredients individually, especially saltpetre, were a familiar part of the alchemist's repertoire. Boyle's treatment demonstrates an attempt to bring gunpowder back into the chemical fold.

[72] On the introduction of phosphorus to seventeenth-century natural philosophy, see: Golinski, "Phosphorus," 17-20.

To use gunpowder in his chemistry, Boyle would need to successfully pull it over into that domain from the world of the craftsmen. From the beginning of his scientific career, Boyle was associated with a Hartlibian tradition, which advised publicising craft knowledge for the good of the kingdom.[73] Boyle took a product of artisanal skill and reconfigured it as a philosophical tool. However, this meant taking certain materials out of the hands of artisans and so-called ignorant empirics. This was not necessary a noble act in the eyes of artisans. In a sense Boyle was appropriating artisanal secrets. To use these secrets for philosophical purposes, however, was noble in Boyle's eyes.

Oster argues that Boyle had two ideas of knowledge.[74] One pertained to theory and the scholarly elite, and the other was based in practice. The latter, such as ways of making explosives or medical aids, should, in Boyle's mind, be divulged and published. [75] Gunpowder, if we accept this division, definitely fit the latter category. Indeed Bacon had illustrated the transformative power of chemistry in his statement that chemistry, alongside agriculture, cooking, and gunpowder, for example, illustrated the transformative power of art. This listing was made alongside everyday phenomena, such as weaving and carpentry, which 'consist principally in the subtle motion of the hands or instruments' and are 'alterations of natural bodies' that 'give accurate information concerning local motion, which is a thing of great importance in many respects.'[76] Boyle understood the importance of Bacon's listing of everyday instances along with chemistry, and by relocating them within the laboratory he reconfigured them as philosophically interesting.

Engagement with craft knowledge was a key component of the early programme of the Royal Society, of which Boyle was a member. Yet in spite of a shared reverence for Bacon's *great instauration,* Boyle's working environment and goals were very different to those of the Society. Boyle's attendance at the Royal Society's meetings has been shown by Hunter to be quite infrequent.[77] He attended

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[73] On the publishing of craft secrets and knowledge, see: Eamon, *Secrets,* 329-32.

[74] Oster, "The Scholar and the Craftsman," 273.

[75] Oster, "The Scholar and the Craftsman," 273.

[76] Bacon, *Preparative, SEH*, IV, 257.

[77] Hunter, *God and Science,* 144-45. See also: *idem.,* "Robert Boyle and the early Royal Society: a reciprocal exchange in the making of Baconian science," *The British Journal for the History of Science* 40 (2007), 1-23. Hunter argues that although Boyle was clearly part of a different

many meetings at the outset but his attendance soon became sporadic. Like the Royal Society, Boyle did seek to produce works. He would need to transpose his laboratory-acquired knowledge into practical solutions if it were to fulfil the Baconian project. However, he was less concerned with the public campaign or institutionalisation of science than were many members of the Society.

Experiments of light could eventually turn into experiments of fruit, and the two were not mutually exclusive. Boyle was aware of 'that famous Distinction, introduc'd by the Lord *Verulam,* whereby Experiments are sorted into *Luciferous* and *Fructiferous.*'[78] He was also aware that there was no clear distinction between the two. Fructiferous experiments could 'promote our Knowledg' as well as 'advantage our interests.' Likewise light-bearing experiments whilst 'enrich[ing] our Understandings' could be in 'other waies useful.' If the experimenter is good enough, then 'there are few Fructiferous Experiments which may not readily become Luciferous to the attentive considerer of them.' In making the desired fructiferous effects, we get some insight into the potential causes, as well as into the nature of the produced effects. Experiments of light could, by virtue of highlighting the 'Nature or Causes of things' lead to the experiment becoming 'exceedingly Fructiferous.'[79]

Gunpowder illustrates the blend of *fructiferous* and *luciferous* experiments made in laboratory study. A practical example combines two of Boyle's favourite materials—gunpowder and phosphorus:

> If the lucid virtue of the *Constant Noctiluca* could be (as I see not, why it may not be) considerably invigorated, it may prevent a great deal of danger, to which *Men of War,* and other Ships are expos'd, by the necessity Men often have to come into the *Gun-Room* with common flames or fire, to take out *Powder,* which has occasion'd the blowing up of many a brave ship.[80]

Using phosphorus as a light source would make it safer to enter a dark powder-house. This tells us how an experiment of light (gaining knowledge of gunpowder and phosphorus and what happens when they interact) can produce works. We are

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experimental tradition than the virtuosi, the Royal Society influenced Boyle in his approach to natural history and the gathering of information under 'heads'.

[78] Boyle, *Usefulness II, Works*, VI, 433-34

[79] Boyle, *Usefulness II, Works*, VI, 433-34

[80] Boyle, *The Aerial Noctiluca* (1680), *Works,* VII, 275.

reminded that works are indeed the terminus of Boyle's Baconian programme. Laboratory produced knowledge could be exploratory, but it could also answer direct problems, as shown by the above example.

Natural Magic

Philosophising the everyday could lead to great power over nature, or magic in the Baconian sense. Boyle perceived gunpowder's power to be 'stupendous' in comparison to its basic composition.[81] Principe has correctly observed that Boyle had a keen 'interest in great effects produced by comparatively trifling causes.'[82] Gunpowder is a dramatic example of an effect outstripping the cause. The Baconian project aimed at realizing this powerful aim of natural magic.[83] Boyle is careful not to describe gunpowder, or his work in general, as 'magic' but the description and the goal fit his endeavours nonetheless.[84]

Wolfram Schmidgen maintains that 'Boyle's relationship to natural magic seems rather like Bacon's.'[85] Bacon's definition of natural magic, as you will recall from the previous chapter, is not concerned with superstition or demonology—and is in fact scathing of these. Hunter has shown Boyle's similar distaste and views on demonic magic, but argues that Boyle collected material concerning the spiritual realm with the goal of showing that it was real in order to help disassociate mechanical philosophy from atheism.[86] Yet, he neglects the aspect of Boyle's employment of natural magic, which is about the capacities of matter to produce wonders.

Based on *The Sceptical Chymist* (1661), in which Boyle set out his opinions on aspects of the nature of chemistry, Schmidgen argues: 'Boyle expresses his belief that a chemistry preoccupied with reducing bodies to some simpler or purer state fails to realize its scientific promise. Rather than making separation and purification

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[81] Boyle, *The Christian Virtuoso* (1690), *Works,* XI, 309-10.

[82] Principe*, Aspiring Adept*, 183.

[83] Bacon, *Novum Organum, OFB*, XI, 440-43.

[84] Michael Hunter, "Alchemy, Magic and Moralism in the Thought of Robert Boyle," *The British Journal for the History of Science* 23 (1990), 387-410.

[85] Wolfram Schmidgen, *The Exquisite Mixture: The Virtues of Impurity in Early Modern England* (Philadelphia: University of Pennsylvania Press: 2012), 51.

[86] Hunter, "Alchemy, Magic and Moralism," 395.

central, Boyle elevates the ontological and experimental value of mixture and promotes its use in other fields of inquiry.'[87] Furthermore, Boyle's claim that chemical mixtures had this power to transform was not far off from alchemical ideas of transmutation and generation,[88] which as we have already seen, Boyle was sympathetic towards. The basic tenet of corpuscularianism was that corpuscles mixed together in different combinations and textures to provide an infinite range of bodies and properties. For Boyle, effects that would often be described as occult or magical could be performed via basic chemical mixtures and procedures.

The epigraph to this chapter, which describes the actions of matter when 'agents' are applied to 'patients', owes a great debt to the tradition of natural magic. The phrase 'agents to patients' (or 'actives to passives') is a borrowing from Agrippa and others in the renaissance magic tradition,[89] to describe the creation of magical effects. Rossi describes Agrippa's approach as showing 'that the so-called miracles of magic are not, like the miracles of saints, a violation of natural laws, but the result of developing natural powers. They are miracles only in the etymological sense: things worthy of admiration.'[90] Gunpowder was composed and manipulated by a human agent who, by merely mixing certain materials, triggered powerful insensible motions of matter thereby generating huge phenomenal effects. Boyle, in his descriptions of gunpowder, appeals to its huge and impressive effects. A basic knowledge of the simple mixture gave men a power much stronger than themselves.

Of all substances producing a great effect from a comparably small cause, gunpowder must surely rank supreme. It was for Boyle and his contemporaries an obvious example of the prodigious capabilities of tiny bodies of matter. To take just 'a single corn of Gunpowder, or two or three together' will not be of requisite 'Force to do much mischief.'[91] When you take 'two or three Barrels of those Corns taking Fire altogether,' however, you 'are able to blow up Ships and Houses, and perform prodigious things.'[92] Boyle argued that it is an instance demonstrating the 'celerity of

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[87] Schmidgen, *Exquisite Mixture*, 42; Boyle, *The Skeptical Chymist, Works*, II.

[88] Schmidgen, *Exquisite Mixture,* 51-52.

[89] Heinrich Cornelius Agrippa von Nettesheim, *Three Books of Occult Philosophy,* trans. J. F. (London: 1651); Rossi, *Magic to Science,* 18-19.

[90] Rossi, *Magic to Science*, 19.

[91] Boyle, *Essays of Effluviums* (1673), *Works,* VII, 258.

[92] Boyle, *Effluviums*, *Works,* VII, 258.

the motion of very minute Bodies, especially conjoined to their multitudes' that 'may perform very notable things, as may be argued from the wonderful effects of fired gunpowder, Aurum Fulminans, or flames that invisibly touch the Bodies they work on.'[93] These bodies may be tiny but they can swiftly make a huge impact. In gunpowder Boyle saw that there is potentially a huge power to be gained from the minutest parts of nature.[94] Huge powers need not be miraculous in any superstitious or supernatural sense, but rather an example of what chemistry could do. Like Bacon, Boyle used gunpowder as an example of the ability of mechanical arts to affect huge changes.

Gunpowder's Dual Power: Manifest and Inquisitional

In this section, I argue that gunpowder offered Boyle a dual power. It contained an obvious physical power given off on ignition. But it also had an internal philosophical power, to look inwardly at nature. This section provides practical examples of how Boyle perceived gunpowder and what it could do when re-housed in the laboratory. Understandably, the manifest power of gunpowder would have attracted Boyle's attention. But his main goal was to use gunpowder as a possible route to true Baconian power over nature, based on knowledge of the occult virtues and motions of matter.

Manifest Power

Bacon made a point of emphasising the marvel of gunpowder. Boyle did the same. A vocabulary of awe and fascination colours Boyle's descriptions of gunpowder and its effects. From the descriptions Boyle provides of gunpowder's forces, it is easy to see why he found it philosophically arresting. Recounting a 'most memorable instance' of a ship blown up on the River Scheldt, Boyle describes the physical devastation of ignited gunpowder. The ship was a 'floating mine' and the

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[93] Boyle, *Effluviums*, *Works,* VII, 261. Aurum Fulminans is a powerful fulminating gold powder.

[94] Bacon used the speed of gunpowder's reaction as one of the reasons that it was a magical instance, *Novum Organum, OFB,* XI, 442-43. Gunpowder imparts its energy so quickly that opposing bodies have no time to respond.

motions of this gunpowder explosions are so powerful that they travel 'through differing mediums, one of them as solid as earth.'[95]

> On a sudden the fatal ship burst, with such a horrid crash, as if the very Sky had rent asunder, Heaven and Earth had charg'd one another, and the whole Machine of the Earth it self had quaked. From the Storm of Stones, Chains and Bullets being cast out with Thunder and Lightning, there followed such a Slaughter, as no man, but that actually it happen'd, could have imagin'd. The Castle on which the Internal Ship fell, the Pile-work of the Bridge to St Mary's Fort, that part of the Naval Bridge next the Castle, Souldiers, Mariners, Commanders, a great number of Cannons, Armour and Arms; all these furious whirlwind swept away together, tossed in the air, and disperst as Wind doth Leaves of Trees. The *Scheldt* prodigiously gaping was first seen to discover its bottom, and then swelling above the Banks, was even with the Rampiers, and overflowed *Mary's* Fort above a foot. The motion of the painting Earth *N.B.* extended its force and fear above nine Miles. There were found Stones, and that very great ones, as Grave-stones, and the like, a Mile off the River, struck into the Ground, in some places four palms.[96]

Gunpowder's force was massive. Its energy was destructive. The impact of the explosion was felt for miles, and the impact was a lasting one. It tore down castles, injured soldiers, and devastated the surrounding environment. The explosion of gunpowder may be momentary, but it lives longer in the form of physical destruction. A substance capable of such things was a more than worthy topic of natural inquiry.[97]

The manifest effects of gunpowder, said Boyle, were so powerful that they had to be experienced to be believed:

> If Experience did not both Inform and Certify us, Who would believe, that a light black Powder should be able, being duly manag'd, to throw down Stone-Walls, and blow up whole Castles and Rocks themselves,

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[95] Boyle, *An Essay of the Great Effects of Even Languid and Unheeded Motion* (1685), *Works,* X, 294. The passage is, according to Hunter, based on an account of 'Famianus Strada,' a Flemish historian who accounts for the same event in his work *De bello Belgico* (1632-47).

[96] Boyle, *Languid and Unheeded Motion, Works*, X, 294.

[97] Gunpowder was not the only source of massive power that elicited Boyle's interest. He described aurum fulminans, the extremely powerful yet extraordinarily volatile fulminating gold powder, as 'the most wonderful thing that chymistry has presented us with.' From: The Royal Society Archives. Robert Boyle, "Note on Aurum Fulminans," *Boyle's Commonplace Book,* 187 fol 137 in "The Boyle Collection," Ref: RB/2/18/49. On the importance of wonder in the emergence of early modern science see: Lorraine Daston and Katharine Park, *Wonders and the Order of Nature, 1150-1750* (Cambridge, Mass: Zone Books, 2001).

> and do those other Stupendous things, that we see actually perform'd by Gun-powder, made use of in Ordnance, and in Mines?[98]

This tells us why gunpowder is a natural philosophical curiosity, and why experience would be necessary in comprehending it. On the surface of things gunpowder seems unassuming but when practically manipulated in particular ways it produces these stupendous, magical, effects. To those unfamiliar with gunpowder in the 'Indies', claimed Boyle, it was hard to perceive how 'twas possible for the *Europeans* [...] in a Moment [to] produce Thunder and Lightning, and kill Men a great way off, as they saw Gunners and Musqueteers do.'[99] Only a 'few barrels of gunpowder' is requisite to blowing up 'many hundred, not to say thousand, tonnes of common rock.'[100] Such quotidian examples of gunpowder's employment are evidence that magical effects are within reach.

Boyle realised that gunpowder was capable of much more than its battlefield applications:

> Thus Gun-powder artificially temper'd, tho', if it be fir'd in the open Air, it will give only a rude and sudden Flash, that presently vanishes; yet, if it be skilfully dispos'd of in Rockets and other well-contriv'd Instruments, and then kindled, it will exhibit a great and pleasing variety of Shining Bodies and *Phaenomena,* that are justly admir'd in the best sort of Artificial Fire-works.[101]

This is why human skill must form a part of natural philosophy in Boyle's view. A practical understanding of gunpowder meant that practitioners could employ it in much more sophisticated ways. Fireworks were a fine example of what else gunpowder had to offer. Boyle wanted to find more ways to manipulate the substance, not just to elicit practical effects but also to reveal knowledge.

And this takes us into the laboratory. The scholastic doctrine would not possibly comprehend or give gunpowder its due analysis. Gunpowder's manifest power was sufficient to indicate that gunpowder was common but not ordinary. It begged the question, what made gunpowder have such huge power? The manifest

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[98] Boyle, *The Christian Virtuoso* (1690), *Works,* XI, 309-10.

[99] Boyle, *Some Considerations about the Reconcileableness of Reason and Religion* (1675), *Works,* XIII, 309. It is important we remember that in this passage, Boyle is simply assuming the viewpoint of other peoples.

[100] Boyle, *Usefulness II, Works*, XI, 497.

[101] Boyle, *Free Inquiry into the Vulgarly Received Notion of nature, Works*, X, 563.

gunpowder was an important and valuable attribute of gunpowder, but for Boyle this was not true Baconian power. He knew that by studying it chemically, new powers—manifest and theoretical—could be discovered.

Gunpowder's Inquisitional Power

> I might to illustrate the power of mechanicall contrivances [have] mention'd the strang and scarce credible increase of force which we have seen modern Gunsmiths give to Gunpowder by dischargeing it & leaden bullets out of Barrels scru'd within. And I might also add severall new Applications that have been made of the force of Gunpowder by Engineers one of whom a great aquantance of mine has lately <before numerous & some of them severe Eye-witnesses> perform'd things of that Nature <whose Effects I was sorry to see so admirable>, But instead of instanceing in such destructive Experiments wherein Mankind has been but too ingenious (to its owne mischief) I shall rather add that by Mechanicall contrivances not onely strange Effects may be produc'd but strong truths alsoe discover'd.[102]

Boyle's theory of matter offered to provide mechanical explanations for natural phenomena. He wanted to combat occult explanations to understand the real causes of nature's hidden powers. The corpuscular theory of matter and his Baconian method, thought Boyle, were sufficient to explain those seemingly inexplicable properties of bodies that other schools of philosophy had failed to address. Millen has shown that Boyle incorporated occult qualities into his programme as something to be explained mechanically, but that he did not prioritise these over the investigation of other qualities.[103] He argues that occult qualities were just another sort of quality to be explained, along with primary qualities, sensible qualities, and secondary qualities. In agreement with Millen, Hutchison claims that Boyle 'took on a philosophical stance that assumes no ultimate distinction between the occult and the seemingly manifest.'[104]

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[102] Boyle, *Material Relating to The Usefulness of Natural Philosophy. Sections from the original version of Usefulness, Works*, XIII, 300-01.

[103] Millen, "Manifestation of Occult Qualities," 211-14.

[104] Hutchison, "Occult Qualities," 246. He suggests that for Boyle, manifest qualities were just as problematic and in need of explanation as occult qualities, effectively removing the Aristotelian barrier between occult and manifest. A small departure to the approach of Hutchison and Millen is taken by Eaton, who interprets Boyle as objecting to occult *explanations,* rather than occult properties: William Eaton, *Boyle on Fire: The Mechanical Revolution in Scientific Explanation* (London: Continuum, 2005), 8. It was not possible to object to occult properties, as they were simply re-presented as hidden causes and these were a fact of matter.

Boyle's manuscript 'Considerations touching occult qualities,' can tell us more about how he approached the occult properties of matter.[105] He criticises the Aristotelians for failing to get to grips with occult qualities, claiming that they do not explain them by labelling them occult, but merely 'disguise them by new names.'[106] The manuscript demonstrates Boyle's strong interest in occult properties and his desire to combat occult explanations of them. He stated that he was not interested in replacing occult properties, but rather he wanted to 'deprive occult qualityes of that name.'[107] He hoped that as knowledge increases, the amount of qualities deemed occult would be reduced.[108]

Boyle portrayed '*Effluvia,* of *Pores* and *Figures,* and of *Unheeded Motions,* as the three principal Keys to the Philosophy of Occult Qualities.'[109] Gunpowder fits into most of these categories. In Boyle's ontology, gunpowder gave off effluvia or tiny particles that permitted it to invisibly act on distant patients. Boyle cites gunpowder as an example of a body emitting effluvia in order to affect action at a distance.[110] He uses the instance of a grenade, whereby the action is produced 'not by the feeble agent itself, but by the parts of the Engine workeing upon another.' When the spark ignites the grenade, it is not the spark that 'blow[s] up […] neighbouring body's,' but rather it kindles a corn of gunpowder which then propagates the flame to the rest of the corns and blows up the shell which is too feeble to accommodate 'soe vast an Expansion'.[111]

Moreover, gunpowder's motion was unheeded.[112] It was typically taken for granted, in spite of its huge power. In spite of its ubiquity, ignited gunpowder was one of the most, if not the most, powerful phenomena in nature.

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[105] Boyle, "Notes upon ye Sections About Occult Qualities," in Royal Society Boyle Papers XXII, 201-44, fos. 10lr-122v. Reproduced in: Marie Boas-Hall, "Boyle's Method of Work: Promoting his Corpuscular Philosophy," *Notes and Records of the Royal Society of London* 41 (1987), 111-43, on 124-43.

[106] Boas Hall, "Boyle's Method of Work," 125.

[107] Boas-Hall, "Boyle's Method of Work," 125.

[108] Boas-Hall, "Boyle's Method of Work," 137-38.

[109] Boyle, *Effluviums, Works,* XII, 229. Copenhaver, "Two Fishes," provides a useful case-study and account of approaches to 'action at a distance' in early modern philosophy.

[110] Boyle, "Notes About Occult Qualities," 134.

[111] Boyle, "Notes About Occult Qualities," 134.

[112] C.f. above quotation '…nothing but their being common and unheeded can keep them from being admir'd': Boyle, *Certain Physiological Essays, Works,* II, 24.

> [I] doubt, whether we know any thing in nature, except kindled Gunpowder, that bulk for bulk moves more forcibly, though the motion seems to be very slow.[113]

This quotation is making a comparison between the force of gunpowder and the force of water turning to ice. Like gunpowder, freezing water is an example of a languid and unheeded motion. He argues that 'men often undervalue the motions of bodies too small to be visible or sensible, notwithstanding their numerousness, which inables them to act in swarms.'[114] Boyle showed that even slow-moving phenomena could have great force. He challenges common views of effluvia, which many of his contemporaries incorrectly supposed to be 'but much finer sorts of dust' that are 'blown against the surfaces of the bodies they chance to meet in their way'.[115] Rather, Boyle says, effluvia are bodies that can 'invade' other bodies owing to their size and numerousness. This is what happens during the ignition of gunpowder and in the phenomenon of 'the expansive endeavour of freezing water'—both of which are incredibly powerful processes.[116] Both the ignition of gunpowder and water turning to ice are the result of effluvia that move in an unheeded but powerful way to slowly take over opposing bodies with massive force.

Boyle aimed to mechanise these hidden but powerful processes underlying gunpowder's manifest effects. He used a very powerful substance as an obvious example of an occult quality. However, he endeavoured to incorporate occult qualities in his presentation of an alternative theory of matter. In the process of doing so, he could eliminate the major scholastic and Paracelsian competitors. Whereas the Paracelsians would reduce all matter to fundamental principles, Boyle would show that they could be reduced to corpuscular structures.

Gunpowder and Matter Theory

Boyle made several experiments with the aim of commenting on gunpowder's occult qualities. In these experiments, he explains gunpowder

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113 Boyle, *Languid and Unheeded Motion, Works*, X, 267-68.

114 Boyle, *Languid and Unheeded Motion, Works*, X, 263.

115 Boyle, *Languid and Unheeded Motion, Works,* X, 263.

116 Boyle, *Languid and Unheeded Motion, Works*, X, 268.

according to the corpuscular theory. This is why he brought gunpowder into the laboratory. It was one of the most powerful forces in matter, so to explain gunpowder could lead to explaining many things. Boyle had to distance himself from alchemical matter theories to show the validity of his Baconian project. If he could show that his way of thinking was suitable to explicating the mysterious causes of gunpowder, he could surely garner support for it. He directly challenged alchemical conceptions of matter, explaining that the mechanical nature of gunpowder,

> may be illustrated by what happens in Artificial Fireworks. For, though in most of those many differing sorts that are made either for the use of War, or for Recreation, Gunpowder be a main Ingredient, and divers of the *Phaenomena* may be deriv'd from the greater or lesser measure, wherein the Compositions partake of it; yet, besides that there may be Fire-works made without Gun-powder, (as appears by those made of old by the *Greeks* and *Romans,*) Gun-powder it self owes its aptness to be fir'd and exploded to the Mechnanical Contexture of more simple portions of Matter, *Nitre, Charcoal,* and *Sulphur*; and Sulphur it self, though it be by many Chymists mistaken for an Hypostatical Principle, owes its Inflammability to the convention of yet more simple and primary Corpuscles; since Chymists confess, that it has an inflammable Ingredient, and experience shews, that it very much abounds with an acid and uninflammable Salt, and is not quite devoid of Terrestreity. I know, it may be here alledg'd, that the productions of Chymical Analyses are simple Bodies, and upon that account irresoluble. But, that divers Substances, which Chymists are pleased to call the *Salts,* or *Sulphurs,* or *Mercuries* of the Bodies that afforded them, are not simple and homogeneous, has elsewhere been sufficiently proved; nor is their not being easily disipable or resoluble a clear proof of their not being made up of more primitive portions of matter.[117]

Boyle shows that gunpowder is not made up of hypostatical principles, but mechanical contrivance. The *tria prima* of the Paracelsians would reduce all bodies to three fundamental principles—salt, sulphur, and mercury. That first two of these principles were, in their physical form, ingredients in gunpowder, was important for Boyle. For this reason gunpowder offered a good platform from which to attack elemental matter theories and replace them with corpuscularianism.

Gunpowder's primary ingredient, saltpetre, was the subject of one of the most crucial moments in Boyle's natural philosophy, when he carefully explicated his corpuscular theory. The 'Redintegration of Nitre', first edition 1661, placed a

[117] Boyle, *Excellency and Grounds of Mechanical Hypotheses* (1674), *Works*, XIII, 111.

chemical experiment at the heart of an extended explication on matter theory.[118] Newman and Principe rightly describe the essay, respectively, as ‘a work at the vanguard of [Boyle’s] program of placing chymistry in the service of natural philosophy’, and an attempt to ‘dignify’ chemistry.[119]

Frank argues that nitre had a huge appeal to Boyle as a young chemist.[120] Boyle’s work diaries show saltpetre becoming an increasingly regular feature in his chemical endeavours from the early 1650s, as it ‘was a most useful laboratory reagent.’[121] The second reason that Frank attributes to nitre’s importance to Boyle is its role in the much sought-after gunpowder.[122] Finally, he correctly notes that saltpetre was a substance well suited in explicating the value of his corpuscular philosophy—as shown by the redintegration experiment.

Boyle put saltpetre at the heart of this important experiment for many reasons. Firstly, it was high status and well known. Saltpetre was not only in high demand for use in chemistry, but for wider use in gunpowder. To convince others to a new way of thinking about matter, he could not in the first instance dwell on novelties or rarities. He was providing new and better ways of explaining old and necessary things. Moreover, as salts formed part of the *tria prima* Boyle could deliver an attack on Paracelsianism by showing that salt is not fundamental and could itself be reduced further to its corpuscular structure, along with all other supposed principles.

The conflict between Boyle and the Paracelsians pertaining both to methodology and theory is important; Boyle learned his art from alchemists. Salts were fundamental to alchemical work and saltpetre was a highly significant

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118 Boyle, *Certain Physiological Essays,* 2nd edn. (1669),*Works,* II. This experiment is also known simply as the ‘essay on nitre’. I agree that Boyle put saltpetre to a different use than did his colleagues in the Hartlib Circle, as argued by Hunter, *God and Science,* 116. It is likely that Boyle’s interest in saltpetre started when he became involved with the scholars of the Hartlib Circle who worked enthusiastically on developing new and improved ways of procuring it.

119 Newman and Principe, *Alchemy Tried in the Fire,* 311; Principe, *Aspiring Adept,* 33-34.

120 Frank, *Oxford Physiologists*, 121-22.

121 Frank, *Oxford Physiologists*, 121-22.

122 Frank, *Oxford Physiologists,* 118-22. Although Frank attributes Boyle’s interest in nitre to its role in gunpowder, I argue it was at least it was a two way street. Saltpetre certainly precedes gunpowder in Boyle’s written work. It is seen often in his work diaries and treatises from the 1650s, whereas gunpowder research for Boyle is at a peak in the 1660s and 70s. When brought together, the ingredients of gunpowder performed effects far beyond what they could do individually. Thus to get to grips with the most mysterious component of the mixture could lead to a better understanding of gunpowder. Indeed, Frank has also argued that Boyle and his contemporaries understood nitre as the root of gunpowder’s explosive effects, 118.

substance for the alchemists, often being styled as a universal body, and linked to life itself.[123] The 'aerial nitre' of the Paracelsians, was interpreted in a similar way to that in which oxygen is understood today, as vital to combustion and respiration.

Whilst Boyle gives no indication of subscribing to the aerial or 'philosophical' nitre, he does acknowledge the importance of saltpetre's almost universal presence in a great many bodies. Rather than simply explain saltpetre as aerial or universal however, he sought to instigate an investigation into its corpuscular properties. The essay begins:

> SALT-PETRE, *Pyrophilus,* though in that form wherein it is sold in Shops, it be no very obvious Concrete; yet either in its rudiments, or under several disguises, is to be found in so great a number of Compound Bodies, Vegetable, Animal, and even Mineral, that it seems to us to be not only one of the most Catholick of Salts, but so considerable an Ingredient of many sublunary Concretes, that we may justly suppose it may well deserve our serious enquiries, since the knowledge of it may be very conducive to the discovery of the Nature of several other Bodies, and to the improvement of divers parts of Natural Philosophy.[124]

To gain an understanding of something so fundamental in matter and so universal would surely be of use for understanding nature. Boyle implies that the universality of saltpetre is important, because understanding a body found so widely in nature could lead to developments in other parts of natural philosophy purely from the fact of its analogous function in a great many diverse instances.

The experiment suggested that saltpetre was not homogenous, but rather was made up of two components—one acidic, one alkaline. The procedure, said Boyle, forced off the volatile acidic component. On adding spirit of nitre to the remaining fixed alkaline component, the mixture is 'redintegrated' or turned back into saltpetre. Boyle argues that we can obtain different substances from nitre, and compound them again.[125]

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123 On the 'aerial' or 'universal' nitre, see: Allen G. Debus, "The Paracelsian Aerial Niter," *Isis* 55 (1964), 43-61, on 47-48; Henry Guerlac, "The Poets' Nitre," *Isis* 45 (1954), 243-55; Roos, *Salt of the Earth,* 23-25; Zbigniew Szydlo, "The Influence of the Central Nitre Theory of Michael Sendivogius on the Chemical Philosophy of the Seventeenth Century," *Ambix* 43 (1996), 80-96.

124 Boyle, *Certain Physiological Essays, Works*, II, 93.

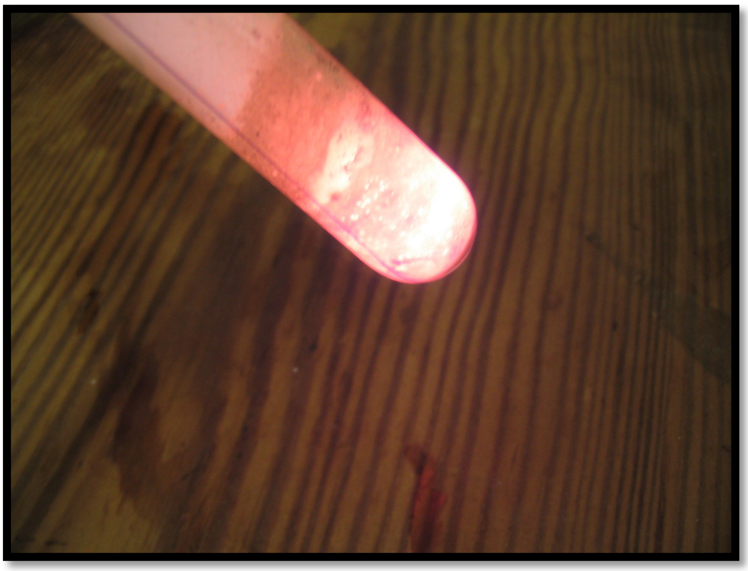
125 Boyle, *Certain Physiological Essays, Works*, II, 93.

Experiment 1: The Redintegration of Nitre

From: Robert Boyle, "Redintegration of Salt-petre," *Certain Physiological Essays* (1669), *Works,* II.

Experiment by Haileigh Robertson and Peter Smithurst 2013.

Boyle placed an unspecified weight of nitre in a crucible that was then placed over a fire in order to melt it. To make the reworking of the experiment more manageable, we used a test tube held with tongs over a flame. Lit coals are then cast one-by-one into the melted saltpetre. We used tongs to heat up tiny pieces of coal before dropping them into the test tube. This causes a bright, hissing reaction. Boyle interpreted this as the 'volatile' acidic component of the nitre being driven off, leaving the 'fixed' alkaline component behind. The addition of coals, we know now, drives away the oxygen from the nitre.



The remaining substance was dissolved in water and tested with a litmus paper, which proved it to be alkaline. Boyle, in modern terms, had turned potassium nitrate into potassium carbonate. To return the mixture to its nitrous state, 'spirit of nitre', which is nitric acid, is added. This reintroduced the oxygen and acidic component to reproduce the potassium nitrate.

Saltpetre's qualities, in Boyle's view, are the result of the interactions of the volatile and fixed corpuscular parts. Thus there is no substantial form or inherent essence of saltpetre, as scholastic explanation would posit, because it could be taken apart and these qualities removed and then restored:

> The Redintegration (or Reproduction) of an analys'd body, if it can be accurately and really perform'd, may give much light to many particulars in Philosophy, and would certainly be very welcome both to the embracers of the Atomical Hypothesis, and generally to those other Modern Naturalists, who aspire to such Explications of Nature's *Phenomena* as may at least be understood: all whom I wish, that though men cannot perhaps in all things, yet at least as far as they can, they would accustom themselves to speak and think as nature does really and sensibly appear to work; and not to acquiesce in notions and Explications of things which, strictly examin'd, are not intelligible.[126]

Boyle suggests that 'the Reflections which may be made on this Experiment are more than I have either the skill or leisure to prosecute'.[127] He shows that the corpuscular theory is based on simple architectural concepts to explain natural phenomena, without appealing to imaginary occult or abstract principles.

The experiment provided a clear example of how arrangements of corpuscles produce the qualities of bodies that we sense on a daily basis. He reflects:

> And first, this Experiment seems to afford us an instance by which we may discern that Motion, Figure, and Disposition of parts, and such like primary and mechanical Affections (if I may so call them) of Matter, may suffice to produce those more secondary Affections of Bodies which are wont to be called Sensible Qualities.[128]

Boyle's major claim then is that the scholastic doctrine of forms is problematic because the form of the body is not inherent in nitre, unless the Aristotelians were willing to change their views and admit that a form could in fact be created by human art. Otherwise, Boyle was adamant that he had shown how a substance could be taken apart to produce bodies that have natures entirely different from the nature they share when they come together. Two substances

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126 Boyle, *Certain Physiological Essays, Works*, II, 108.

127 Boyle, *Certain Physiological Essays, Works*, II, 98.

128 Boyle, *Certain Physiological Essays, Works*, II, 98.

when brought together gain a nature foreign to what they had individually, so 'there emerges a third body differing in qualities from either.'[129]

According to Boyle the experiment did not produce 'an exact and Adequate Redintegration' but it was 'not far from being a real one.'[130] He did recombine the parts to make a 'body of the same nature,' however this was not 'of the same bulk'.[131] He ended up with a smaller volume of saltpetre than he had started with. As correctly observed by Newman and Principe, however, this was not a huge obstacle, as Boyle's endeavour was not necessarily intended to make an exact redintegration but to champion the corpuscular theory of matter.[132] Discovering the nature of nitre was secondary; this was about presenting a challenge to the scholastic theory of forms, and in this, Boyle was successful.

The redintegration experiment bears similarity to Bacon's *crucial instances*. As you will recall from Chapter 1, the *crucial instances* were intended to provide experiments or considerations that would help the operator decide between two or more possible theories or outcomes. Boyle's experiment addresses three matter theories—scholastic, alchemical, and atomic (and by extension Boyle's version of atomism, corpuscularianism). It shows that the former two will not work to explain the phenomenon of saltpetre, so it guides the intellect towards the latter. Moreover, Boyle had advanced the cause of chemistry by showing how the chemical method afforded a route into nature's inner workings. His experiments not only explained activity at the micro level but also on the experiential or phenomenal level.

The essay was well received. So much so that Henry Oldenburg recommended it to some of his contacts, including Benedict Spinoza.[133] Whilst he appreciated parts of the essay, Spinoza was critical of its underlying principles. Oldenburg mediated the ensuing controversy between Boyle and Spinoza. That gunpowder, or at least its main ingredient, was at the heart of such high-level

[129] Boyle, *Certain Physiological Essays, Works*, II, 110-11.

[130] Boyle, *Certain Physiological Essays, Works*, II, 108.

[131] Boyle, *Certain Physiological Essays, Works*, II, 108.

[132] Newman and Principe, *Alchemy Tried in the Fire,* 311-12.

[133] "Henry Oldenburg to Borri 1661," in *The Correspondence of Henry Oldenburg,* 9 Vols, Vol. I, ed. Marie Boas and A.R. Hall (Milwaukee: University of Wisconsin Press, 1965-73), 418 -19; Oldenburg to Spinoza 1662, *Oldenburg Correspondence,* I, 432.

discussions underlines its importance. As Spinoza admits, Oldenburg would not have passed on the work 'unless it was of great moment.'[134]

The redintegration controversy has not received the attention that we might expect; given the status of the protagonists. Moreover, sufficient attention has not been given over to understanding the huge gulf in the conceptions of natural inquiry that separated Boyle and Spinoza. It has been recognised that the discussion was more about method than saltpetre itself, and that Spinoza and Boyle were not really on the same wavelength. Marie Boas-Hall and A. R. Hall say that Spinoza was 'unable to comprehend the more limited objectives of such an experimental scientist as Boyle.'[135] Filip Buyse explains that Oldenburg thought that Spinoza had 'missed the point' as Boyle meant to undermine substantial forms and qualities, rather than making an accurate redintegration.[136] It is perhaps fairer to say that Spinoza did not miss the point, but rather, he had an entirely different view on how to reach fundamental truths. Regardless of the subject of the experiment, Spinoza would have reached a different conclusion because he had a different method and an irreconcilable approach to natural philosophy.

Sargent observes that Spinoza, a Cartesian, thought that experiment should begin with mathematical reasoning in order to learn the truths about matter.[137] Buyse argues that Spinoza's main point of contention 'was with the empiricist underpinnings of Boyle's experiments.'[138] Spinoza was not opposed to experiment and he did not support scholasticism, but his method was deductive. He did not think, as Boyle did, that experiment was the way to knowledge.[139] Spinoza was not interested in the way chemical properties provide information, as he did not think that they did. In his view, he had the underlying causes of properties already so he would work from these to explain phenomenal properties. This is in opposition to the Boylean approach that began with the phenomena in hand and then would work downward until eventually causes are reached. Spinoza does not sanction Boyle's

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[134] "Spinoza to Oldenburg Letter VI 1662," in *The Correspondence of Spinoza,* ed. A. Wolf (Frank Cass & Co. Ltd., 1996), 84-99, on 85.

[135] "Spinoza to Oldenburg 1662," in *Oldenburg Correspondence,* 448-470.

[136] Filip Buyse, "Boyle, Spinoza and the Hartlib Circle: The Correspondence which Never Took Place," *Society and Politics* 7 (2013), 34-53.

[137] Sargent, *The Diffident Naturalist,* 68-69.

[138] Buyse, "Boyle, Spinoza and the Hartlib Circle," 46.

[139] Buyse, "Boyle, Spinoza and the Hartlib Circle," 45-46.

view of the importance of experiment. He is not particularly interested in power in the Baconian sense, but more in explanation and resolving religious, ethical and political controversy. In that sense he differs from Boyle in the way Thomas Hobbes differs from Boyle: both of Boyle's opponents produced magisterial systems—an activity at odds with Bacon's demand for a union between the contemplative and the operative.

This conflict is significant. It highlights the non-obviousness of experiment as a scientific method, and on that score Schaffer and Shapin are entirely correct.[140] Nitre was, in a sense, just a means to an end for Boyle. He wanted a good medium through which he could explain his corpuscular philosophy and the inherent nature of nitre made it appropriate for this task. Nonetheless, the fact that nitre was considered appropriate for Boyle to explicate corpuscularianism tells us of the importance of the material. The relocation of gunpowder and its components to the laboratory shows the important issues on which they could comment. They could generate high-level discussion from the most important scholars of the day.

Separating the Ingredients of Gunpowder

The redintegration of nitre was the starting point of Boyle's corpuscular philosophy and from this he developed *On the Origin of Forms and Qualities.*[141] We have seen how the experiment although concerned with saltpetre is relevant to Boyle's research on gunpowder. Now it is time to return fully to the latter. Boyle conducted a chemical experiment with the aim of separating gunpowder from the tripartite mixture back into its original components. This not only comments on corpuscular theories, but also on chemical mixtures.

Boyle used chemical processes to show how corpuscular interactions between bodies could generate new and sometimes powerful properties. In an experiment to separate the ingredients of gunpowder, Boyle would prove that these three ingredients, which alone could produce effects nothing like that of gunpowder, need only be slightly mixed to perform wonders:

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[140] See: Shapin and Schaffer, *Leviathan and the Air-Pump,* 4-6.

[141] Boyle, *Origin of Forms, Works,* V, 287. *Origin* was written following observations gathered during the 'essay on nitre'.

> these differing Bodies whereof, as of parts, or as of ingredients, a compounded Body is made up, are by virtue of the Composition and peculiar Fabrick thereof so put together or contriv'd, that they concurre to those Actions or Operations which are proper to the Body as such, and therefore are presum'd to flow immediately from the Form of it. For an instance of which I shal name Gunpowder, where three ingredients upon a very slight mixture (as I shall anon show theirs to be) do by a concurrent action produce those wonderfull effects that are scarce to be match'd by Nature herself.[142]

When corpuscles or bodies interact, they retain their own qualities but by virtue of interacting, produce a mixed effect.[143] These bodies 'act jointly, and mutually modifie each others actions'.[144]

Gunpowder, for Boyle, is a testament to the power of the most simple agitations or manipulation of matter:

> The prodigious operations that men admire in Gunpowder, yet not onely, as we formerly intimated, this strange power is but the effect of the mechanical texture and of the way wherein the ingredients are mingled, and as it were contexed, but this artificial mixture is far more slight [than] those of nature are wont to be. For as the efficacy of the mechanical texture in Gun-powder may appear by this, that neither of the ingredients (whether the Sulphur, the Nitre, or the Coal,) is apart able to produce effects any thing neer like those of Gun-powder.[145]

In its inquisitional capacity, gunpowder was the ideal substance to comment on the power of chemistry. This method used mixture to affect transmutation, to transform bodies by virtue of mixing them with other bodies. Schmidgen, who argues that chemical mixture was an important part of Boyle's programme, correctly describes gunpowder as 'Boyle's favourite example for the transformative powers of even slight mixture'.[146] Gunpowder could comment on the great power of matter as well as reinforcing the notion that forms are not substantial, but the result of chemical interactions.

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142 Boyle, *Origin of Forms*, *Works,* V, 452-53.

143 Boyle, *Origin of Forms, Works*, V, 458.

144 Boyle, *Origin of Forms, Works*, V, 459.

145 Boyle, *Origin of Forms, Works*, V, 460.

146 Schmidgen, *Exquisite Mixture*, 57.

Experiment 2: Separation of the Ingredients of Gunpowder

From: Robert Boyle, *The Origin of Forms and Qualities* (1666), *Works,* V, 459-460.

Experiment by Haileigh Robertson and Peter Smithurst 2013

The goal of this experiment was to put gunpowder through a chemical process that separates it out into its original three ingredients: saltpetre, sulphur, and charcoal. We placed 25 grams of gunpowder in a beaker. We then dissolved it in water before placing the beaker over a flame in order to boil the mixture. The liquid was then poured through a filter paper into another beaker. The clear filtrate is evaporated to obtain ingredient 1: saltpetre.

A black residue was left behind in the filtre. We confirmed Boyle's observation that this residue will burn with a blue flame. The residue was then boiled in a 'pretty strong lixivium' which is the early modern equivalent of caustic soda.

This process dissolves the sulphur, and you can tell this by the ensuing smell. The liquid is then filtered, and 'spirit of salt' (hydrochloric acid) is added. This heightens the sulphureous smell and the liquor turns white as the 'sulphureous corpsucles' precipitate to give us ingredient 2 as solid sulphur forms in the solution. If the hydrochloric acid is added to the 'clear solution', that is the solution from which Boyle obtained the nitre, such a reaction does not occur. This shows that the nitre obtained was pure and separate from the other components of gunpowder.

Ingredient 3, charcoal, is left behind in the filter paper.

Gunpowder is artificially mixed. Saltpetre, a natural body, was a compound. Even this naturally occurring compound could be taken apart, as shown by the 'redintegration'.[147] Part of the definition of a compound was that a compound when entering into a mixture would retain its own nature. This happens in gunpowder wherein nitre, charcoal and saltpetre retain their natures whilst by virtue of their mixture gain properties to perform things together that they could never do singularly.

Schmidgen has argued that mixture was an important concept for Boyle, and that when matter is reduced to corpuscles of differing properties, arranged in differing textures, there is a huge potential to elicit 'transformative relationships.'[148] In contrast to previous ideas of mixture whereby transmutation was seen as a 'higher agent', Schmidgen holds that in the seventeenth-century mixture became a 'fully legitimate cause'.[149] Gunpowder was evidence that an 'imperfect mixture can produce a new body with unprecedented powers and qualities.'[150] This mixture was imperfect because it could be unmixed using a very simple chemical procedure, as shown in the separation experiment above. Gunpowder was a profound example of the possibility of transmutation, but at the philosophical level it demonstrated the power of corpuscularianism to explain how a simple mixture could engender unimaginable properties. These three ingredients which do little alone, combined to perform massive effects far exceeding their individual properties.

Gunpowder, the Air, and Expansion

> Mr. Boyle proposed, that it might be examined, what is really the expansion of gunpowder, when fired.[152]

Boyle was able to explain gunpowder using his theory of corpuscles, but the key question for him was what actually happens to the mixture when it is ignited. Boyle, like Bacon, conceived of gunpowder's manifest power as the effect of

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[147] Clericuzio, "Redefinition," 575.

[148] Schmidgen, *Mixture,* 41-42.

[149] Schmidgen, *Mixture,* 24.

[150] Schmidgen, *Mixture,* 48.

[152] Thomas Birch, *The History of the Royal Society of London for Improving of Natural Knowledge,* 4 Vols (London: 1756-57), Vol 1, 455. The quotation comes from the minutes of a meeting in 1664.

expansion. On ignition the ingredients of this simple mixture conspired to expand to an awesome degree with enough rapidity to destroy all bodies that get in its way. He says that nature allows gunpowder to 'toss up into the Air, Houses, and the Rocks they are built on, to give the kindled Gun-powder the Expansion that its new state requires.'[153]

Gunpowder discloses expansion, contraction, the air, flame, heat, sound, motion, movement and even cold.[154] These are all manifestations of nature's hidden capacities, and they all reduce fundamentally to the powers of expansion and contraction. These are also everyday properties disregarded or taken for granted for the most part, but ones that Boyle is adamant that chemistry can and should explore —not just for their own sake, but also to uncover what causes expansion and contraction across all these diverse phenomena.

This section explores Boyle's perception of the relationship of gunpowder to the expansive properties of the air. It further emphasises how important gunpowder was in Boyle's developing of a chemical adaptation of Bacon's programme. Gunpowder was so directly intertwined with other familiar phenomena that Boyle used gunpowder in his explorations of these related phenomena, most prominently in his air-pump experiments. Gunpowder was frequently integrated with discussions on the air. This was a very specific inquisitional role for gunpowder, both in Boyle's chemistry and in his thinking on the nature of matter in general.

Gunpowder's Expansion

According to Boyle, gunpowder was a 'small quantity of matter' that when ignited required a 'great quantity of space.'[155] He proposed that gunpowder, on ignition, expanded into masses of invisible particles, or effluvia. This was what enabled gunpowder to act so violently upon distant bodies. The effects of gunpowder could be felt far beyond the site of ignition. Boyle made these observations while

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[153] Boyle, *A Free Enquiry Into the Vulgarly Received Notion of Nature* (1686), *Work*s, X, 500.

[154] Boyle, *Mechanical Origin of Heat and Cold, Works,* XIII, 335, says that gunpowder 'seems to be of so igneous a nature, that, when 'tis put upon a coal, it is turn'd presently into flame capable of promoting the deflagration of the charcoal, and kindling divers bodies it meets with on its way […] yet if gunpowder is thrown into four or five times as much water, it will very manifestly impart a coldness to it, an experience made *with,* as well as *without,* a sealed thermoscope has assured me.'

[155] Boyle, *Effluviums, Works,* VII, 250.

hunting, supposing that 'if grains of Gunpowder emit Effluviums capable of being by some animals perceiv'd at a distance by their smell, one may probably suppose that the small grains of this powder may hold out very many times longer to supply an Atmosphere with odorable steams, than the Corpuscles left on the ground by transient animals.'[156]

Based on this idea of effluvia emitted after ignition, Boyle conducted an experiment in an attempt to measure its expansion. The experiment was conducted by placing a half-grain of gunpowder on a tile with a glass tube on top and a brass plate covering the top orifice of the glass.[157] He observed the smoke filling the space after the grain was fired, noting that the smoke emanated from the gunpowder in 'two or three little intervals', and when the top plate was removed, it continued to ascend for at least seven minutes to a height of two feet into the air.

This experiment aimed to accurately quantify the expansion of gunpowder. Boyle calculated that the glass could hold 'two and twenty pints' of water (almost a pound in weight according to his calculations), and in turn it could hold 16,000 grains of powder.

> That this Gunpowder would readily sink to the bottom of Water, as being (by reason of the Saltpeter and Brimstone, that make up at least six parts of seven of it) *in specie* heavier than it, and in likelihood twice as heavy [...] we may probably guess that the space to which the smoak reached to exceed 50,0000 times that, which contain'd the unfir'd Powder; and this, though the smoak being confin'd in the vessel, was thereby kept from diffusing it self so far as by its streaming out it seem'd likely that it would have done.[158]

Boyle calculates gunpowder's expansion as exceeding 50,000 times the grain size.

Boyle's calculations pertain to the effluvia given off by gunpowder on ignition. Effluvia, as discussed above, are streams of particles that integrate with bodies to produce effects. The example of the gunpowder experiment cited above tells us how Boyle used effluvia to explain occult properties. In gunpowder's case, the effluvia are only given off when the material is brought into contact with even the tiniest spark and then they act in their multitudes. He explains gunpowder as

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[156] Boyle, *Effluviums, Works,* VII, 251.

[157] Boyle, *Effluviums, Works,* VII, 239-40.

[158] Boyle, *Effluviums, Works,* VII, 240.

expanding into these invisible effluvia at a massive rate, and this is what allows the material to act furiously upon bodies in its vicinity after ignition.

Gunpowder and the Air-Pump

With the expansion of gunpowder being a key question for Boyle, it is no surprise that it was the subject of many experiments *in vacuo*. Inspired by the vacuum chamber used by Otto von Guericke,[159] in 1658 Boyle ordered outstanding technician Robert Hooke to build his own version. The machine comprised a glass receiver and various mechanical arrangements for removing the atmospheric air.[160] In *New Experiments Physico-Mechanical, Touching the Spring of the Air and its Effects* (1660), Boyle used the device to investigate respiration and the nature of the air, and in 1673 he investigated the relationship between flame and air.[161] In the same work Boyle tried to ignite gunpowder by channelling sunbeams through a burning lens, and he further devised a contraption to rig up a pistol inside the chamber. Although sparks were given off as the hammer struck the flint on ignition, the priming powder, and thus the main charge, was not ignited.[162] Although unsuccessful on that occasion, Boyle continued his efforts to discover gunpowder's relationship with the air. Indeed it was such a promising topic that it became a central feature of the latter treatise on *Flame and Air.*

Hunter states that that the air-pump experiments 'illustrate Boyle's extraordinary ingenuity in devising trials which would reveal significant information about the phenomena under scrutiny.'[163] Experiment reveals, and this was what the air-pump was meant to do. Initial experiments indicated to Boyle that the air had a 'spring'.[164] It could exert pressure and expand. When the pump is evacuated, the air is at liberty to exert its spring, or, as we would say, expand. When the air is let back

[159] On the history and development of the air-pump, see: Anne C. van Helden, "The Age of the Air-Pump," *Tractrix* 3 (1991), 149-72.

[160] Shapin and Schaffer, *Leviathan and the Air-Pump,* 26-30.

[161] Boyle, *New Experiments Physico-Mechanical* (1660), *Works*, I, 141-302; *New Experiments, touching the Relation betwixt Flame and Air* (1673), *Works,* VII, 73-213.

[162] Frank, *Oxford Physiologists,* 251-55, discusses the combustion experiments focusing on respiration.

[163] Hunter, *God and Science*, 126.

[164] Boyle, *Physico-Mechanical, Works,* I.

in, its spring is constrained and so contracts. Investigating the nature of the air was an important natural philosophical project. Boyle realised that the air, or at least something in it, was necessary to life.[165] He also realised that something in the air was also necessary to the ignition of gunpowder.

Boyle's experiments on flame and air connected the issues of combustion, respiration, and expansion/ contraction. As the 'aerial nitre' took hold in natural-philosophical accounts, gunpowder became associated with physiological studies on respiration and combustion, most notably in the efforts of Thomas Willis and John Mayow.[166] The 'gunpowder theory of muscular contraction', for example, used gunpowder's forces as an analogy to conceptualise the hidden processes happening inside the human body. This explanation proposed that the nerve fibres in the body contained particles of animal spirits, and that these mixed with 'saline-sulphurous particles' in the blood to join in a 'copula' which would 'break apart and explode like gunpowder' causing the muscle to contract.[167] This idea arose from the concept of the *Flamma Vitalis,* or 'vital flame'. Just as a sort of nitre in the air was perceived as being vital to life, so was a fiery aerial element, which Debus has equated with sulphur.[168] It is the interaction of these nitrous and sulphureous particles in the air that Mayow and some of his colleagues used to explain several natural phenomena, including basic bodily processes.

We can see why gunpowder became associated with these basic processes concerning respiration and combustion. Considering that these were hot topics, Oldenburg asked Boyle to experiment on the relationship between flame and air.[169] Boyle asked if gunpowder needed the air, or something in it, to be ignited.[170] Whilst he did not comment on the aerial nitre directly, Boyle conceived of saltpetre as

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165 Boyle, *Flame and Air,* 189-91

166 Frank, *Oxford Physiologists,* 221-32; Debus, "Paracelsian Aerial Niter," 51-54; Guerlac, "Poet's Nitre."

167 Frank, *Oxford Physiologists,* 221-23. See also: Debus, "Paracelsian Aerial Niter," 61; Guerlac, "Poet's Nitre."

168 Debus, "Paracelsian Aerial Niter," 44-46, 51.

169 Boyle, *Flame and Air*, 133. Appended to the main title was an appendix on explosions, directly derived from discussions on the *flamma vitalis,* a notion that Boyle disregards. The gunpowder theory of respiration speculates that the fluids of bodies make explosions on mingling. However he points out that the gunpowder analogy used by the supporters of the idea, is not a liquor but is rather 'consistent and brittle' needing real fire or a very intense heat to ignite. See also: Guerlac, "Poet's Nitre," 243-44.

170 Boyle, *Physico-Mechanical, Works*, I, 189-91.

having a key property that would account for the reaction of gunpowder. Like the air, flame too was capable of expansion. Gunpowder incorporates both of these phenomena, and with great vigour. It is also the case that gunpowder is generally very easy to ignite; one spark is all it takes to ignite a large charge. Thus gunpowder was an obvious or fruitful means to study the relationship between flame and air.

Consequently, in *Flame and Air* gunpowder assumed a prominent position. The treatise had three titles concerning flame: kindling, preserving, and propagation. Throughout these titles gunpowder was used in eight of a total of twenty experiments.[171] Frank makes the case that the titles on the production, preservation and propagation of fire without air 'are best considered as a whole.'[172] However, I find it useful, particularly when it comes to the gunpowder experiments, to consider what the titles of the different sections tell us. The division into three headings tells us that Boyle envisaged the production of flame to incorporate three separate stages. He wanted to see the necessity of air to all three of these steps to figure out where exactly air, or one of its constituents, entered the process of combustion.

The first title was on the production of flame. Boyle started by repeating the experiment to kindle gunpowder *in vacuo* using sunbeams.[173] The experiment was unsuccessful, but it did show that the sulphurous part was capable of kindling. He noticed that the powder would smoke, but ultimately 'the newly recited experiment was not the single one, we made about that time, that discover'd a great indisposition even in Gunpowder to be fir'd in our *Vacuum.*'[174] They continued by setting up a device to drop a small parcel of gunpowder on a heated iron but the 'desired explosion of the Powder did not insue.'[175] Part one of the investigations had shown to Boyle that air was necessary for at least this initial stage of the combustion process. Furthermore, these are examples of a Baconian negative instance: because the effect does not occur, it furthers the need for a missing but essential element.

The second title concerns the preserving of fire *in vacuo.* Gunpowder could not be ignited without air, but Boyle explored the possibility that it might burn without air. To test this he used not the vacuum chamber, but a 'thinner medium'

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171 Four of nine in the first title, one of six in the second title, and three of five in the third title.

172 Frank, *Oxford Physiologists*, 252.

173 Boyle, *Flame and Air, Works,* VII, 89-90.

174 Boyle, *Flame and Air, Works*, VII, 90.

175 Boyle, *Flame and Air, Works*, VII, 90.

than air—water. He stuffed serpentine gunpowder into a goose quill, which he ignited before plunging it under water.[176] The gunpowder did continue to burn. Boyle suggested that air could be trapped in the pores of the water, between the grains of gunpowder, or even in the saltpetre. He was convinced that gunpowder needed something in the air to ignite and burn, and so proposed that although it was burning under water, it was not doing so without air.[177] Boyle subsequently theorised on nitre, suggesting that it may be,

> empty bubbles close stop'd, whose moister parts may be by the fire that kindles the nitre be exceedingly rarified, and in that estate emulate air, and violently burst their little prisons, and throw about the fragments of them with force, and in numbers enough to make their aggregate appear such a flame, as is wont to be made by unctuous and truly combustible bodies; and yet this rarifi'd substance, that thus shatters the nitrous particles, may really be no true and lasting air, but only vehemently agitated vapours.[178]

Boyle suggests that on ignition, the nitre makes and releases temporary or 'factitious' air, and it is this air that allows gunpowder to burn without oxygen.

Stage three in Boyle's exposition was on the 'strangely difficult Propagation of Actual Flame' *in vacuo*.[179] The aim was to test if fire could spread without air. To resolve this, Boyle conducted 'a strange experiment upon gunpowder, shewing, that though it were fired it self, yet it would not fire the contiguous grains in vacuo boyliano.'[180] Gunpowder's chemical properties made it suited to such questions. The substance ignites through,

> contiguous grains […] a great heap whereof will, almost in the twinkling of an Eye, be turn'd into flame by the propagation from any one small kindled grain; nothing seem'd fitter to manifest how much Flame is beholden to Air, than if such an Experiment could be made, as might shew, that, even amongst the contiguous grains of kindled Gunpowder, Flame would not be propagated without the help of Air.[181]

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176 Serpentine gunpowder is a dry mix of the finely pulverized three ingredients. By this period corned gunpowder, whereby the ingredients are wetted then sieved in order to secure a more durable and more intimately mixed gunpowder, was widely used.

177 Boyle, *Flame and Air, Works*, VII, 103.

178 Boyle, *Flame and Air, Works,* VII, 104-05.

179 Boyle, *Flame and Air, Works*, VII, 109.

180 Boyle, *Flame and Air, Works,* VII, 111-12.

181 Boyle, *Flame and Air, Works*, VII, 111.

For the experiment, a train of gunpowder was formed before the receiver was evacuated. Sunbeams were used to ignite the powder but it only went as far as smoking and melting. Tried in a finer glass, Boyle found that several of the grains fired one at a time. However, the flame did not spread from grain to grain, rather they ignited on their own accord.[182] This indicated that flame would not spread without air, thus showing the apparent necessity of air to these three stages of the combustion process. Flame and air evidently did have an intricate relationship, as the former was dependent on the latter, or something in the latter.

Boyle found that gunpowder had an 'indisposedness […] to be fired in our *Vacuum.*'[183] Of course we know now that this result seems problematic; the reason behind gunpowder's force is that it has its own supply of oxygen in the saltpetre. Yet it would not go off in the vacuum, says Frank, possibly owing to the low oxygen rates combined with the air pressure in the receiver.[184] The question of gunpowder's complex relationship to both flame and air was a question on how specifically each of gunpowder's components contributes to the effects of the tripartite mixture.

The experiment highlighted the centrality of saltpetre and brought the discussion back to the chemical composition of gunpowder. A dominant question was whether the air was chemically combined in the saltpetre, or just mechanically incorporated.[185] Boyle argued the latter, proposing that the texture of saltpetre, consisting of 'very minute' corpuscles, was such that 'little aerial particles' could infiltrate it. The lack of air is further proven, he claims, by observing the 'great windiness of the flame that is produced upon the deflagration of nitre.'[186] Hooke on the other hand, taking on a more chemically minded explanation, thought that 'air and nitre [contained] a common constituent.'[187] The air-pump experiments then tackled the relationship between flame and air showing saltpetre as the key to understanding this. Yet despite proving that the air was necessary for combustion and respiration, gunpowder itself still remained mysterious. Nonetheless, Boyle

182 Boyle, *Flame and Air, Works*, VII, 112.

183 Boyle, *Flame and Air, Works,* VII, 91-92.

184 Frank, *Oxford Physiologists*, 254.

185 McKie, "Fire and the *Flamma Vitalis,*" 473-76; Frank, *Oxford Physiologists,* 137-39.

186 Boyle cited in McKie, "Fire and the *Flamma Vitalis*," 479.

187 McKie, "Fire and the *Flamma Vitalis*," 479.

highlighted the relationship of gunpowder's expansion to the air, a theme which was the basis for the development of chemical theories of combustion of gunpowder into the eighteenth and nineteenth centuries.[188]

Gunpowder and the Air

Boyle had shown that gunpowder needed something in the air in order to expand violently. He suspected that the material had 'a Fluid Substance, determin'd to convenient Motions, may be equivalent to an Internal Spring; especially if it be assisted by friendly external Agents'.[189] On another occasion he conjectured that something in the air carried gunpowder's fire and forces. In gunpowder we see the,

> strange force and effects of boisterous Winds and Whirlewinds, which yet are but Streams and Whirlepools of invisible Air, whose singly insensible parts are by accidental causes determined to have their motion made either in a straight or almost streight line, or as it were about a common Centre. But in an instance much more conspicuous may be afforded by a Mine charged with Gunpowder; where the flame or some subtile Aethereal substance that is always at hand in the Air, though both one and the other of them be a fluid body, and the powder perhaps be kindled but by one spark of fire, exerts a Motion so rapid and furious, as in a trice is able to toss up into the Air, whole houses and thick Walls; together with the firm soil, or perchance solid Rocks, they were built upon.[190]

The phenomenon of gunpowder exploding also gave rise to a controversy between Boyle and Franciscus Linus, who responded to Boyle's conclusions from the first round of vacuum experiments. Linus was an Aristotelian and proposed that the Torricellean experiment could be explained by a funiculus, a sort of invisible rope that pulls when air is extracted. Boyle wanted to use various explanations—scholastic, corpuscularian, Cartesian—to explain the phenomenon of expansion. In response Hooke, on behalf of Boyle, published 'A defence of the doctrine touching the spring and weight of the air' in 1662.[191] In the ensuing debate, Boyle explains

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188 Mauskopf. "Gunpowder and the Chemical Revolution," 94-97.

189 Boyle, Vulgarly Receiv'd Notion of Nature (1686), Works, X, 562-63.

190 Boyle, *Of the High Veneration Man's Intellect owes to God* (1684-5), *Works,* X, 167. Used to demonstrate both the power and wisdom of God.

191 Boyle, *A defence of the Doctrine Touching the Spring and Weight of the Air (by Robert Hooke)* (1662)*, Works,* III, 87-88.

gunpowder's expansion based on the expansion of the air, bringing together those two everyday but necessary substances whose power lay in their powerful expansion and contraction.

Linus lamented that it was 'impossible to explicate the *Phaenomena* of Gun-powder', encouraging Boyle's response that '[Linus'] reasons to confirm which three Impossibilities, because drawn from a meer mistake, or ignorance of those *Hypotheses* which have been invented by the Assertors of that Opinion, I shall pass over, and content my self to explain a way how these impossibilities may become Possibilities, if not Probabilities'.[192] Boyle showed that even with a Cartesian explanation, it was possible to explain the rarefaction of air:

> For supposing those Terrestrial parts of the Gun powder to be first at rest, and afterwards agitated by the rapid motion of his first Element, there will be sufficient difference of the former and later condition in respect of Extension; and supposing the particular constitution of Gun-powder (arising partly from the Specifick forms of the Particles of its ingredients; Nitre, Sulphure and Char-coal, and partly from their proportionate commistion) to be such as will readily yield to the motion of his *Materia subtilis,* so soon as an ingress is admitted to it by the fireing of any particular parcel of it, the Expansion will be speedy enough.[193]

Linus was then asked to imagine a barrel of gunpowder ignited in a closed room. Upon kindling, the texture of the gunpowder causes the grains to be fired so that 'many Millions of parts' which prior to ignition were at rest, are owing to the 'burning coals' shattered and henceforth positioned so that they can be 'agitated by the rapid motion of the *Materia subtilis.*' This positions the grains to be 'agitated and whirled sufficiently' so then there is as a result a 'vast Expansion of that part of Gun-powder so fired.'[194]

Boyle posited that on ignition, the grains of gunpowder are violently 'whirl'd and hurried round' so that the particles of gunpowder expand to take one thousand times as much space as they had previously. He proposes that the particles located towards the edges of the barrel were the first to expand, and that they ignite the grains moving towards the centre, putting them into motion and thus able 'to receive

192 Boyle, *defence*, *Works,* III, 87-88.

193 Boyle, *defence*, *Works,* III, 87-88.

194 Boyle, *defence*, *Works,* III, 87-88.

the action of the *Materia subtilis.*' This 'subtle matter', in the Cartesian ontology, is present everywhere. It is responsible for transposing the ignition through the contents of the barrel and 'disorder[ing] it with 'great impetuosity.' It can move lighter air and also 'vast accumulated Masses of the most compacted Structures of Stone, and even shake the very Earth it self, or whatever else stands in its way, whose Texture is so close as not to give its Particles free passage through its pores.' Thus Linus's argument that 'there are no more Corpuscles in the room before the Gun-powder is fired then after' is disproven by Boyle, given this corpuscular explanation of expansion.

Boyle's response is quite simple and adequately suited to corpuscularian principles: 'all these things happen because the Gun-powder so kindled and turned into flame takes up a much greater space then before. Whence it comes to pass that seeing the Chamber was before quite full, by this means the walls are broken that there may be no penetration of bodies.'[195] Although Boyle and Hooke responded to Linus in Cartesian terms, they were still close enough to explaining gunpowder's massive expansion in terms of the underlying motions and textures of bodies. The 'first element' of Descartes is able to agitate the grosser parts of gunpowder to set them into motion generating a speedy expansion and dispersion of the powder. The subtle material when liberated has high velocity sufficient to agitate the surrounding grosser parts.

Linus claimed that no explanation could be provided for gunpowder, and Boyle responded critically. The most mysterious and occult powers of matter could be, and were, shown to be nothing more than the effects of motion and configuration. The properties of expansion, contraction, heat and cold, are all common everyday occurrences yet they are all made manifest in a dramatic fashion within the effects of ignited gunpowder. The material cuts across these common but essential phenomena and so it makes sense that Boyle would use gunpowder to draw together his studies on these topics.

The role of gunpowder and its expansive effects in explanations of other everyday phenomena shows us how the corpuscular philosophy was employed by Boyle to produce novelty from the everyday. True to the idea of Baconian analogy,

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[195] Boyle, *defence*, *Works,* III, 87-88.

Boyle utilised the laboratory to identify the commonalities across a range of everyday phenomena. The corpuscular philosophy, he maintained, explained these effects and promoted in very easy to understand principles the Baconian idea that matter could be indefinitely reconfigured for the production of novel effects.

Conclusion

Gunpowder was an ubiquitous material that Boyle rendered philosophical by relocating it to his chemical laboratory. Whilst the more well known external uses of gunpowder were what initially attracted Boyle to the material, he was not immediately interested in expanding gunpowder's role in warfare, fireworks, and mining. Rather, Boyle was interested in what gunpowder could be made to reveal about nature's sub-phenomenal processes. He saw gunpowder as a source of information on such matters precisely because of its external applications. Boyle understood that the massive explosions of gunpowder that were made on a daily basis were the result of highly potent corpuscular interactions that were set into motion via human agency. These interactions, however, could not be understood on the outside at the site of detonation. They could only be made intelligible in Boyle's chemical laboratory, whereby the materials could be controlled and manipulated as he pleased.

Gunpowder played an important role in the essential component of Boyle's programme which was the Baconian marriage of operation and contemplation. Boyle's chemical investigations of gunpowder facilitated constant interactions between hand and mind. Gunpowder was placed in a variety of experimental set-ups in order to be employed in the investigation into a variety of processes. Not only was gunpowder to be studied using both operation and contemplation. The outcome of this analysis was to provide both theoretical and practical advancements. Boyle told us that gunpowder is to be contemplated as well as simply utilised for its manifest power. This would lead to genuine power rather than its crude deployment for mere military power.

We have seen how gunpowder was an important factor in Boyle's promotion of chemistry as the science of matter's transformative power. By submitting familiar substances to chemical operations, Boyle adhered to the Baconian imperative to focus on everyday (as well as extraordinary) materials with a view to exploiting their inquisitional powers. Boyle argued that chemistry was obliged to study these materials; not for the sake of elucidating knowledge on the materials per se, but rather because of what these materials might be made to reveal under chemical scrutiny. In the laboratory, via the transformative powers of chemistry, gunpowder's manifest and inquisitional uses could be embraced. Owing to gunpowder's inherent nature that cut across many of matter's most basic but most important phenomena, including expansion, the air, combustion, and hot/cold, it was an invaluable chemical resource. Gunpowder could help to explain these common effects, as well as demonstrate how age-old ubiquitous phenomena could, under Boyle's chemical methodology, produce novel effects.

We will extend the focus on the importance of experiment and practical intervention in nature in Chapter 3. The next chapter will demonstrate that the Hartlibian interpretation of Baconianism sought to use experiment to find new and improved ways of producing saltpetre and gunpowder for the good of the state. In Boyle's case gunpowder was transferred into the laboratory. In the following chapter we will see how the Baconian experimenters had to transfer themselves physically to the craft environment and undergo an immersive experience in the craft knowledge.

PART TWO: GUNPOWDER IN THEORY AND PRACTICE

Chapter 3

Reworking Early Modern Experiments with Gunpowder: Theory and Practice

> He saw with his own eyes the whole way of making salt-peeter, which is never discovered in books.[1]

Introduction

Discussing the experiences of his correspondent Mr. Unmussig, Samuel Hartlib in the epigraph refers to a crucial tenet of the emerging Baconian sciences of the seventeenth century.[2] In order to understand nature, scholars had to start working with it practically. Operation had to be combined with speculation. Making saltpetre was a complex and tactile craft whose processes were not understood from books alone. Not only does the epigraph statement disclose the increasing seventeenth-century drive towards experiment and practical inquiry into nature, but it also makes the case for current historians of science to think beyond the historical text that informs our work.

In this chapter I argue that the reworking of experimental processes in the history of science is a methodologically fruitful approach. To make this case, I draw on my own experience making saltpetre according to early modern manuals. By presenting a distinct methodology for reworking past procedures, we will see that the actual practical experiments that we study are simply the tip of the iceberg. As historians of science, we are afflicted by the same predicament as Mr. Unmussig: the full procedures and complexities of early modern experiment are never discovered in books.

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[1] Samuel Hartlib, *Ephemerides,* Part 1 (1650), in *The Hartlib Papers Online,* eds. M. Greengrass, M. Leslie and M. Hannon (Sheffield: HRI Online Publications, 2013), Ref: 28/1/39B. Available online **http://www.hrionline.ac.uk/hartlib**.

[2] 'Mr Unmussig' is an alias of Johannes Brun, one of the key chemical minds in Hartlib's correspondence, see: Stephen Clucas, "Samuel Hartlib: Intelligence and Technology in Seventeenth Century Europe," in *Leonardo da Vinci and Heinrich Schickhardt: On the Circulation of Technical Knowledge in Early Modern Europe,* eds. Robert Kretzschmar and Sönke Lorenz (Stuttgart: Verlag W. Kohlhamer, 2010), 58-86, on 68-69. See also: Ronald Sterne Wilkinson, "The Hartlib Papers and Seventeenth-Century Chemistry, Part 1," *Ambix* 17 (1970), 54-69, on 65-69.

Following Otto Sibum, I employ the term 'reworking' as opposed to 'replication.'[3] The latter term is fraught with problematic associations.[4] It indicates that the past can be actually and fully replicated. It implies that what we are doing in the present is the same as what our past protagonists were doing. Another possible term, 're-enactment', is slightly less alarming, but nonetheless brings images to mind of subjective performance and dramatization that are not the prerogative of investigative experimentation.[5]

'Reworking' not only highlights that there is actual work and labour involved in these past procedures. It also openly acknowledges that our historiographical work is a modern day interpretation of past events and processes. This interpretation is unavoidably coloured by our modern day social biases and sensibilities. We cannot reproduce the seventeenth century in the twenty-first century. Yet we can use the surviving documentary and material evidence to produce something that can be an invaluable aid in increasing our understanding of past natural philosophical practice. We can create environments or situations that to some extent simulate the material conditions of past actors. This, as I will argue, is enough to gain the insight we seek.

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[3] Heinz Otto Sibum, "Reworking the Mechanical Value of Heat: Instruments of Precision and Gestures of Accuracy in Early Victorian England," *Studies in the History and Philosophy of Science* 26 (1995), 73-106.

[4] On the use of 'reconstruction' in experimental archaeology, see: Alan K. Outram, "Introduction to experimental archaeology," *World Archaeology* 40 (2008), 1-6. He goes over some of the problems with 'replication,' 'reconstruction' and similar words prefixed 're-' arguing that these words imply that we can properly know the past. Since this is impossible, we cannot actually replicate it, thus the term is moot. Outram duly notes that 'some aspects of an experiment must be hypothetical and being tested, and, hence, not a reconstruction, otherwise there is little point in doing it,' 2.

[5] Re-enactment does have its value for historical research. It can potentially have investigative functions in addition to dramatic purpose. See: J. Kim Siddorn, *Viking Weapons and Warfare* (Stroud: Tempus, 2000). Siddorn proposes re-enactment or living history as a way to penetrate the potential experiences of past peoples. He uses his experience in re-enactment to inform his research on the nature of Viking warfare, poetically claiming, 'the living moment that joins us to the lives of our ancestors are so long dead – that rare, unforgettable moment when the gunwhale of the ship dips into the sea and 50 gallons of Baltic rushes aboard; when the shield wall collapses and shouting men run you down; when you roll out of bed to pull your soggy turn shoes on for the fifth day in succession – and it comes to you, "it might have been just like this,"' 14. On the highly personal nature of re-enactment, see: Elizabeth J. Goodacre and Gavin Baldwin, *Living the Past: Reconstruction, Recreation, Re-enactment and Education at Museums and Historical Sites* (London: Middlesex University Press, 2002). Goodacre and Baldwin note that re-enactment 'is an extremely fluid and ephemeral phenomenon. It is never the same twice, even if scripted, and will be perceived in many different ways depending on the disposition, former knowledge and experience of the visitor,' 200. See also: Vanessa Agnew, "History's Affective Turn: Historical re-enactment and its work in the present," *Rethinking History* 11 (2007), 299-312. Agnew argues that the increasing turn to re-enactment reflects the recent 'affective turn' of History, focussing on empathy to the lives and experience of individuals over events and systems.

It opens up a world of possibilities and encourages us to ask questions that otherwise would not be obvious or apparent.

The reworking of historic experiments is not commonplace in the history of science, technology, and ideas, but neither is it new. It is now over fifty years since Thomas B. Settle reworked Galileo's experiments on acceleration and motion, disproving commentators who had doubted Galileo's actions and observations.[6] Several commentators have taken to reworking experiments in more recent years.[7] They have many means, motivations, and ends. Hasok Chang's work on the boiling point of water and electrochemistry in late-eighteenth and early-nineteenth centuries is well known.[8] Chang proposes that there are different types of reworkable experiments for the historian of science.[9] He proposes that 'historical experiments' are those seeking to produce a reproduction of a past experiment. These are quite separate from 'physical replication' that aims to 'reproduce the physical phenomena that were created and observed in past experiments.'[10] In a novel contribution to the replication/ reworking literature in the history of science, Chang proposes a third type to his typology—'complementary experiments.' This brand of inquiry, Chang argues, has a pedagogical value. Not only can complementary experiments be used

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[6] Thomas B. Settle, "An Experiment in the History of Science: With a simple but ingenious device Galileo could obtain relatively precise time measurements," *Science,* New Series, 133 (1961), 19-23.

[7] Reworking is a topic that has also attracted significant media interest: Richard Webb, "Do it again: what can we find out by re-enacting the science of yesteryear, asks Richard Webb," *New Scientist,* issue 2004 (2015), 31-35. This article features five examples, inclusive of my own work on gunpowder testing, of reworking in the current historiography of science. See also: Sarah Everts, "Science Historians Revive Ancient Recipes," *Chemical & Engineering News* 93, 35-37.

[8] Hasok Chang, "The Myth of the Boiling Point," *Science in Progress* 91 (2008), 219-40; *idem.,* "How Historical Experiments Can Improve Scientific Knowledge and Science Education: The Cases of Boiling Water and Electrochemistry," *Science & Education* 20 (2011), 317-41. For an overview of Chang's experimental research on the boiling point of water, which he demonstrates through reworked experiments is not necessarily always one hundred degrees, and accompanying videos of his efforts, see: *idem.,* "The Myth of the Boiling Point" (2007), http://www.hps.cam.ac.uk/people/chang/boiling/

[9] It should be noted that Chang does not use the term 'rework,' but rather sticks to 'replication,' and 'reproduction.' The use of 'reworkable' in text above is my own interpretation.

[10] Chang, "Historical Experiments," 319-20. In Chang's typology, 'historical experiments' would seek to use apparatus and materials as close as possible to those used in the original experiment, whereas in 'physical experiments', the goal is to reproduce the actual physics/ chemistry of the historic procedure (as opposed to the experiment as a whole), not necessarily using historically appropriate apparatus.

in the recovery of forgotten or lost knowledge. Science students can also study them in order to further their interest and appreciation for the discipline.[11]

Another brand of inquiry concerns the clarification of historic claims. Principe and Newman successfully replicated George Starkey's 'philosopher's tree,' proving possible an old experimental claim previously thought spurious.[12] Melvyn C. Usselman *et al*., working on nineteenth-century chemist Justus Liebig, successfully validated and clarified their subject's observations on the 'kaliapparat' device for organic elemental analysis.[13] Yet both of these studies do more than prove a historical actor right or wrong. Principe sheds light on the context of the experiment, emphasising the prominent role of the laboratory in early modern alchemy.[14] He also suggests, drawing upon his experimental experience, that alchemy in that period had a closer relationship to chemistry than has previously been realised by commentators. Usselman and collaborators examine, via their reworking, the emergence of chemistry as a valid profession in the late-nineteenth century. For this reason it is not useful to think of rigid reworking typologies, I argue. Of course one goal may be more prominent than another, but the reworking process is so wide ranging that many things can be accomplished, and various observations can be made based on the findings.

The examples given above provide valuable insight into the wider context of experimentation in their specific fields and time periods. Yet they aim mostly at reproducing historic results or findings. Whilst successful in achieving what they set out to achieve, they are not the most useful in terms of the specific goals of this thesis. I propose an approach that has more in common with the work of Otto Sibum and Peter Heering.[15] Both have reworked experiments with the aim of understanding

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[11] Chang, "Historical Experiments," 333-27. Chang employs the term 'complementary' as he believes these experiments are complementary to science education.

[12] Newman and Principe, *Alchemy Tried in the Fire*, 184-86; Lawrence M. Principe, "Apparatus and Reproducibility in Alchemy," in *Instruments and experimentation in the history of chemistry,* ed. F. L. Holmes and T. H. Levere (Cambridge, MA: MIT Press, 2000), 55-74, on 68-70. The experiment heated sophic mercury with gold in a glass flask (or 'egg') that is sealed and heated. This causes the mixture to rise and move into a tree-like appearance in the bowl of the flask.

[13] Melvyn C. Usselman *et al*, "Restaging Liebig: A Study in the Replication of Experiments," *Annals of Science* 62 (2005), 1-55.

[14] Principe, "Apparatus and Reproducibility," 68-70.

[15] Sibum, "Reworking the Mechanical Value of Heat." *idem.,* "Experimental History of Science," in *Museums of Modern Science,* ed. Svante Lindqvist (USA: Science History publications, 2000), 77-86; Peter Heering, "An Experimenter's gotta do what an Experimenter's gotta do—but how?" *Isis* 101 (2010), 784-805.

the experimental process and its ancillary skills, as well as the inherent tacit knowledge that is difficult to portray in in writing. They ask *how* experiment worked, and not just *if* it worked.

Sibum designates his work 'experimental history of science.'[16] By reworking James Prescott Joule's 1850 experiments with the paddle wheel, he was able to '[generate] a range of historically specific possibilities that might have played a role in the research practice that forms a fundamental goal of experimental history of science.'[17] In reworking an experiment, we experience some of the challenges faced by our protagonists, as well as the tacit nature of their interaction with their apparatus and surroundings. Heering's objective is to examine the relationship between the experiment and the person conducting it. He looks at the influence of apparatus and environment on the experiment, as well as 'nonscientific factors' affecting the process and result in order to argue that the equipment and the experimenter have a shared agency in determining the nature and outcome of the experiment.[18]

As will be shown throughout this chapter, an experiment is much more than the five minutes spent manipulating materials in the laboratory. The focus on skills adopted by Sibum and Heering is productive in allowing us to think about the complexities of the experimental process in early science. Importantly, they show that by reworking experiments we can reveal information that does not survive in our texts—whether that is data, or tacit or experiential knowledge that does not survive the written word. As Sibum puts it, '[e]xperimental history of science is above all interested in the human use of these technologies, […] We are able to grasp those cultural traditions that are usually regarded as non-verbal or as constitutive of an oral knowledge tradition.'[19]

Yet this thesis, concerned with the transition of gunpowder from battlefield explosive to laboratory inquisitional material, needs its own specific approach. My crucial point of departure from all of the excellent studies outlined above is an emphasis on what happens before and after reworking experiments. Anthropologist

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16 Sibum, "Experimental History of Science," 80.

17 Sibum, "Experimental History of Science," 81.

18 Heering, "Experimenter's gotta do," 802-04.

19 Sibum, "Experimental History of Science," 83.

Tim Ingold in his excellent interdisciplinary study on ‘making,’ notes that ‘the processes of making objects appear swallowed up in objects made; processes of seeing in images seen.’[20] It is the same case with experiments. When it comes to historic experiments, in the case of both the modern researcher and the historic actor, there are larger processes that we must bear in mind in order to gain a fuller understanding of our topic. Experiment is what happens after hypotheses have been formed, equipment and locations procured, and procedures painstakingly planned, and before further reflection and interpretation.

I propose a four-stage methodology for reworking past experiments. This is an original approach that emphasises that experiment is much more than the time spent in the laboratory. This methodological proposal deals with experiment as modern day historians can approach it in investigating knowledge about historic processes. Yet by showing that the physical experiment is just one stage of something much bigger, this idea could be adapted and applied to early modern actors as well. Experiment aims not only at obtaining theoretical knowledge. Its procedures can also elicit hitherto unobserved phenomena. It requires that the investigator be involved in the procedures, both bodily and mentally. The four stages can be briefly summarised as follows.

1. Selection.
2. Planning.
3. Experiment.
4. Reflection.

I argue that thinking about wider experimental processes is a good way to understand the minutiae and complexities of early experiment. We get a better sense of everything that went into early scientific practice. It also highlights the particular challenges and complexities that specific materials and processes brought to the table. Of course it is important to keep in mind that as the historian, we are operating on two levels. The first level is a historiographical one. We are not conducting gunpowder experiments to gain knowledge about corpuscular structures of matter.

[20] Tim Ingold, *Making: Anthropology, Archaeology, Art and Architecture* (Abingdon: Routledge, 2013), 7.

We are reworking these experiments to gain knowledge about what gunpowder offered early modern scholars of nature. Reworking these experiments gives us more data and knowledge to think with as an historian of science and opens up new routes for inquiry. This is in contrast to the second level that we must acknowledge: that of the early modern practitioners. We must remain aware that they had the direct aim of understanding nature. They had motivations contrary to our own, and were operating in a different environment—socially, mentally and physically. These categories are not mutually exclusive, however. By necessity, we also must learn to think about how the historical terminology is reflected in the materials and their effects.

In Chapter 2 we saw two examples of reworked chemical experiments with gunpowder as conducted originally by Boyle. Working practically with gunpowder in this way has shown that gunpowder satisfied different demands under different conditions. In this chapter we probe deeper into the conditions and procedures that affected the employment of gunpowder in natural philosophy. The Boyle experiments employed the finished product. As we shall see, it takes a great deal of effort to get gunpowder to that stage. An important point of departure from the existing 'replication' literature is that I am going beyond the early modern laboratory. The saltpetre experiments at the heart of this chapter require us to reproduce, as far as possible, the physical environment that was prerequisite to early modern gunpowder making. I argue that the procedures of making saltpetre in the early modern period directly affected how scholars treated saltpetre and gunpowder when the finished product was brought into the more sterile laboratory environment.

I draw on my experience making saltpetre with the Medieval Gunpowder Research Group (hereafter MGRG).[21] In 2013 I joined its on-going project investigating medieval and early modern saltpetre making. The efforts of the MGRG offer a stark contrast to the efforts of A.R. Williams to make saltpetre in 1975.[22] Williams's unsuccessful attempts to make saltpetre were actually conducted in the micro-laboratory scale. We conducted this project on a larger scale, using equipment

[21] Also known as 'The Ho Group' because some of their earliest efforts took place on the small island of Ho in Denmark. In 2013 and 2014 the MGRG comprised: Kay Smith (Independent Scholar), Ruth Brown (Independent Scholar), Peter Vemming (Director, Middelaldercentret), Axel Müller (Director, International Medieval Congress), Jens Christiansen (Blacksmith, Middelaldercentret), Dr. Iona McLeery (University of Leeds), Lasse Matilla (Conservator, Finland) and Haileigh Robertson (University of York). See: Medieval Gunpowder Research Group, "Making Saltpetre: Report 11," (draft report, 2013); *idem.,* "Making Saltpetre-part 2: Report 12," (draft report, 2014).

[22] A.R. Williams, "The Production of Saltpetre in the Middle Ages," *Ambix* 22 (1975), 125-33.

that was as historically authentic as possible. To use Chang's typology, Williams engaged in 'physical experiments' whereas we participated in something closer to 'historical experiments.' That said, we also had an element of the 'physical experiments' in that we were trying to reproduce the chemical procedure in addition to the historically appropriate circumstances and experiences. We learned not only about physically producing saltpetre. We also learned about the whole procedure of making it, inclusive of physical, mental and tacit engagements with the process.

This chapter comprises three sections. Firstly, we will look at how saltpetre was procured and made in the early modern period. I explore the surviving documents concerning early modern saltpetre-making processes before giving an overview of the method used by the MGRG in 2013 and 2014. Secondly, I explore the value of historical reworking of experiments and present in more detail the suggested four-stage methodology. The final section uses the example of saltpetre making in order to explore the challenges and the benefits of reworking experiments. With reference to the saltpetre theories and experimental proposals suggested by the Hartlib Circle in the mid-seventeenth century, we see that the ways of making saltpetre and gunpowder were relevant to the natural philosophy surrounding them.

Reworking experiments brings practice back into the picture as a necessary constituent of natural inquiry. My own background is in archaeology, a discipline in which practice is the central component of research. I hope to bring to this chapter an awareness of the power of the material culture and physical environment of the past to inform our understanding of it. To fully grasp the complexities of the emerging blend of theory and practice in seventeenth-century natural philosophy, we must engage both theory and practice in our own inquiries.

Early Modern Saltpetre Making

In this section I outline the process of making saltpetre, and explore the relevance of the procedure to seventeenth-century science. We already know that the substance had an important role to play in early modern chemistry. For Boyle and his contemporaries, saltpetre was a regular laboratory material useful not only for its role in gunpowder, but for a variety of other chemical procedures.

Cressy emphasises saltpetre's importance and relevance in his statement, 'no regime could do without it, and none could get enough.'[23] The well-known dual role of saltpetre in science and in war allows us to focus on the burgeoning relationships between theory and practice in the seventeenth century. At this point natural philosophers began to realise that the established chemical uses of saltpetre could perhaps provide a basis for more exhaustive investigations into the behaviours of gunpowder. The practice of making saltpetre in the seventeenth century became highly intertwined with the theory.

Scientific Saltpetre

> Nitre, that admirable salt, hath made as much noise in philosophy as it hath in war, all the world being filled with its thunder.[24]

Much of the scholarship on saltpetre, like that of gunpowder, has been concerned with military procurement. Yet saltpetre's presence in natural philosophy has received a little more attention than gunpowder. This is largely owing to the well-known Paracelsian theories of the aerial or universal nitre, as discussed in Chapter 2. Saltpetre in the mid-seventeenth century was becoming a much studied and utilised material in natural philosophy.

After discussing some of the philosophical interest in saltpetre, Cressy concludes that even by the mid-late eighteenth century the 'English understanding of the chemistry of explosives remained backward and derivative [...] work on gases and combustion contributed little to military technology.'[25] It may be true that in this period in England, the work on saltpetre did not really extend into the military sphere. To banish the work as 'backward', however, is too strong. Work on saltpetre may not have reached its modern status, but it was advancing. The effort by the Baconians is an important stage in the history of saltpetre. That they employed it in myriad ways and strove hard to improve the methods of its procurement is important. They may have been unsuccessful in their endeavours, but the fact that they were fervently engaging with the material experimentally reveals its

[23] Cressy, *Saltpeter,* 2.

[24] John Mayow, *Tractatus I, De Sal Nitro et spiritu nitro-aerea* (1674), 2, cited in: Needham, Gunpowder Epic, 546.

[25] Cressy, *Saltpeter,* 34.

significance in the experimental philosophy. Cressy himself points out some of the other ways that saltpetre was employed, for example, in medicine and cookery.[26] Saltpetre was a crucial tool in the chemist's laboratory. If we take saltpetre as an example of a larger group of materials, salts, as Roos has done, then perhaps we can better appreciate how important it was to chemistry in its own right.[27] It is unfair to be so dismissive of seventeenth-century saltpetre research, simply owing to its relatively low-impact on contemporary military technology.

A remarkable source for uncovering saltpetre's many personas is the Hartlib papers. Ronald Wilkinson maintains that in the interregnum 'Hartlib was eagerly searching for chemical processes of practical value' and this is reflected in his correspondence.[28] We see saltpetre being studied in terms of procurement for gunpowder, but we also see it in more varied roles. One commentator noted that saltpetre might be mixed with butter to make leather waterproof.[29] Foods could be preserved in saltpetre. It could even be used to cool beer.[30] Saltpetre was of interest within and outwith the laboratory, in contrast to gunpowder, which in this period was primarily known for its non-laboratory applications.

Saltpetre's practical uses were very well known, but it was perceived as being little understood. Writing to Boyle, Hartlib commented that it would be valuable to have a work on the 'production, viz my intended book of the whole of nature, intrinsical qualities, preparations, and all manner of uses of saltpetre; a body of too noble a nature, and too universal use, for to be so much neglected, and unknown, as hitherto it hath been.'[31] Improving the manufacture of saltpetre would be unavoidably intertwined with understandings of its nature.

The biggest issue tackled by the Hartlib Circle was the artificial generation of saltpetre. They sought to apply philosophical theories to saltpetre procurement.

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[26] Cressy, *Saltpeter,* 29-32.

[27] Roos, *Salt of the Earth,* 23-25, 33-41. Roos describes the philosophical interest in nitre in the works of Tymme, and Glauber, for example. The theories might not hold up to modern chemical scrutiny, but they were definitely influential in their own time.

[28] Wilkinson, "The Hartlib Papers Part 1," 57.

[29] Hartlib, *Ephemerides,* Part 3 (1635), in *The Hartlib Papers Online,* Ref: 29/3/34A.

[30] Hartlib, *Ephemerides* (1660), in *The Hartlib Papers Online,* Ref: 29/8/13A. Saltpetre is here described as a 'universal preservative' that also 'cooles excellently, and keeps the bier etc. long and fresh etc.'

[31] "Letter, Hartlib to Robert Boyle," 28 Feb 1654, in *The Works of Boyle Honourable Robert Boyle*, ed. T. Birch, 2nd edn, 6 vols, Vol. VI (London, 1772) 78-83, on 81, in *The Hartlib Papers Online.*

Considering the difficulty of manufacturing it from nitrous earth, that we will see in this chapter, it is clear to see why the Hartlib Circle, concerned with answering practical problems,[32] were keen to find ways of making saltpetre that were quicker, cheaper, and more effective. Hartlib wrote that a colleague was working on a way to make saltpetre from sea salt.[33] He reported that Mr Stahl possessed a secret for producing saltpetre from lime and chalk, both of which are abundant in England.[34] Mr Dymock had observed that there was sort of 'saltpetre coale' found plentifully and cheaply in Yorkshire 'which if it prove true and that the saltpetre can be extracted from it is one of the richest mines in England.'[35]

Mr Jursang and Monsieur la Grange presented a method of scattering saltpetre (dissolved in water) over sheltered manure-rich earth. This method, they said, would require the operator to pare back the earth by a half-foot every six months to repeat the procedure, eventually producing an 'everlasting mine of saltpetre'[36] These schemes are compatible with Paracelsian conceptions of nitre.[37] In this view, saltpetre is present (in varying states) in the air, the earth, and living things.[38] Considering its well-known application as a fertiliser, we can see how the early moderns believed that saltpetre could be multiplicative. It is no surprise that Paracelsian theorists proposed practical solutions like those outlined above. The theoretical conditions more or less stipulated that saltpetre could be grown, fermented, or farmed owing to its supposed status as the vital aerial nitre responsible for the generation and maintenance of life.

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32 Webster, *Great Instauration,* 355ff. Webster explains that Hartlib and his correspondence sought to utilize the riches of the natural world to advance the conditions of mankind according to the puritan utopian eschatology prominent in the interregnum era.

33 "Letter from Hartlib to Robert Boyle," 5 April 1659, *Works of the Honourable Robert Boyle*, VI, 116-17, in *The Hartlib Papers Online.*

34 Hartlib, *Ephemerides* (1658), in *The Hartlib Papers Online,* Ref: 29/7/10B.

35 Hartlib, *Ephemerides,* Part 3 (1653), in *The Hartlib Papers Online,* Ref: 28/2/70A-B.

36 "Letter from Hartlib to Robert Boyle," 28 Feb 1654, *Works of the Honourable Robert Boyle*, VI, 78-83, on 80-81, in *The Hartlib Papers Online.* They discuss sowing the saltpetre like seeds, and say that they needed at least ten thousand franks to 'discover' this way of working. The saltpetre in this practice would be dissolved in water and thrown on the ground, roughly a pound of saltpetre per square foot.

37 Webster, *Great Instauration,* 377-79. Webster notes that the chemists believed that salts, along with metals and minerals, 'were generated in the earth whenever conditions were suitable' and that they 'were somewhat optimistic about the possibilities of such processes,' 77. He points out that Benjamin Worsley was among those who believed that saltpetre was made on the surface of the earth.

38 Roos, *Salt of the Earth,* 23-25; Debus, " Paracelsian Aerial Niter."

Not only would a successful way of generating saltpetre on home-turf benefit the war economy, it would also alleviate a real social problem: the saltpetre-men. These men were notorious for raiding lands for nitrous earth, leaving behind a trail of destruction in their wake. They even prompted Boyle to complain about those 'two legged moles.'[39] These suggestions were not just for natural philosophers to pore over, but actual parliamentary proposals were made. Sir William Lockine, Francis Joyner and William Hyde proposed to parliament 'a new way of enriching earth with severall materials and ingredients which have not heretofore used, & doe undertake thereby to make such a plentiful proportion of saltpeeter as that thereby they will yerlie furnish his majestie and the kingdom with 300 tun of good refined salt-peeter'.[40]

Another memo concerned poor relief, proposing that a system may be made that employs the poor in making saltpetre. It would boost the economy and reduce the hassle of the saltpetre-men.[41] Correspondents suggest that they have found a ferment that can, when mixed with 'fit Matter', turn into nitre. Further, by their 'many experiments' they have found 'how to excite the Vertue the operation of this ferment.' And lastly they have found a 'certain Matter' that when mixed with another 'ordinary base Matter,' can breed nitre in cheaply in any country.[42]

Benjamin Worsley (1618-77) was the man at the heart of the most high profile instance of proposals to improve saltpetre making. Cheney Culpepper wrote to him: 'The touch you give from Mr Morian concerning Saltpeter, rayses my chymicall thoughts' and he desired to know more about Worsley's efforts.[43] Projects to satisfy the demand for saltpetre had come to be connected with charlatans and monopolies. Yet in the early 1640s the scene was changing and many patents were

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[39] "Letter Boyle to Benjamin Worsley." 21 Nov 1646, in *The Correspondence of Robert Boyle,* eds. Michael Hunter, Antonio Clericuzio and Lawrence M. Principe, 6 Vols (London: Pickering & Chatto, 2001), Vol. VI, 42-43.

[40] Anon, "Draft Act in Scribal Hand B, on the Making of Saltpetre," Undated, in *The Hartlib Papers Online,* Ref: 71/11/2A-7B.

[41] Anon, "Memo on Poor Relief and Saltpetre," Undated, in *The Hartlib Papers Online,* Ref: 53/26/2A-B.

[42] Hartlib, "Notes On Saltpetre in Scribal Hand G & Johann Morian," part dated 18 May 1653, in *The Hartlib Papers Online,* Ref: 39/1/11A-12B.

[43] "Copy Letter, Sir Cheney Culpeper to Benjamin Worsley, Scribal hand B," Undated, in *The Hartlib Papers Online,* Ref: 13/223A-224B.

overthrown so monopolies could be challenged.[44] As explained by Thomas Leng, 'Worsley had thus demonstrated his public credentials, but not as yet the efficacy of his method. Apart from the workhouse design, there is little clear evidence of the precise way in which Worsley planned to make saltpetre'.[45] Leng convincingly argues that the fact Worsley was still investigating methods to make saltpetre in 1646 could tell us why the project was not carried through; Worsley had not actually found or decided upon the best procedure.[46]

Several decades after the Hartlib Circle's heyday, physician William Clarke wrote the *Natural History of Nitre* in 1670.[47] This is perhaps the most detailed treatise on saltpetre. It comments on its history, generation, and a wide range of applications. He says it can make 'a pleasant and cooling acid' or 'a hot and burning corrosive.'[48] It 'produceth so many wonderful effects upon all the other Minerals, that we may justly call it the *Universal Agent in Chymistry.*'[49] He details its use in calcination, sublimation, and Dissolution.[50] Further it can be used in the alkahest or great elixir.[51] Moreover, he sees it as the key to gunpowder's mammoth effects, as nitre's role in the tripartite mixture is:

> suddenly to produce a great airy exhalation, in which all the force of this Powder consists, and is therefore the *Basis* of the Composition; and as it is in the greatest quantity, so it is the only and principal cause of the great and wonderful Effects of this *Powder*; the other two substances being to excite the burning quality, and correct the moisture of the *Nitre,* that it may be always qualified, and may in a moment go off in a flame and smoak: no otherwise than the Physitian in his compositions doth not only excite the vertues of the basis of his Medicines, but correct the ill qualities.[52]

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[44] Leng, *Benjamin Worsley,* 20-21. Also on Worsley's project: Cressy, *Saltpeter,* 130-31; Webster, *Great Instauration,* 377-84.

[45] Leng, *Benjamin Worsley*, 24.

[46] Leng, *Benjamin Worsley,* 24.

[47] Clarke, *The Natural History of Nitre* (London: 1670).

[48] Clarke, *Natural History of Nitre,* 65.

[49] Clarke, *Natural History of Nitre,* 66.

[50] Clarke, *Natural History of Nitre,* 66-69.

[51] Clarke, *Natural History of Nitre,* 69-71. On the employment of saltpetre as the 'alkahest' in the works of Glauber, see: Roos, *Salt of the Earth,* 33-46.

[52] Clarke, *Natural History of Nitre*, 85.

As also realised by Boyle and Bacon, saltpetre was the crucial ingredient in gunpowder. To really get to gunpowder's causes, they would need to go through saltpetre first. This substance, and the ways of making it, was of huge interest to natural philosophers. Knowledge about it, Paracelsian and otherwise, had been increasing in the seventeenth-century. With the Baconian emphasis on practice, scholars also looked to combining theory and practice to do even more with nitre—philosophically and practically.

The difficulties in reworking saltpetre making can be linked to those that the early moderns would have faced. The early modern practitioners were aware of just how complicated and unpredictable the processes were. This is why we have this list of quick and easy but probably ineffective methods.[53] They had to step back from the process that was known to work in order to overcome the slowness. I will show practically that this was a time-consuming, labour intensive and unpredictable process that required skills and sensitivities obtained over lifetimes of tacitly accumulated know-how. This undertaking was hardly inviting even for the most committed of the Hartlib Circle. Their gentlemanly epistolary proposals for increasing production were confined to communications and the material necessities were not something they envisaged labouring at themselves.

My experience brings out how the complex and erratic behaviour, the slow learning curve, and the intractability of the materials also hint at the comparable complexities and intractability of the hidden powers of matter—it is apparent that they too will be difficult to coerce and control even under laboratory conditions and that is the actual experience of Boyle and others. Translation to a new environment does not remove the need for skill—it means a development of novel habits and knowhow. Indeed, as rightly observed by Christoph Bartels, 'to produce (and not simply pick up) materials means to reproduce and steer chemical and physical (or biological) natural processes.'[54] Neither on the macro nor on the micro level will matter give up its secrets without intense labour allied to theoretical effort.

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[53] I say 'probably ineffective' owing to modern chemical knowledge and the fact that the ideas seem to have gotten no traction.

[54] Christoph Bartels, "The Production of Silver, Copper, and Lead in the Harz Mountains from the Late Times to the Onset of Industrialization," in *Materials and Expertise in Early Modern Europe: Between Market and Laboratory,* eds. Ursula Klein and E. C. Spary (London and Chicago: University of Chicago Press, 2010), 71-100.

Making Saltpetre

In early modern England, there were three primary options for procuring saltpetre. The most common of these was importation, often from India.[55] Another option was to gather naturally occurring saltpetre, which could be scraped off walls if the conditions were right.[56] This method, however, was rare and unreliable. Finally, saltpetre could be artificially extracted from the earth. This latter method was of interest because if done correctly, it promised to make the state self-sufficient. In times of war, import supplies could be cut off which would be disastrous.

Concerning the economy and political consequence of saltpetre procurement, there are several commentators to whom we can turn. Buchanan has shown that the English had great difficulty in maintaining an efficient saltpetre industry that could match the ever-increasing demand for the product.[57] As she has shown, it may be considered successful in the sense that in the early modern period more and more nitre-beds were being made in the countryside, meaning that gunpowder makers could purchase saltpetre outside of the confines of the royal monopolies on the craft. Cressy's efforts are focused on the wide-reaching early modern networks of saltpetre. He correctly argues that saltpetre brought together the 'interactions between science and technology, society and war'.[58] He shows the importance of saltpetre to the early modern state. It is not the goal of this chapter to examine the politics and economy of saltpetre making, but it is important to keep in mind that saltpetre was more than a curiosity. It was a necessity.

Knowledge of the saltpetre extraction process had circulated in Europe from the medieval period. Although mentioned in the secretive texts of Roger Bacon in the thirteenth century, the first text on actually making saltpetre in Europe is from Conrad Kyseser's military manual *Bellafortis* (1405), where he presents a vague procedure for layering the earth with salt water and quicklime in order to make

55 Cressy, *Saltpeter,* 34.

56 Smith, *Rewriting the History of Gunpowder,* 26-27. The walls conducive to 'growing' saltpetre would normally be in a cellar, dovecot, or similar environment. However, when MGRG tested a salt growing on cellar walls, it was analysed and proven to be potassium sulphate, not potassium nitrate.

57 Buchanan, "Art and Mystery," 238-40.

58 Cressy, *Saltpeter,* 2.

gunpowder's majority component.[59] The 'earliest unambiguous description', according to Williams, is Gerard Honrick's 1561 recipe.[60] Further variations on the procedure known as 'lixiviation' were printed in the *Pirotechnia* (1540) of Vanoccio Biringuccio, Georgius Agricola's *De Re Metallica* (1556), and Lazarus Ercker's *Treatise on Ores and Assaying* (1580).[61] The treatises have slight differences but all operate on the same principles of lixiviation. Saltpetre making was a lucrative enterprise, and naturalists were ever keen to adapt and evolve the difficult procedure.

The lixiviation procedure begins with the preparation of large quantities of soil mixed with animal faeces. This creates the right chemical environment for nitrates to form. This nitrous pit is treated with urine and air (for oxygen) at regular intervals while it is left to ferment, before the nitrous crystals can be extracted. The salts must then be washed out of the earth. Lixiviation operates on the premise of solubility. Water is run through the earth to dissolve the salts before allowing them to crystallise, and putting the resulting liquor through a purification process that removes impurities and non-nitrous salts. Saltpetre is quite literally the salt of the earth.

Making saltpetre was not easy. Williams, following his unsuccessful attempts to produce saltpetre based on medieval sources, concluded:

> [Saltpetre making] can never have been a very rapid or efficient process. It is remarkable that it was devised at all, and the author, has acquired a considerable respect for the powers of observation and experimental skill of the 14th century chemists who discovered how to operate the artificial nitre bed.[62]

He found that the process was incredibly difficult. Even with several early sources to use as a guide, the technology of saltpetre making would not easily give up its secrets to the modern investigator. The innate challenges tell us why saltpetre was the most elusive out of gunpowder's three ingredients. Williams's attempts to make saltpetre according to medieval principles took place in his basement laboratory,

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59 Conrad Kyser, *Bellafortis* (1405), cited in: Williams, "Saltpetre in the Middle Ages," 125.

60 "Honrick's Recipe," (1561), reproduced in: Williams, "Saltpetre in the Middle Ages," 128-30.

61 Georgius Agricola, *De Re Metallica*, 1556, trans. Herbert Clark Hoover and Lou Henry Hoover (New York: Dover, 1912), 561-64; Lazarus Ercker, *Treatise on Ores and Assaying* 1580, trans. Anneliese Grünhaldt Sisco and Cyril Stanley Smith (Chicago: University Chicago Press, 1951).

62 Williams, "Saltpetre in the Middle Ages," 133.

using modern chemicals. He was trying to recreate the chemistry of saltpetre in a 'physical experiment.' This does not really tell us much about saltpetre making beyond that it is a difficult process that needs a precise combination of chemical reactions to give any decent yield. The large-scale process of producing saltpetre has much to tell us about how it, and gunpowder, was approached by early natural philosophers.

Reworking Saltpetre

The MGRG in 2013 and 2014 continued a long-term project to experimentally investigate and rework medieval ways of making saltpetre. The group's first attempt was in 2001-04, when a nitre-bed was constructed comprising layers of soil, chicken manure, and lime in a sunken pit beneath a chicken coop.[63] The pit was maintained for three years, and the extraction process in 2004 produced disappointing results. They had obtained potassium sulphate, instead of potassium nitrate. The correct chemical materials had formed in the pit, but had not converted into nitrates.

The group, on reflection, suspected that there was not enough urine added to the mixture, and that the use of bird faeces may have produced an overly acidic environment that was detrimental to the production of nitrates, which favours an alkaline environment. Although lime was added to the pit to facilitate this, it was evidently not enough to counteract the acidity. Finally, being a pit as opposed to a built-up pile, it is possible that not enough oxygen could penetrate the mixture.[64] It is evident that the nitre bed depends on a sensitive balance of chemical materials and environment. It is no wonder that Williams had nothing but admiration for the tacit skills involved in medieval saltpetre production.

The second attempt began in Spring 2012 with the creation of a new nitre bed in the museum grounds. This consisted of soil mixed in equal parts with pig dung, with regular turning and the addition of pig urine. A half-shelter was built over the pile to protect it from the elements. The extraction process began in September

[63] Smith, *Re-writing the History of Gunpowder*, 31-34.

[64] Smith, *Re-writing the History of Gunpowder*, 31-34.

2013.[65] Our procedure was primarily based on the treatises of Honrick, Ercker, and Thomas Henshaw.[66] The five day long lixiviation process took place behind-the-scenes at the museum, using modern apparatus owing to temporal and financial constraints. We learned a great deal about the nature of making saltpetre, although the yield was disappointing as we obtained roughly only one hundred grams of unrefined saltpetre.

After almost one year, in which several planning meetings took place, the group reconvened for twelve days in 2014 to try again. The nitre bed had been maintained during this time. After showing in 2013 that the methodology had promise, and learning from our past experience and mistakes, this second attempt was conducted on a larger scale. We worked inside the museum in public view, wearing medieval costume, using historically appropriate apparatus comprising everything from wooden barrels to a medieval style wheelbarrow. Most equipment, the centre already had. Other items, such as our 'settling tubs' and wicker rundles, were made prior to arrival at the centre.

We realised that to gain a full appreciation of the complexities of the procedure, we would need to reproduce, as far as possible, the equipment and environment at the heart of the craft—as well as the chemical materials. Fortunately, Ercker provides us with several descriptions and illustrations that helped us to rework the early modern saltpetre factory. We set up a row of 'settling tubs', which are half-barrels fitted with taps—we used wooden taps made for beer barrels. These were set up on a table upon trestles. Further, on the table the backs of the barrels were slightly tilted by placing them on a plank of wood to make for easier draining and lifting (after lessons learned in 2013).

We used iron cauldrons and wood fires, and carried the water in wooden buckets. Thus we ended up with a set-up analogous to the ones described and illustrated in our sources. For our efforts, we again obtained a small yield of just over 100g of refined product. Yet this time our saltpetre looked much more like what it should look like, according to our sources, which is large needle-like crystals. Moreover, we greatly enhanced our knowledge of the procedure as early modern

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[65] I am grateful to The Society for the History of Alchemy and Chemistry (SHAC) for a 'New Scholars Award' to fund my research trip to the Medieval Centre in September 2013.

[66] Thomas Henshaw, "The History of the Making of Salt-peter and Gunpowder," in Thomas Sprat *The History of the Royal Society* (London: 1667), 260-83.

craftsmen may have conducted it. Below is a detailed exposition of the lixiviation process conducted by the MGRG in its 2014 session (in four steps, not to be confused with my suggested four-stage methodology as seen in the next section).

Figure 3: medieval style wheelbarrow

Step 1: Settling Tubs

The first step was to set up our site. The primary apparatus was our 'settling tubs.' Henshaw suggests preparing eight to ten of these at once.[67] Our team was, at any one time, at least four strong. We had four people in costume doing the work, with an additional team member, not in costume, observing and taking detailed notes. A suitable workload was for us to set up four tubs at one time. To prepare the tubs, they must be layered with materials. As instructed by our sources, these tubs

[67] Henshaw, "History," 268.

were layered with straw, ashes, and a slatted wooden frame made to fit the barrel.[68] On top of this, the nitrous earth is added until it reaches a hands-breadth from the top. We used roughly 40kg of earth per tub.

Figure 4: set-up of settling tubs and trough for draining

These layers have distinct purposes. The straw prevents the lixivium, the liquid that is drained from the nitrous earth via lixiviation, from becoming too muddy at the point of draining near the bottom of the barrel. The ash helps to filter the lixivium from the nitrous earth as well as providing an alkaline environment favourable to the production of nitrates by counteracting any acidity. The wooden framework positioned just above the level of the tap helps to prevent the tap becoming stopped with mud.

[68] Henshaw, "History," 268-69. Henshaw uses twigs instead of a pre-made wooden frame. We found the frame to be more effective than twigs.

Figure 5: wooden boards to prevent tap blockage

Water is poured into the earth over a wicker rundle. This is an essential part of the procedure.[69] The 2013 extractions did not use this item, as we were unclear on its purpose. We soon found out that pouring water directly onto the nitrous earth tends to create a tunnel. The rundle ensures an even distribution of water, so that it can penetrate more earth and more salts can be dissolved.

Henshaw suggests leaving the tubs to settle for eight to ten hours.[70] We left them all overnight for the first wash. Leaving the water in the tubs for some time allows for the water to dissolve the salts in the nitrous earth. In the mornings, we would slowly drain the liquid through the taps. As an efficiency measure, we emulated the draining system that appears in some of our sources.

[69] Henshaw, "History," 269.

[70] Henshaw, "History," 269.

Figure 6: lixivium of four settling tubs draining via the trough

Below the taps we placed a trough-like contraption made of two planks of wood joined together to make a right angle. This was held up with bricks with the right side tilted slightly higher than the left. This meant that all taps could be opened at once to drain into an empty tub underneath the end of the trough. Once drained, we would fill these up with water again for a 'second wash', and they would settle until the end of the day. This was done in order to maximise the yield, hoping that the second wash might catch some of the salts that the first wash missed. At the end of the day, the second wash is drained and new settling tubs prepared. This procedure was followed over eight days.

Step 2: Boiling

From the settling tubs we had a dilute nitrous solution or 'lixivium'. This must be boiled down to make a concentrated nitrous solution.[71] Without the luxury

[71] Henshaw, "History," 269-71.

of a fast acting gas burner as we had in 2013, we used four small iron cauldrons above wood fires. These had to be constantly maintained with firewood, which we chopped as we went along. As instructed by our sources, we kept a vigilant eye on the cauldrons, removing the black scum whenever it appeared with an iron ladle. After days of boiling, we reached the desired almost-oily consistency. The lixivium was boiled down to roughly 20 litres and when a drop was dropped on a flat surface like a knife, it was possible to see needle-like shapes: a positive indicator that the solution had saltpetre in it. The next stage was to convert the calcium salt to potassium so the lixivium, heated up, was poured through a tub of ashes. This was after adding ten litres of water to wet the ashes so that not all of the nitre was dissolved there. This was left overnight before the liquor was run out.

Figure 7: cauldrons for boiling down the lixivium

Figure 8: crystals in trough before (above) after (below) draining

Step 3: Crystallisation

Our solution was now a rich, transparent dark brown. Once drained from the tub of ashes, it was left in a flat rectangular trough for thirty-six hours to crystallise. Yet when we returned to this, nothing had happened. It is suspected that the solution was not concentrate enough. Owing to time-constraints, we boiled the lixivium down in the gas boiler behind the scenes and left the newly reduced solution overnight in the trough. When we returned the next morning, several crystals were visible. They gathered on the bottom of the tub. There were some clusters, and some singular crystals roughly 12cm long by 0.5 cm wide. They were the correct shape for saltpetre, so this was very promising. There was no way to analyse the findings but potassium nitrate is known to precipitate in long needle crystals.

Step 4: Refining

The last stage is the refining or purification process.[72] The 350g of crystals were dissolved in one litre of clean water and slowly boiled. In correspondence with early modern descriptions, the solution becomes concentrated and impurities fall to the bottom of the cauldron or pot where they can be removed with a spoon, ladle, or spatula. The solubility is the key to this whole process. Different temperatures will dissolve different salts. The non-nitrous salts or impurities have roughly the same solubility in hot and cold water, but saltpetre is dependent on temperature. After we were satisfied that impurities had fallen out of the mixture, it was cooled to room temperature. What remained was 200g of wet saltpetre, which was left to dry overnight. As it dried, the brown colour became lighter although still not obviously white. Saltpetre, as purchased today, should be white. Yet it is clear that this was a problem known to the early moderns. Our sources sometimes gave instructions to make the saltpetre whiter. Henshaw suggests adding a 'shovel full of quicklime' during the refining process.[73] So whilst our brown saltpetre was discouraging, this is only because we know the modern pure chemical to be white and crystalline.

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[72] Henshaw, "History," 273-74.

[73] Henshaw, "History," 273-74.

Reworking Experiments in the History of Science

> The Knowledge of the Nature of *Nitre* would be esteemed barren, and the labour in its Extraction vain, if the practical uses did not follow its Philosophical speculation.[74]

The way of making saltpetre was highly complex. It seems to have been complicated even to early modern philosophical commentators who sought new ways of applying science to its improvement. I argue that reworking experiments help us gain a much fuller appreciation and understanding of the aforementioned multifaceted approaches to saltpetre making. Reworking experiments helps us to balance out the historiographical preference for theory. Practice was a crucial part of early modern Baconian philosophies, and reworking experiments is a way to access this crucial part of early science. In this section I explore some of the theory behind reworking experiments as a historical methodology before presenting my own four-stage process for reworking.

Reworking Experiments

Early modern philosophy, when it was at the cusp of the Baconian experimental methodology, was innately interdisciplinary. It required the natural philosophers to think in multiple ways, as well as use craft and practical inquiry to stimulate inquiry and generate knowledge. Tara Nummendal captures the eclectic ethos of early modern science and alchemy:

> Simultaneously bookish, experiential and experimental, alchemy stubbornly resists any attempt to separate out the histories of reading, writing, making, and doing. In fact, it demands that these various engagements with nature, the relationships among them, and the people of all social strata who created them all be kept in play in any account of its history. In this sense, alchemy offers a model for thinking about early modern science more generally, particularly in light of recent work that has explored the intersection of scholarly, artisanal, and entrepreneurial forms of knowledge.[75]

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[74] Clarke, *Natural History of Nitre*, 48.

[75] Tara Nummendal, ''Words and Works in the History of Alchemy,'' *Isis* 102 (2011), 330-77, on 331.

Reworking experiments offers a much fuller and complex understanding of how these changing ways of generating knowledge actually worked. It requires historians to step outside of their own discipline and think more broadly. From simply reading about procedures, it is hard to grasp the particular challenges, minutiae, and experiences that accompanied the changing sciences of the early modern period. Reworking the past is a way to attempt to approach at least some of these interdisciplinary experiences.

The role of artisan and craft knowledge has long been recognised as important in the development of early modern science. The sociologist Edgar Zilsel advanced the claim that craftsmen made an essential contribution to science in the early modern era, pertaining to the role of scientific instruments and experiment in scientific method.[76] More recent historiography of science has built on this thesis. Pamela Long examines late medieval/ early modern technical manuals on topics such as artillery that played a role in the emerging relationships between practical skill and knowledge. [77] She argues that 'whereas authorship helped to transform some arts from the arena of learned know-how to that of discursive knowledge, it did not change artisans into learned men. It is more accurate to say that it prepared certain of the mechanical arts for appropriation by learned culture.'[78]

The essays in *The Mindful Hand* (2007), edited by Lissa Roberts *et al,* deal with the connection between hand and mind in the early modern era, focussing largely on manual practises and their roles in knowledge formation.[79] Pamela Smith, for example, takes us inside the workshop of the sixteenth-century goldsmith.[80] She argues that the processes of craft production had an inherent investigative component. In the example of the goldsmith's casting of animals she argues that the

[76] Zilsel, "William Gilbert's Scientific Method."

[77] Long, "Power, Patronage, and the Authorship of the Ars."

[78] Long, "Power, Patronage, and the Authorship of the Ars," 38-39.

[79] Lissa Roberts, Simon Schaffer and Peter Dear eds., *The Mindful Hand.* Most useful to this thesis is the first section 'Workshops of the hand and mind' that explores sites of craft and knowledge production that show a fusion of theorizing and craft skill.

[80] Pamela Smith, "Inside a sixteenth-century goldsmith's workshop," in *The Mindful Hand: Inquiry and invention from the late Renaissance to early industrialisation,* eds. Lissa Roberts, Simon Schaffer and Peter Dear (Amsterdam: Royal Netherlands Academy of Arts and Sciences, 2007), 33-57. See also: *idem., Body of the Artisan*. Smith explores craft knowledge and artisans conceptions of knowledge in the Renaissance era, exploring how hand and mind were required to come together.

practitioner had to investigate other natural phenomena, namely the behaviours of both animals and materials.[81]

Materials and Expertise in Early Modern Europe (2010) looks to the places, such as workshops, markets, and laboratories, where the collaboration of theory and practice actually took place. For example, Bartels explores the development of technologies in mining in the Harz Mountains in the early modern period.[82] He argues that early modern technical developments such as hydraulic systems and gunpowder blasting arose from a complex blend of skills and hands-on knowhow of mining and metallurgical materials, with mathematical, alchemical and organisational knowledge. This mix of expertise was crucial in the expansion of the mining industry.[83]

What I seek to add to this literature is an enhancement in our understanding of how hand and mind engaged. We can learn more of its complexities if we engage both hand and mind ourselves. Food historian Peter Brears produces the recipes that form the heart of his work on medieval cookery. He argues that the food 'must be cooked and tasted, for only in this way can its range of colours, flavours, textures and aromas be fully appreciated.'[84] Reworking experiments and procedures gives us an enhanced appreciation, as Brears argues, but it also gives us an enhanced knowledge—pertaining to both an increase of data, and an understanding of the experimental complications and procedures that do not survive in text.

A focus that places interest on the use and experience of artefacts, apparatus, environment and materials is not standard in the history of science. Yet this is the primary interest of archaeology. A discipline concerned with using the material past to generate historical knowledge, archaeology has much to tell us about research into practice in the past. This discipline realises and thrives on the fact that material phenomena demand a different sort of approach than texts do:

> Material things are exactly that – physical objects. Their properties are, in many ways, very different from words. Material things can be functional in ways that words are not…The material world, then, is not

81 Smith, "Inside a goldsmith's workshop," 56.

82 Bartels, "Silver, Copper, and Lead."

83 Bartels, "Silver, Copper, and Lead," 81-84.

84 Peter Brears, *Cooking and Dining in Medieval England* (Totnes: Prospect Books, 2008), 11.

> reducible to language, and more broadly, the material world is a complex thing that is not easily understood in its own right. Perhaps, in that case [we] should not talk about 'meanings', but rather more broadly about 'understanding' and 'experience'.[85]

Material things are intricately connected with the human agents who make, use, and discard them. We cannot assign specific meanings to objects owing to the potential pluralities of interactions the objects may have experienced in their lives. Looking towards experience, however, can increase our understandings of object-person interactions, and subsequently shed light on a particular historical context.

A real blend of theory and practice must always be present in archaeological method and interpretation. Archaeology is not necessary a stranger to the history of science. For example, Marcos Martinón-Torres excavated a seventeenth-century laboratory in Oxford, shedding light on the nature of early modern laboratory equipment and materials.[86] Material culture, whether surviving in a museum, landscape, or textual description, presents a fruitful locus of inquiry.

Yet the topic of this thesis is not one that is suited to recovery via excavation. Gunpowder is ephemeral. It was not meant to last, certainly not beyond the moment of ignition. If we look to particular sub-disciplines of archaeology, however, there is more that we can do to understand historic approaches to gunpowder. It is not my goal to uncover lost compositions of gunpowder, but rather to understand the human uses of it. Particularly, natural philosophical uses of it. For this purpose, experimental archaeology can be used to illuminate our existing historical knowledge. Experimental archaeology is devoted to the use of experimental methods to illuminate aspects of past life, technology, and society. In experimental archaeology, we are afforded the opportunity to go beyond the information provided by our surviving objects, landscapes, and texts:

> An experimental, positivist approach [to archaeology] can escape the shackles of simple historicism and empiricism, because it allows one to move beyond the limited range of options made available by records of

[85] Matthew Johnson, *Archaeological Theory: An Introduction,* 2nd edn. (Oxford: Blackwell, 2010), 117.

[86] Martinón-Torres, "An Archaeological Study of the Old Ashmolean Chymical Laboratory in Oxford," *Ambix* 59 (2012), 22-48. See also: *idem.,* "Why should Archaeologists take History and Science Seriously?" in *Archaeology, History and Science: Integrating Approaches to Ancient Materials,* eds. Marcos Martinón-Torres and Thilo Rehren (California: Left Coast Press, 2009), 15-36.

> the currently known world. It allows investigation of the counter intuitive and for the possibility of deductive leaps, rather than simply relying on probabilistic and inductive extrapolations of existing knowledge.[87]

Experiment allows us to address issues that we cannot reach via material remains or historical texts alone. It expands our inquisitional horizons.

Like experiment in the history of science, experiment in archaeology comes in a range of forms. Experimental archaeology may test hypotheses in an isolated laboratory environment. It may be used to offer insight into past skills. On a larger scale, it can even be used to generate ideas on past behaviours, experiences and systems. At base level, however, the discipline's aim is to replicate some dimension of the past. Daniel Mayer and James R. Mathieu conjecture that 'by allowing the experimenter to potentially put themselves in the shoes of a past person, experimentation lets us confront the world of possibilities as past people may have'.[88]

> Experimental archaeology […] approaches archaeological remains in a questioning way, and attempts to understand what ancient man was doing, how he was doing it, and why he was doing it. [It is] a study designed to look at ancient man as an inventor, technician, a craftsman, an artist, and a human being. By reproducing his actions archaeologists can better understand not only his technical abilities but also his reasons for choosing one course of actions rather than another.[89]

If we rework potential actions or experiences, we gain a much more varied understanding of our subjects. We realise that experimenters were more than experimenters. They had a variety of skills, abilities, and personalities that informed their experiences.

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87 Outram, "Experimental Archaeology," 1.

88 Daniel A. Meyer and James R. Mathieu, "Reconceptualizing Experimental Archaeology: Assessing the process of experimentation," in *Experimental Archaeology: Replicating past objects, behaviours and processes,* ed. James R. Mathieu (Oxford: BAR International Series 1035, Archaeopress, 2002), 73-82, on 76.

89 John Coles, *Experimental Archaeology* (London: Academic Press, 1979), vii, 2. Coles's work is considered a definitive work in experimental archaeology.

The goal in experimental archaeology, according to Mathieu, is to generate analogies that can be used in archaeological interpretation.[90] The reworked artefact, skill, or experience gives the modern investigator something more to think with, more ways to interpret the past. This branch of experimental archaeology is one that I would carry through to the history of science. We are trying to look beyond the evidence we already have. For some philosophers, such as Boyle, we are fortunate to have their papers and work diaries.[91] Reworking allows us to go further beyond what they actually published to get an insight into their laboratory life. Bruno Latour's and Steve Woolgar's mode of investigating scientific culture was to follow scientists around in the laboratory.[92] From their efforts they developed 'actor network theory', a theory that postulates that human actors and objects hold agency in the networks that produce scientific knowledge.[93] This chapter does not employ this theory but the way in which it resulted from observations of scientific practice merits mention. Reworking allows us to go further still beyond our theoretical ideas. A crucial point is that what we read on paper is just the tip of the iceberg, the material selected for publication. Using methods like working papers and reworked processes lets us go further still.

Methodology

The above theoretical treatment gives us some indication as to why reworking experiments is a good idea. The existing replication literature has done much to test hypotheses, test the validity of historic claims, and explore skills and the agency of apparatus and materials. What is missing, I argue, is an approach that looks more broadly to the larger process of experiment. There is an immense amount of planning and preparation that must take place before any practical work can take

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[90] James R Mathieu "Introduction" *Experimental Archaeology: Replicating past objects, behaviours and processes,* ed. James R. Mathieu (Oxford: BAR International Series 1035*,* Archaeopress, 2002), 1-4, on 1.

[91] Michael Hunter, *The Boyle Papers: Understanding the Manuscripts of Robert Boyle* (Aldershot: Ashgate, 2007). The Boyle papers (The Royal Society, 2004). Available Online: http://www.bbk.ac.uk/boyle/boyle_papers/boylepapers_index.htm

[92] Bruno Latour and Steve Woolgar, *Laboratory Life: The Construction of Scientific Facts* (California: Sage, 1979).

[93] Bruno Latour, *Reassembling the Social: An Introduction to Actor-Network Theory* (Oxford: Oxford University Press, 2005).

place. The nature of the modern historian's procedure will of course differ from that of past actors, but it generates an analogy and reminds us that there would be a lot going on behind the scenes and between the lines of the experiments that we study.

With a four-stage approach, we can think about the wider actions necessary for an experiment's successful execution. This presents us with the bigger picture regarding experiment, as well as a greater appreciation for all that went into it. Importantly, this also highlights that particular materials or ideas bring particular challenges that not only affect the practical experiment, but the work leading up to it.

Stage 1: Selection

The first stage in reworking experiments or processes is selecting experiments or procedures to rework. This may seem like an obvious point to make, but it is one that is more loaded than it may initially seem. Not every experiment will lend itself to a modern-day adaptation. It may be that our source does not provide enough detail to be reworked. There could be health and safety issues; these are particularly prominent when working with gunpowder. An experiment proposed in front of the Royal Society to make a gunpowder-operated flying machine is probably best left alone.[94] So too is the infamous gunpowder-propelled cat.[95] It is the case that many seventeenth-century gunpowder experiments used tiny amounts of the material and would not be particularly dangerous. But we must be sure of this before proceeding.

With the exception of the saltpetre experiment at the heart of this chapter, the reworked experiments in this thesis were all conducted with the Royal Armouries. The museum provided the necessary safety and legal expertise necessary to conduct our research. Moreover, the team at the museum provided invaluable knowledge, experience, and time. The experiments selected for reworking were chosen after

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[94] This proposal from 1674 is found in: Birch, *History*, III, 181.

[95] Mitch Fraas, "A Rocket Cat? Early Modern Explosives Treatises at Penn," *Unique at Penn,* (2013). http://uniqueatpenn.wordpress.com/2013/02/05/a-rocket-cat-early-modern-explosives-treatises-at-penn/. For more on gunpowder animals, such as 'fire-ox' and 'magic-fire flying crow', see: Needham, *Gunpowder Epic,* 210-219, under the apt title 'bizarre delivery methods.'

several detailed planning meetings.[96] A shortlist of experiments was compiled, and together we narrowed this down to those that could feasibly be reworked.

An obvious, but crucial, criterion for selecting our experimental projects is that we must choose experiments deemed historically important and relevant to our research. Boyle's 'redintegration' was chosen because it was a defining moment in Boyle's natural philosophy. The separation of the ingredients of gunpowder was historically interesting and pertained to the fundamental question asked by Bacon and Boyle about the huge effects that arise from such a simple composition. The laboratory settings of these two Boyle experiments depart from the way that we normally perceive gunpowder, as a violent explosive. In contrast, the experiments to test the strength of gunpowder reminded us of gunpowder's spectacular explosive properties. In a laboratory setting, this experiment promised to offer an insight into the connections between natural philosophy and military concerns in the seventeenth century.

When considering the conduciveness of a particular experiment for repetition, we must also bear in mind the intentions of the historical author. Some experiments are documented with replication in mind, such as those performed in front of the Royal Society and documented in the *Philosophical Transactions.* However we cannot assume that our sources volunteer all of the necessary information for reworking, in particular early modern alchemical texts which are notorious for their ambiguity and secrecy.[97]

The saltpetre experiments on the other hand, offered an insight into the material behind gunpowder's massive expansion. As a craft procedure as opposed to a laboratory experiment, we also get to work on a larger scale to see how chemicals are made before they are transported to the laboratory or gunpowder-making factory. Thus we had a good cross-section of experiments to rework. Some were laboratory experiments that challenged our assumptions about gunpowder's uses, another was a

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96 The Royal Armouries staff involved in the project: Peter Smithurst (Curator Emeritus of Firearms), Graeme Rimer (Curator Emeritus)Jonathan Ferguson (Curator of Firearms), Alison Watson (Curatorial Manager), Suzanne Kitto (Conservation Manager), Trevor Weston (National Firearms Centre). From the Universities of York and Leeds: myself (University of York), Dr. Sophie Weeks (University of York), Dr. Chris Kenny (University of Leeds). Regarding the eprouvette experiment, we consulted via email with Prof. Steven Walton (Michigan Technological University) who designed and built the device.

97 Principe, *Secrets,* 143-56. Principe argues that chrysopoetic texts were secretive, but also had the function of revealing chemical procedures via these allegorical 'keys'.

laboratory experiment that did play upon gunpowder's explosive properties but in a philosophised way, and another studied the way of producing the material in a craft knowledge context.

Stage 2: Planning

When we have chosen the topics of inquiry, a painstaking planning process must take place before the experiment can begin. To plan the experiment is to translate it. We must translate historical texts into something that we can comprehend today. This relates at base level to the terminology of apparatus and materials, but also to the wider process. This is not dissimilar to the translation from field to laboratory that was undertaken by Boyle. He had to be able to work with gunpowder and interpret it in his own familiar intellectual and physical environment, and we must do the same. When reworking experiments we are seeking a different sort of knowledge than we would be when we are analysing texts. In experiment, we must be thinking about the dimension of practice as well as theory, and thinking about the actions and experiences of our protagonists. We must translate the experiment into our own terms, and after the experiment, retranslate our experiences as historical knowledge relevant to our particular research topic.

A potentially challenging feature of reworking experiments is deciphering early modern terminology. Jon Eklund's *Chemical Dictionary* is especially useful for explaining materials and concepts in early chemistry.[98] For example, 'spirit of salt,' which appeared often in Boyle's work, is hydrochloric acid.[99] The Oxford English Dictionary Online is also a valuable resource for relating historic terms to modern ones.[100] This is where some degree of chemical knowledge comes in useful. The team at the Royal Armouries had a range of skills and expertise. Smithurst, who instructs and supervises our experiments, has a background in chemistry as well as an extensive knowledge about gunpowder and its ancillary technology. Thus we

98 Jon Eklund, *The Incompleat Chymist: Being an Essay on the Eighteenth-Century Chemist in his Laboratory, with a Dictionary of Obsolete Chemical Terms of the Period* (Washington: Smithsonian, 1975).

99 Eklund, *Incompleat Chymist*, 34.

100 For example, the Oxford English Dictionary has definitions of the term 'redintegration' '2.a. *Chem.* 'The restoration of a substance to its original state, esp. by combining its constituent parts; regeneration' from the year 1550 onward: Oxford English Dictionary Online, http://www.oed.com.

were able to plan together about what we can use for the experiments. In advance, we must procure all of the necessary materials and apparatus. In a sense, we must create a 'shopping list' of all the materials that we will require on the day. Some experiments may require us to build, as well as procure.

One of the biggest challenges was finding a suitable location for our experiments. As a student in a university history department, I did not have easy access to a laboratory for the chemical experiments. Likewise, the Royal Armouries did not have a laboratory. Thus the Boyle experiments were actually undertaken, safely and legally, in Smithurst's kitchen. We had access to heat, water, and basic chemistry apparatus, so were able to conduct the experiment easily there. To test gunpowder using early modern devices and methods, we worked at the National Firearms Centre. Finding an arena to rework experiments is one of the most challenging dimensions of this methodology.

In addition to solving the materials and apparatus question, we must make a detailed step-by-step plan that we can easily follow on the day. We must go through our texts with a fine-tooth comb to form a sort of instruction manual. We should also take care to note the results and sensory observations noted in the text. Whilst it is true that we may not obtain the same results as our protagonists, this way we can at least tell what the difference is between our modern interpretation and the past one. I would argue that the exercise up to stage 2 is a useful one, even if it is not possible for us to go to stages 3 and 4. Making such a detailed modern interpretation forces us to get to grips with the minutiae and details that we may gloss over. When reading an experiment with mind to reworking, we get an enriched appreciation and comprehension of it.

Stage 3: Experiment

Once sufficient planning has been undertaken, and everything is in place, it is time to experiment. A crucial part of this is observation and recording. We must also be prepared for unexpected challenges. Reworking the experiments with early modern gunpowder testers required several adaptations to be made to the apparatus on the day in order to get it to work, as we shall see in Chapter 5. There are some things that you cannot predict without actually undertaking the experiment. We must also be aware of skills—the potential disparity between our own skills and that of historical experimenters.

Stage 4: Reflection

During the final stage of reflection we re-translate our modern experimental data into something meaningful with regard to our research. We must carefully choose how to interpret and present the data. Many choose to provide the process and results in modern nomenclature and equations. I argue that this is not useful when it comes to the presentation of results. Rather, I suggest that modern chemical knowhow is more useful in stages 2 and 3. I am in agreement with both Principe and Kleber Cecon, that in order to replicate early modern experiments, some degree of modern chemical knowhow is needed.[101] We must know, to some extent, what we are doing in a modern sense in order to rework it. Having the historic terminology translated may also allow for a greater ease in interpreting the experiment.

With regard to presenting the findings, however, modern chemical nomenclature and equations are problematic. Modern nomenclature is useful only to those who actually understand it. These words and figures mean little to everyone else. We must also be careful to avoid anachronism. Boyle, the Royal Society, and seventeenth-century powder makers would not be familiar with the modern terminology. They interpreted their chemical experiments via a sense-based understanding.[102] In my work I am trying to understand gunpowder and saltpetre experiments in the way that early moderns would have, so to draw on modern chemistry in my depictions is futile. The goal is not to find out what was actually happening to gunpowder chemically, but rather to figure out what these experiments meant for natural philosophical research in the seventeenth century.

Value of Reworking Experiments

Now that we have explored the basics of early modern saltpetre making, and the theory and method behind reworking experiments, we can move on to the

[101] Kleber Cecon, "Chemical Translation: The Case of Robert Boyle's Experiments on Sensible Qualities," *Annals of Science* 68 (2011), 179-98.

[102] Cecon, "Chemical Translation."

benefits of this methodology. To do this I draw on the saltpetre experiments. Reworking experiments provides us with insight into the tacit knowledge of early practitioners, as well as providing us with new data and ideas. We can get to grips with the minutiae of experiments, as well as the significance of the experimental environment. Further, we gain knowledge—tacit, intellectual, and material—that we would be unlikely to gain from reading texts alone. Importantly, as Heering observes, reworking experiments allows us to 'reread source material from a different perspective.'[103]

Challenges of Reworking Experiments

Before we move onto the values of reworking experiments, we must be aware of the specific challenges and problems of this method. There are some more general criticisms of reworking as a methodology, which are important to address. There are also localised challenges, specific to particular materials.

An obvious point that we must acknowledge is that we cannot 'replicate' the past. We are only reworking specific aspects of the past. We can reproduce materials, apparatus and procedures to the best of our ability, but we must be very aware that we are working in a far different socio-political context. We cannot say for sure how past actors thought and acted. The social context of the past would be influential on science, as Shapin and Schaffer have repeatedly argued.[104] Yet this is something we can only speculate upon. As Principe states: 'what is certainly true is that the ways substances behave and react have remained the same, even as the ways human observers explain and conceptualise them have changed.'[105] We may be able, to some extent, replicate the physical context, but some things simply cannot be emulated today.

Historians cannot expect to suddenly become expert in their selected field of experiment. The craftsmen who made saltpetre and gunpowder would be working their trade for years to develop the necessary skills and ability to generate their product. Indeed the years of immersive experiential engagement with nature along

[103] Heering, "Experimenter's gotta do," 796.

[104] For example: Shapin and Schaffer, *Leviathan and the Air-Pump,* 155-224; Shapin, "House of Experiment."

[105] Principe, *The Secrets of Alchemy*, 138.

with their obvious productive power are the reason for the Baconians' keen enthusiasm for craft knowledge.

In our saltpetre experiments, it took some time to get used to the process, but we did start to develop an instinctual knowledge concerning how to handle our materials. Biringuccio admiringly writes on the skilled saltpetre maker, noting that 'when the experienced craftsmen believes [the saltpetre] to be melted, he uncovers it and looks at it.'[106] In these operations with saltpetre, the makers' experiential knowledge results in an ability to generate the substance artificially from a manmade nitre-bed: 'the intelligence of man has become so acute that it has found a way of causing saltpetre to be produced in soils and in places that did not possess it before hand.'[107] This habitual and practical knowledge is what leads to improvements and changes in the practice.

Tacit Knowledge

While it is true that the modern scholar cannot be transformed into an early modern craftsman by spending brief time in the field, our situation is actually not that different from the scholars whom we study. The Hartlib Circle and Baconians were in likelihood not getting their hands horrendously dirty. When studying trade processes, their approach was akin to directing and observing. Despite what we recognise as the desirable experiential knowledge of workers, they did not become fully immersed in this world.[108] In this regard we may be considered to be in the position of the Baconian scholar, observing trade processes hoping to reconcile and develop theoretical ideas based on practice. The difficulties of building up the tacit knowledge and intense practical knowhow of tradesmen is an important factor in the laboratory or equivalent experimental space becoming the hub of activity in seventeenth-century experimental philosophy. Gentlemen virtuosi were more comfortable in their laboratories where craft processes and materials could be translated into more familiar terms and given a theoretical and philosophical gloss.

[106] Biringuccio, *Pirotechnia*, 409.

[107] Biringuccio, *Pirotechnia*, 409.

[108] Eamon, *Secrets*, 81-83.

Nevertheless, the translation of craft practices into elite spheres demanded skill and the building up of habitual tacit knowhow. Hence, reworking experiments is a good way to access the process of acquiring practical skills in an early modern laboratory. As well as getting to grips with experiments and the nature of practice, we can also to some extent access the tacit knowledge and habitus that is not portrayed in texts. Tacit knowledge relates to skills and actions, the habitual, bodily, and learned practices that are not easily conveyed in words. Michael Polanyi explains tacit knowledge as 'knowing more than we can tell', arguing that 'our body is the ultimate instrument of all external knowledge, whether intellectual or practical.'[109] He claims that tacit knowledge forms an important part of the generation of scientific knowledge. He even suggests that because of our bodily interaction with our subjects, the putative objective and detached knowledge that modern scientists often aspire to is impossible. So when we consider that 'tacit thought forms an indispensable part of all knowledge, then the ideal of eliminating all personal elements of knowledge would, in effect, aim at the destruction of all knowledge.'[110]

Sibum finds tacit knowledge to be a valuable thing to access during the reworking of scientific experiments. He claims that tacit or 'gestural' knowledge, is 'embodied within the concrete actions of a person.'[111] Tacit knowledge reflects on the actual practice of a practitioner or experimenter—their skills, repeated behaviours, abilities, habits, problems, and sensory experiences.[112] The practical dimensions of experiments—skills, apparatus, and environment—are essential components in the formation of knowledge. They are not supplementary to it.

However, the inherently tactile and sensory experiences of experiment, in virtue of being tacit, are often left out of our written sources. The study of tacit knowledge aims to go beyond the over-refined published experiment depicted in our sources (although Boyle is very forthcoming about his failures and disasters in the laboratory).[113] Keith Thomas, promoting a blend of anthropology and history, has

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[109] Michael Polanyi, *The Tacit Dimension* (London: Routledge & Kegan Paul, 1967), 15.

[110] Polanyi, *The Tacit Dimension*, 20.

[111] Sibum, "Experimental History of Science," 83.

[112] Sibum, "Experimental History of Science," 82.

[113] He admits to his long-suffering laboratory assistant being set alight during an experiment with gunpowder and phosphorus, see: Boyle, *The Aerial Noctiluca, Works,* VII, 292-93.

lamented how difficult it is for the historian to broach the mindsets of past actors.[114] I do not argue that mindsets are possible to access. However, tacit knowledge embraces non-cognitive influences that impact on experimental practice, allowing us to explore how a variety of physical and intellectual factors work together in the process of knowledge production.

Closely intertwined with the development tacit knowledge, is *habitus.*[115] Jean-François Gauvin, argues that to 'each instrument was attached a special training, a particular practice or *habitus,* which involved either the mind and/ or body.'[116] *Habitus* pertains to repeated and habitual actions, a sort of practical know-how that can only be learned with time. The mind and body becomes accustomed to particular actions and develops particular skills. Owing to *habitus,* Gauvin conjectures that 'the early modern instrument of knowledge can be identified as both the mind and the body of the natural philosopher'.[117]

The concept of *habitus* raises questions pertaining to the habitual and knowledgeable interaction between the experimenter and their environment and apparatus. Heering proposes that both the experimenter and the apparatus play roles in generating knowledge. The theoretical or conceptual notions pertaining to the experiment are as influential as the practical factors, all of which myriad factors influence the outcome of the experiment.[118] Indeed, as argued by Lissa Roberts, there existed a 'sensuous technology' in chemistry whereby sensory experience combined with precision instruments and other factors in the production of knowledge.[119] It is not the case, she argues, that the increasing reliance in mechanised precision apparatus in the eighteenth century reduced skilled sense-based engagement with the world. Experiment employed an embodied knowledge that was guided and developed only by experience and practice.

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[114] Keith Thomas, "History and Anthropology," *Past and Present* 24 (1963), 3-24.

[115] Habitus is a concept deriving from the work of sociologist Pierre Bourdieu.

[116] Jean-François Gauvin, "Instruments of Knowledge," in *The Oxford Handbook of Philosophy in Early Modern Europe,* eds. Desmond M. Clarke and Catherine Wilson (Oxford: Oxford University Press, 2011), 315-37, on 316. See also: *idem.,*"Artisans, Machines, and Descartes's *Organon,*" *History of Science* 44 (2006), 187-216.

[117] Gauvin, "Instruments of Knowledge," 333.

[118] Heering, "Experimenter's gotta do," 804-05.

[119] Lissa Roberts, "The Death of the Sensuous Chemist: The 'New' Chemistry and the Transformation of Sensuous Technology," *Studies in the History and Philosophy of Science* 26 (1995), 503-29.

Although it is challenging to broach tacit and habitual knowledge, reworking does provide insight into practice that we could not otherwise obtain. Importantly, reworking experiments raises in the historian an acute awareness of the centrality of tacit knowledge in early natural philosophy.[120] The 2014 saltpetre project got off to a much quicker start than did the 2013 experience, because we had been able to build up a bank of experiences and familiarity with the materials and procedure. We were aware of, for example, how much soil we could comfortably and safely lift at one time. We knew that the lixivium would boil down quicker if we did not put it all in the boiler/cauldron at once, but added it gradually. Over a relatively short time we gradually got to know our materials and apparatus, and how to handle and interpret them.

Data

Reworking experiments also allows us to access practical data and information; even data that does not appear in our sources. This is because when reading a text with a mind to reworking it, we must understand every little detail in order to move forward. Experiments can only be reconstructed following a meticulous reading of our sources. This is the importance of my suggested 'stage 2'. We must know what 'nitrous earth' or 'spirit of salt' actually is in modern terms, if we want to use them. When we are planning to rework experiments, we are necessitated to think about the practicalities of the operation in hand. What equipment did our protagonists require? How many pairs of hands do we need? What sort of location should we work in? There are several reasons that a source may leave out information. They could be hesitant to divulge trade secrets upon which their livelihood depends. It could also be the case that some things are so habitual, obvious or taken for granted, that they see no need to divulge them. Those who engage in reworking must perforce supplement the text by adding the omitted but essential details.

[120] Sibum, for example, says that the 'crucial gestures' in his experiment were 'reading temperatures' and 'doing the work' which he argues were met in 'an artistic mechanical performance', "Reworking the Mechanical Value of Heat," 81.

Sibum proposes that reworking experiments may be considered 'an archaeology of the taken for granted.'[121] Not only does it facilitate an examination of the minutiae, but it also allows us to experience those taken-for-granted sensory and habitual experiences that are part-and-parcel of craft or experimental processes. A constant challenge in making saltpetre was the blocking of the tap-hole when attempting to drain the lixivium from the settling tub. It would become blocked with the earth if the layers were not thick enough, but often, a vacuum would form around the tap. The way around this was to break the vacuum with a stick. Undoubtedly, this was a typical challenge for early modern saltpetre-makers, but it is not mentioned in the texts.

Environment/ Experimental Location

Clarke, in a rather Paracelsian claim, said that saltpetre is 'not confined to one element' but rather is an 'Amphibious Creature' capable of thriving in water and on land.[122] The impact of the physical environment on experiment was important. In the case of saltpetre, it was hugely important in determining the success of the procedure. We have already seen that the MGRG's first attempts to extract saltpetre suffered owing to the balance of chemicals in the soil. I further argue that saltpetre's affinity for particular environmental locations was fully understood by the early moderns and gave rise to specific views. Saltpetre was extracted from the filthiest of materials; something that becomes much more glaring and clear once we have tried extracting it ourselves. Moreover it is a difficult and arduous process, which means that the valuable crystalline substance that we ultimately extract seems even more remarkable, and is highly valued by practitioners partly on the grounds of empirical success.

Knowledge of environmental factors contributed a great deal to the final yield—in both the past and present. Different geographical locations naturally have different minerals in the water and soil. Soil types can be alkaline or acidic; both are conducive to different sorts of chemical interactions. Saltpetre demands an alkaline environment to thrive in nitrous earth. There are reports of different sorts of animal

[121] Sibum, "Experimental History of Science," 82.

[122] Clarke, *Natural History of Nitre*, 22.

waste being used in the maintenance of nitre-beds in the past. This must be a matter of responding to surroundings. We used pig waste, because our location in Denmark was opposite a pig farm where the resource was in abundance. Often the water would not fully circulate in the nitrous earth. Breaking up the soil with makeshift sieves solved this problem; a solution we came up with at the time to solve the immediate problem at hand. We cannot assume a universality of practice and experience. Factors that may seem insignificant to a reader of a saltpetre treatise, such as the nature of the soil, do make a huge difference in the experimental process.

To illustrate the above claim consider how Buchanan's remarkable discovery of a blueprint for a saltpetre factory in Ipswich has illuminated our knowledge of the operational set-up. We can understand the blueprint in more detail with the reworked experiment in mind. The 'covered arcade,' for example, had a greater role than to 'regulate [....] the watering [of] the black earth and ashes with urine.' [123] The covered part is important to shield the nitrous earth, lest the nitrates dissolve prematurely. This also makes a better environment for the workers, who in wet weather would likely struggle with the process of digging into the nitre-bed and watching over the boiling lixivium. The settling tubs should not be left in the open air in the rain, or they may overflow and valuable nitrates may be lost. It is all about maximising the yield and not wasting anything.

Buchanan's plan presents an area known as 'Dunghill' where the nitre beds were probably maintained.[124] Biringuccio advised finding a location which has a 'large hut or other walled space near water. It is necessary to have a great deal of water as well as much earth, and it must be convenient to the place. The same is true of every other necessity.'[125] It is strenuous work to carry large buckets of earth and water. It is more efficient to have everything close at hand. Efficiency was clearly an important goal of the early moderns, and ancillary factors strongly influence this.

Reworking Experiments

Reworking experiments show that the same procedures will have varying outcomes depending on ancillary factors. Factors like the localised environment, as I

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[123] Buchanan, "Art and Mystery," 238.

[124] Buchanan, "Art and Mystery," 238.

[125] Biringuccio, *Pirotechnia*, 405.

have argued above, can play a massive role in determining the procedure and the results. This brings us to the issue of replication. As Shapin and Schaffer have shown, this was a big problem among early experimentalists who often struggled to repeat experimental results.[126]

Shapin and Schaffer explore Boyle and Thomas Hobbes's controversy over experiment and the nature of 'fact making'.[127] However, although experiment is their focus, Shapin and Schaffer do not fully explicate the actual nature of the experimental process. More particularly, the Baconian revelatory goal of experiment is subsumed in their sociological explanation of knowledge production. They neglect the use of experiment to uncover knowledge about nature. The choice to experiment, for those who conducted experiments in their natural philosophy, was much more than a social choice. In reworking experiments, we can place this important aspect of experiment back at the centre of our investigations.

Furthermore, Shapin and Schaffer emphasise the importance of witnessing experiment.[128] They demonstrate that in order to validate and institutionalise experimental knowledge, it had to be reproducible. This may be in front of an audience, but can also be a 'virtual witnessing' so that readers of an experimental narrative can replicate experiments in their mind.[129] In reworking historical experiments, we are able to witness them—albeit with different intentions than Shapin's and Schaffer's historical actors. In witnessing the experiments we study, we can understand more why experiments were difficult to replicate for the early moderns. In witnessing the ways saltpetre is made, my appreciation and understanding of it is much more dynamic. We have experienced that even when following the sources and conducting the experiment on a large scale, it is difficult to generate a substantial yield. The early moderns were fully attuned to the difficulties of replication, as is evident in Boyle's texts. The failure to replicate was not in itself a denial of the effects.

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[126] Shapin and Schaffer, *Leviathan and the Air-Pump,* 225ff.

[127] Shapin and Schaffer, *Leviathan and the Air-Pump*, 25.

[128] Shapin and Schaffer, *Leviathan and the Air-Pump*, 25, 55-60.

[129] Shapin and Schaffer, *Leviathan and the Air-Pump,* 60-65.

Negative Instances

The challenges encountered in our saltpetre experiments highlighted something that we had not otherwise considered. In conducting an experiment, there is a great deal of trial and error that is often written out of the textual descriptions. Our 2014 attempt was largely based on the mistakes we had made during the 2013 attempt. We must adapt to our surroundings and facilities, and work with our apparatus and materials to ensure a fruitful experimental process. Things go wrong. We must think on our feet, with our hands. This back-and-forth is necessary in learning, and was known by Bacon as 'negative instances'. The procedure of knowledge making for Bacon is described by Weeks as 'cybernetic by virtue of [Bacon's] asymmetrical criterion of truth which incorporates negativity in an error-correcting procedure'. [130] Bacon writes:

> the discovery of new works and active directions not known before, is the only trial to be accepted of; and yet not that neither, in case where one particular giveth light to another; but where particulars induce an axiom or observation, which axiom found out discovereth and designeth new particulars. That the nature of this trial is not only upon the point, whether the knowledge be profitable or no, but even upon the point whether the knowledge be true or no; not because you may always conclude that the Axiom which discovereth new instances is true, but contrariwise you may safely conclude that if it discover not any new instance it is in vain and untrue.[131]

In obtaining unexpected results, we still learn from our experiences. We learn what not to do, and as a result, eliminate certain possibilities concerning the continuation of the experiment that allow us to rethink and to comment on how the experiment should be done. Bacon advocated that rather than discount negative encounters, we should use them to direct future attempts. This is the nature of Baconian induction; it is a process of trial and error.

We must think of negative feedback on both the levels of the historian and the past practitioner. If the historian fails at the experiment, as in fails to produce the results of their sources, then this is in a sense a problem. It indicates either that our protagonist has falsified claims or left out crucial stages in their report, or it could

[130] Weeks, "Mechanics," 184.

[131] Bacon, *Valerius Terminus, SEH,* III*,* 242, cited in: Weeks, "Mechanics," 184.

indicate that in our planning and experimental procedures, something has gone awry. If we stick with the idea that reworking experiments generates analogies, then from an historical perspective, negative results are not a huge problem as we get a sense of the trial-and-error and challenges that could have been faced in the past. Indeed in both years, our saltpetre yield was disappointingly low. Yet the second attempt was far better. We obtained the large needle-like crystals that our sources described, and we did so using mostly medieval-style equipment.

In our efforts we committed many errors that informed our decisions and planning for a second attempt. An example of learning from our errors pertains to the difficulties mentioned in extracting the lixivium. In the first instance we ignored Henshaw's advice to place a wicker rundle on top of the earth, and stir earth with a stick or 'cudgel' as it seemed spurious based on knowledge of 'what should happen.'[132] Upon noticing low levels of nitrate (tested using a nitrate paper) in the lixivium of the initial settling tubs, we decided to try employing Henshaw's advice. We soon realised that in gently stirring the earth, the water is able to infiltrate the earth more fully, rather than channelling straight through. Thus in the first settling tubs we had missed out on potentially large amount of nitrates.

We then considered our sources' instructions to run water through the settling tubs multiple times. We tried this and discovered that the second lixivium still contained sufficient nitrates, and realised that we had been throwing large volumes of saltpetre away. The early moderns had it right. This raises historiographical issues concerning the trustworthiness of our sources. In reworking I advocate we are better to do as our source tells us to. We might not gain the results we are looking for, but we will increase our knowledge of the experimental process, and alter our understandings of our sources.

Conclusion

> Nitre […] is so admirable and various in its Nature and Use, that most who have known it, seem to have had but a share, and contented with a partial knowledge. Some have known only its Extraction, Figure, and Inflammability: The Galenist the Medicinal Use, the Chymist its

[132] Henshaw, ''History,'' 269. Anticipating what should happen is according to Bacon one of the most important implements to natural inquiry.

> Dissolving property, to the Souldier its use in making of Gun-powder, and to Others some Mechanical Uses have been discovered.[133]

Saltpetre was immensely difficult to make. Reworking the process is, as I have shown, the only way to be able to access the complexities and challenges of the procedure. Reading Henshaw, for example, without an eye to reworking would not convey the real difficulties behind the rather clinical descriptions. When simply reading, we do not particularly have to consider what is left out. That emerges in reworking. The misfit between reading a description and practically following one is well known even in modern laboratory work—it just does not always work according to recipe. Translating a material substance to the laboratory does not eliminate difficulties found in the world at large and has its own set of practical problems.

As reworkers of historical experiments, we are not entering into our experiments blindly. To do so would be to contradict the argument outlined in this chapter. In adding practice to the equation, we can change, challenge, and adapt our understandings of our written sources. When reading a description of an experiment with the goal of repeating it, we strive to access both the intentions and the unstated but essential processes of an experimenter. We must interpret, plan, assemble, experiment, and disassemble. Both our sources and our practice inform each other, and both must be used in unison. Just as tacit experience and practical challenges may not find their way into textual descriptions, the theoretical implications or framework may not always be manifest in the practical experiment.

We have seen how gunpowder and its constituents occupy varying environments: fields, laboratories, mines, and more. Experiment is more than a session in the laboratory. It is a larger process that feeds from and feeds into wider systems. On the historiographical level, the four-stage process is likely to differ somewhat from the actual methods of past actors. Yet our historical protagonists would also need to go through stages of planning and reflection. I learned almost as much during the planning stage as I did during the experiment. I have shown how saltpetre is much more than the time spent making it. It required the experience of the negative instances to go back to 'stage 2' to plan for a more successful course.

[133] Clarke, *Natural History of Nitre*, preface.

In the next chapter saltpetre becomes the focus of an intense high-profile debate between the Royal Society and one of its most strident and rancorous opponents. As the debate concerns the procedures of saltpetre making, the knowledge gained in this chapter of the difficulty of the procedure and the need for an exact balance of skills, environment, and materials, is valuable because it casts new light on this controversy.

PART THREE: GUNPOWDER AND UTILITY

Chapter 4

Legends no Histories?: a gunpowder controversy in the early Royal Society

Introduction

The previous chapter presented some of the practical and intellectual challenges that accompanied the early modern process of making saltpetre. At the same time saltpetre, and the ways of producing it, were philosophically enticing. Some scholars were interested in exploiting the material in the laboratory in pursuit of knowledge, and others were interested in devising more efficient ways of procuring it for the good of the state. This chapter demonstrates one of the ways in which the early Royal Society planned to incorporate saltpetre and gunpowder into its programme for the reformation of natural philosophy. We will also see the ways in which the Royal Society's efforts with these materials did, and did not, meet the standards set out by Bacon.

In this chapter we will continue to focus on craft knowledge and its interactions with speculative natural philosophy under the guise of Baconianism. Specifically, we focus on a high-profile controversy concerning the making of saltpetre and gunpowder. This conflict occurred in the publications surrounding the Royal Society in 1670. I argue that this controversy reveals that gunpowder became entwined in the nascent Royal Society's public persona owing to its undeniable utility and centrality to early modern politics. Secondly, the controversy acts as a case study to examine the varying interpretations of the Baconian programme. In particular, the 'Baconian history', and its value for seventeenth-century natural philosophy. The 'history of trades' project began soon after the Royal Society's founding. It was built upon Bacon's suggestions that natural philosophers engage in craft practice and write down their observations, with the long term goal of advancing knowledge and improving industry by the bringing together of scholarly expertise and craft know-how.[1]

The historiography of science has previously focussed on moments of controversy. Conflicts in the history of science, particularly ones occurring during the development and institutionalisation of particular scientific claims, can be revelatory. From a constructivist perspective, conflicts highlight contrasting possibilities to the more obvious or determined outcomes. The profitability of this historiographical approach is best demonstrated by Shapin and Schaffer's *Leviathan and the Air-Pump.*[2] Shapin and Schaffer analysed the controversy between Thomas Hobbes and Boyle. In treating the views of each protagonist as plausible, they provided a new insight into the familiar theme of experiment.

The early modern era was rife with controversies over scientific and technological issues. Yet given the understanding that controversies can be fruitful loci of inquiry it is surprising that so few have received an analysis similar to that of *Leviathan.* One particularly surprising oversight is the conflict over saltpetre and gunpowder between Thomas Henshaw (1618-1700) and Henry Stubbe (1632-76). The former was a well known 'chymical philosopher' and fellow of the Royal Society.[3] The latter was a physician and outspoken politico-religious radical.[4] Stubbe's 1670 pamphlet *Legends no Histories* put forward a damning response to Henshaw's 'The History of the making of salt-peter and gunpowder,' (hereafter *HM*) which was published in 1667 in Thomas Sprat's (1635-1713) *The History of the Royal Society* (hereafter *HRS*).[5] Given that gunpowder is recognised as one of the

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1 The best overviews of the nature of the project and its successes and failures, are: Kathleen H. Ochs, "The Royal Society of London's History of Trades Programme: An Early Episode in applied Science," *Notes and Records of the Royal Society of London* 39 (1985), 129-58; Walter E. Houghton, "The History of Trades: Its Relation to Seventeenth-Century Thought," *Journal of the History of Ideas* 2 (1941), 33-60.

2 Shapin and Schaffer, *Leviathan and the Air-Pump,* 6-8. See also: Marcelo Dascal and Victor D. Boantza (eds.), *Controversies Within the Scientific Revolution* (Netherlands: John Benjamins, 2011). Dascal's and Boantza's edited volume comprises a series of studies on different debates in early modern science.

3 For a brief biographical account of Henshaw, including his role in the early Royal Society, see: Stephen Pasmore, "Thomas Henshaw, F.R.S. (1618-1700)," *Notes and Records of the Royal Society of London* 36 (1982), 177-88, on 180.

4 James R. Jacob, *Henry Stubbe, Radical Protestantism and the Early Enlightenment* (Cambridge: Cambridge University Press, 1983).

5 Henry Stubbe, *Legends no Histories?* (London: 1670); Henshaw, "History"; Thomas Sprat, *The History of the Royal Society of London* (London: 1667).

most important and highly demanded substances in early modern society, it is surprising that its role in this conflict has not been sufficiently acknowledged.

Gunpowder commanded scientific interest both in terms of utility, and in experimental and theoretical reflections on matter. In studying gunpowder, individuals such as Henshaw and Stubbe were forced to go beyond the constraints of the laboratory, to engage in Baconian natural history. They had to break down certain barriers if they were to construct a genuine Baconian natural history: gunpowder could not be properly explored by consulting literature alone.

Bacon saw the boundaries between educated scholars and skilled workers as somewhat artificial and those seeking to study a material substance had to overcome these social boundaries. Henshaw purported to do this in his gunpowder research, but Stubbe questioned his claims of practical experience. The conflict over gunpowder can shed further light on our understanding of the Baconian project of the early Royal Society. Using a crucially important material substance as a case study, this chapter explores the Society's ambitions to develop Bacon's project of rebuilding science via a marriage of theory and practice. Furthermore, it examines the context in which one of the fellows' most vociferous opponents used the same material to expose their apparent pretentions.

Golinski has demonstrated how material substances, in his case phosphorus, shed light on wider social and polemical themes.[6] He argues that the use of the newly discovered phosphorescent phenomena was intricately connected to the emerging public science in the mid-late seventeenth century. Phosphorus, as shown by Golinski, was used to build up interest in the Society, but the uses of the material were also liable to criticism from the Society's enemies. Gunpowder provides an apt comparison point, since it shared with phosphorus this context of the developing Royal Society.

A close reading of the Stubbe/ Henshaw exchange allows for an investigation into contrasting approaches to the technology of gunpowder and its use in early modern natural philosophy. Thus gunpowder's contribution to the emerging scientific integration of theory and practice can be underlined and defined. Further,

[6] Golinski, "Phosphorus," 24-30. The sensory appeal of phosphorus in combination with its novelty status, managed to garner widespread attention. Golinski argues that the problems encountered with replicating some of the phosphorus experiments are cited as points of attack for Royal Society opponents, in addition to phosphorus attracting accusations of religious and social enthusiasm, 35-58.

by integrating the debate into its wider social and intellectual context, much in the manner of *Leviathan and the Air-Pump,* novel insights are provided into the public impact and perception of an emerging institution. This chapter provides a case study of the importance of materials in the emergence of modern science. A focus on gunpowder also allows us to undertake a fresh analysis of the nature of the Royal Society's Baconianism, and perceptions of it.

In order to address the gunpowder controversy, this chapter will focus on the use of gunpowder as an invaluable substance for both the practice and promotion of experimental philosophy. It tells us something of how the new generation of Baconians perceived their programme and how they wished the non-converted to perceive it. I argue that the inclusion of gunpowder in *HM* and Stubbe's rebuttal was deliberate as gunpowder had a distinctively public appeal. Secondly, I explore the backgrounds and motivations of each of the protagonists in order to gain an understanding of what the conflict was really about. Finally, we will look at the Baconian history: what it should be, what Henshaw and Stubbe interpreted it to be, and how they both vocalised their interpretations via gunpowder.

Gunpowder: 'so noble, so common, so necessary'

It is surprising that gunpowder's role in Henshaw and Stubbe's conflict has received little historiographical attention. James R. Jacob in his book devoted to Stubbe gives no mention of gunpowder.[7] Richard Jones in his detailed treatment of Stubbe's wider controversy with the Royal Society neglects to devote space to the nature of Stubbe's various pamphlets individually.[8] The presence of saltpetre and gunpowder in Stubbe's tirade has caught the attention of some historians, however, even if only briefly. Cressy frames the debate in the context of the methodological tension between 'ancients and moderns' in the seventeenth century.[9] Whilst it is the case that Stubbe and his opponents had different views on how to produce knowledge, the conflict is much more than an embodiment of the struggle between the speculative philosophers and the newer wave of experimentalists. In this chapter,

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7 Jacob, *Henry Stubbe,* 78 ff. Jacob discusses Stubbe's conflict with the Royal Society, but with not even a cursory mention of gunpowder's important role in Stubbe's anti-Royal Society ravings.

8 Jones, *Ancients and Moderns*, 244-55.

9 Cressy, *Saltpeter,* 28-29.

we will even see that Stubbe was not strictly an ‘ancient’. It is important to acknowledge gunpowder’s place in the conflict, but it is also important to acknowledge the wider factors that affected the way in which gunpowder was employed by each team.

Werrett, on the other hand, argues that the debate had a religious dimension. He acknowledges that experiments using gunpowder and pyrotechnics were perceived by some philosophers as a threat, because they appeared to represent ‘popish incendiarism.’[10] Whilst he does not go into detail about the nature of gunpowder’s inclusion in the works of both Stubbe and Henshaw, Werrett is successful in conveying that the conflict was about more than gunpowder. It was also about perceived religious dissent. Werrett is right on this matter, but below, we will expand on these issues to analyse more clearly how gunpowder fits in to the wider battle between Stubbe and the Society. I argue that the historiography requires an understanding of the important role that gunpowder played for both parties. It was not chosen at random.

This relative oversight in the existing historiography cannot be because the subject matter is considered trivial or unimportant. Rather, I argue that the pertinent historiography has lost sight of gunpowder’s place within Henshaw’s and Stubbe’s conflict. This is because gunpowder has been subsumed within a much bigger controversy: Henry Stubbe against the Royal Society. *Legends* was just one of several scathing writings which Stubbe directed towards the nascent institution.[11] Stephen Pasmore and K. Theodore Hoppen both state that for Stubbe, Henshaw was nothing more than a ‘representative’ of the Royal Society.[12] This may be true, but I argue that this approach undervalues gunpowder. Stubbe did not attack Henshaw’s treatise because it was Henshaw that wrote it. He attacked it because it was about gunpowder. Though a material substance, its role in the conflict between Stubbe and

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[10] Werrett, *Fireworks,* 80-81. Werrett explains ‘popish incendiarism’ and religious ‘enthusiasm’: ‘Experiments for Catholics, such as Della Porta or the Jesuit Kircher, meant creating playful or wondrous effects that, like fireworks, would astonish audiences and illustrate the miraculous and, ultimately, mysterious nature of the divine creation.’ In England, a largely protestant country by the mid-late seventeenth century, such connections with Catholicism in an organisation like the Royal Society could be seen as dangerous or seditious, 74.

[11] See also: Henry Stubbe, *Campanella Revived* (London: 1670); *idem*., A *specimen of some animadversions upon a book entituled Plus Ultra* (London: 1670); *idem*., *A Censure upon certain passages contained in the History of the Royal Society* (Oxford: 1671).

[12] Pasmore, “Thomas Henshaw,” 181; K. Theodore Hoppen, “The Nature of the Early Royal Society: Part II,” *The British Journal for the History of Science* 9 (1976), 243-273, on 246.

the Royal Society is of major significance. There was a reason, as we will see, that Stubbe chose Henshaw's publication in particular to bear the brunt of his anti-Royal Society polemics.

Gunpowder's public role

The Henshaw/ Stubbe controversy highlights a promotional role for gunpowder in the emergent experimental science. Gunpowder served as a representative for the Royal Society's Baconian histories project, and as a result was the focus of serious opposition towards the institution. In acknowledging this role for gunpowder, it is possible to reconsider the historiography of Thomas Sprat's promotional efforts. There is general agreement that Sprat's *HRS* functioned as propaganda for the Royal Society.[13] The institution, founded in 1660, was still in its infancy. The Baconian ideals and methods that it espoused were by no means the most common or standard ways to approach natural philosophy at the time. The *HRS* served to present the methods, values and aspirations of the Society in order to attract others to this new, and in its view, better, version of natural philosophy.

The very fact that Henshaw's tract was published in Sprat's *apologia* renders gunpowder important. For the early Baconians, gunpowder was not only a useful avenue of scientific inquiry. Owing to its fundamental importance in contemporary society, it was also a medium for Sprat's promotional efforts. As an exemplary Baconian history, Henshaw's account is demonstrative of the ways in which the Royal Society utilised a high profile material to promote its method of experimental philosophy. In the turbulent context of Restoration England, the *HRS* set out to demonstrate the relevance of Baconian science, and the relevance of the Royal Society to the wider social and political landscape.[14]

A primary aim of the Royal Society was to demonstrate its departure from the scholasticism that was taught in the universities, which it perceived as pointless

[13] The role of Sprat's history in providing an apology or justification for the Royal Society is discussed by: P.B. Wood, "Methodology and Apologetics: Thomas Sprat's *History of the Royal Society,*" *The British Journal for the History of Science* (1980), 1-26; R. H. Syfret, "Some Early Reactions to the Royal Society," *Notes and Records of the Royal Society of London* 7 (1950), 207-258, on 210-11; Ochs, "Histories of Trades," 130; Jones, *Ancients and Moderns*, 237.

[14] Wood, "Methodology and Apologetics," 12-21.

and fruitless.[15] The fellows sought to do this by emphasising the utility of their endeavours.[16] What better way to prove the usefulness of their Baconian histories, than a publication regarding one of the most important and useful substances in early modern society? The status of the Royal Society in this period was ‘uncertain’, according to P. B. Wood.[17] It had the prestige of royal patronage, but it relied on its members financially. Moreover, owing to the newness of the institution and its non-scholastic intentions, it was particularly liable to criticism.[18] In its earlier years, according to Margery Purver, the Society sought ‘satisfactory status and permanence’.[19] It had to build and solidify a good reputation in order to ensure the success of its endeavours. For this reason, the Society could benefit from researching socially and politically useful topics that live up to the Royal Patronage that was bestowed upon it.

By using a material of such prevalence, the Society could create a common ground with its audiences.[20] Its readers might not yet be familiar with the Baconian method, but they would be familiar with gunpowder. If the Society could enlighten the world on gunpowder, and even improve its manufacture or performance, then its potential worth could be proven. Moreover, improving knowledge of a material upon which the future defence of the kingdom relied would overcome charges of dilettantish interest.

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[15] Margery Purver, *The Royal Society: Concept and Creation* (London: Routledge and Kegan Paul, 1967). Chapters 2 and 3 detail the new philosophy in terms of its inspiration from Francis Bacon, and the Royal Society’s departure from the philosophy of the universities. Purver writes that ‘the external history of the Royal Society is very much concerned with the struggle against the universities, which continued far longer than is generally realized, until well into the eighteenth century,’ 53.

[16] Sprat, *History.* Several passages in *HRS* emphasise utility. Sprat writes that through their Baconian science, the Royal Society will ‘obtain a dominion over *Things*’, and to ‘restore truths […] to more various uses’, 61-62.

[17] Wood, “Methodology and Apologetics,” 1.

[18] Wood, “Methodology and Apologetics,” 2.

[19] Purver, *Royal Society,* 128.

[20] The gentleman virtuosi composition of Sprat’s intended audience has been explicated in more detail by: Wood, “Methodology and Apologetics,” 10-11, 20. Michael Hunter, *Science and Society in Restoration England* (Cambridge: Cambridge University Press, 1981). Hunter describes Sprat’s Royal Society audience as: ‘predominantly recruited from the professions, land and government, and…not particularly mercantile. In this it was typical of the more general leisured culture of London, which filled the coffee-houses and theatres with cultivated, well-informed dilettantes with a wide range of interests,’ 71.

Sprat's book set out the intended method and principles of the Royal Society. In this, he included the specimen Baconian histories. The object of the Baconian histories project was to:

> make faithful *Records* of all the Works of nature, or art, which can come within [the Royal Society's] reach; that so the present Age, and posterity, may be able to put a mark on the errors, which have been strengthened by long prescription; to restore the truths, that have lain neglected; to push on those, which are already known, to more various uses; and to make the way more passable, to what remains unrevealed.[21]

Henshaw used his gunpowder research to fulfil the Society's aim of creating and promoting a science that would correct the errors of the scholastics, increase knowledge of nature, and maximise nature's productive power.

Henshaw begins *HM* by addressing a controversy between contemporary natural philosophers, centred on whether the nitre written about by the ancients was the same 'species' as the modern saltpetre.[22] He claims that the two substances are the same, but they are collected and refined in different ways. Henshaw states that the only reason for his contemporaries believing that they are different substances, is owing to 'their being unacquainted with the various [phenomena] of *salt-peter* in the making and refining of it', and also to their reliance on older literature, including Pliny.[23] Using saltpetre and gunpowder, Henshaw emphasises the fundamental problems of book-based learning to argue that natural philosophy must do as the Royal Society is doing, and break away from the ancient literature. To make his case, he provided detailed expositions on how to make both saltpetre and gunpowder. These descriptions, he claims, are based on his practical experience in the field.

Similarly, Stubbe used gunpowder's familiarity to expose what he saw as severe flaws in the Royal Society's Baconian project. He devoted *Legends* to exposing the Society's main propagandists, Sprat and Joseph Glanvill.[24] Stubbe realised that Henshaw's *HM* was not just a specimen of the Royal Society's

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[21] Sprat, *History,* 61

[22] Henshaw, "History," 260-61.

[23] Henshaw, "History," 261-62.

[24] *Legends* begins with Stubbe's more general reservations against the Royal Society and his appeal to the universities, before a criticism of Sprat. After his attack on Henshaw, is appended 'the Plus ultra of Mr. Joseph Glanvill reduced to a non-plus.'

researches. The fact that the specimen was written about gunpowder, 'so noble, so common, and so necessary a subject,' [25] was hugely significant. Stubbe saw that Henshaw's exposition on gunpowder was a '*publick Essay* and tryall of [the Royal Society's] *Skill* and *Utility'*.[26] He knew fine well that the fellows were exploiting the vital material in order to gain attention.

Playing the Royal Society at its own game, Stubbe devoted the lion's share of *Legends* to attacking Henshaw's *HM*. As the Royal Society exploited the public presence and knowledge of the substance to build up a case for its Baconian philosophy, Stubbe exploited its commonality to deconstruct it. In gunpowder then, we see the role played by material substances in the formation and institutionalisation of early modern scientific claims. Its inclusion in the controversy was a strategic one, on the part of both protagonists. This calculated incorporation of gunpowder into this conflict, is what the historiography has failed to grasp. However, to really get to grips with the claims of each party, we must look further into their careers and motivations.

The protagonists

Shapin and Schaffer shed new light on the Hobbes/Boyle debate, and more widely, the nature of experiment in early modern science. Hobbes's science is often forgotten because Boyle 'won' in a manner of speaking.[27] However, as Shapin and Schaffer point out, for knowledge to become accepted and institutionalised, it must first be constructed.[28] Unfortunately, the process of building and solidifying knowledge is easily forgotten. The alternative proposals that 'lost' the battle for acceptance are often not treated seriously enough. It is not necessarily the case that the scientific claims that gain acceptance and a prominent place on the history of science timeline were 'correct' or 'better' than the alternatives. There were much wider sociological and cognitive factors influencing the construction and consolidation of knowledge.

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[25] Stubbe, *Legends,* 119.

[26] Stubbe, *Legends,* 64.

[27] Shapin and Schaffer, *Leviathan and the Air-Pump,* 7-15.

[28] Shapin and Schaffer, *Leviathan and the Air-Pump,* 6-7.

There are obvious parallels between the gunpowder controversy and that of Hobbes and Boyle. In treating the tracts of each of our protagonists as plausible and legitimate, in the manner of *Leviathan and the Air-Pump,* the Henshaw/ Stubbe debate can be equally revelatory. In this formative period for experimental philosophy, Stubbe's and Henshaw's approaches to natural philosophy were just two of many possible approaches. In each of their essays we see gunpowder being used to espouse much wider outlooks. Their gunpowder researches were the product of their existing careers and experiences. By focussing on the approaches to gunpowder taken by each of the protagonists, we can obtain a clearer understanding of how each of their respective approaches to natural inquiry and efforts to derive knowledge of the world.

Thomas Henshaw

For such an important task as to represent the Royal Society and its Baconian histories project, the Royal Society had to appoint someone trustworthy and capable. Henshaw was specifically appointed to write the *HM*; he said that the task was 'imposed' upon him.[29] In examining his natural philosophical background, it is evident why Henshaw was chosen to represent the Baconians.

From 1649 Henshaw devoted his attention to chymical philosophy before joining the Royal Society as one of its founding, and most active, members.[30] He was noted particularly for his claims of having the secret of the 'alkahest' or universal dissolvent of metals,[31] but his methods were also the focus of considerable attention. Hartlib commented that Henshaw along with others founded an

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[29] Pasmore, *"*Thomas Henshaw*,"* 180.

[30] Henshaw's status and prominence in the early Royal Society is discussed in: Pasmore, "Thomas Henshaw," 180-82; Hoppen "The Nature of the early Royal Society: Part I," *The British Journal for the History of Science* 9 (1976), 1-24; *idem.*, "The Nature of the early Royal Society: Part II," *The British Journal for the History of Science* 9 (1976): 243-273, on 243-44. Donald R. Dickson is one of few historians who have devoted considerable attention to Henshaw. See: Dickson, "Thomas Henshaw and Sir Robert Paston's Pursuit of the Red Elixir: An Early Collaboration between the Fellows of The Royal Society," *Notes and Records of the Royal Society of London* 51 (1997), 57-76; *idem.,The Tessera of Antilia: Utopian Brotherhoods & Secret Societies in the Early Seventeenth Century* (Leiden: Brill, 1998), 186-207.

[31] Dickson, "Red Elixir," 58. Henshaw claimed to have the receipt for the alkahest of J. B. van Helmont, which van Helmont supposedly passed onto Hugh Platt whilst visiting England. On Glauber's alkahest: Roos, *Salt of the Earth,* 33-51. Roos explains that Glauber thought nitre to be the alkahest owing largely to its ability to be split into two components, one fixed and one volatile, 36.

organisation called the 'Christian Learned Society,' where he spent a great deal of time at work in the 'laboratorie...[striving] to doe all the good they can to their neighbourhood'.[32] In his alchemy Henshaw conducted practical investigations, with utilitarian aims. He studied alchemy, mathematics, and astrology under William Oughtred.[33] Hoppen has claimed that Henshaw 'had no compunctions about bringing his chief interests—alchemy and astrology—to the Society's attention, and saw no contradiction between pursuit of such topics and membership.'[34] Similarly, Donald R. Dickson notes that Henshaw had no qualms about revealing that he was a practising alchemist.[35] The Society, publically, did not want to be involved with such seemingly dubious pursuits. Yet in spite of his predominantly alchemical background, Henshaw's experience and reputation were sufficient for him to garner enough credibility to undertake important tasks on behalf of the Society.

That the Society should elect an alchemist to represent it in its crucial *apologia* may seem surprising. Indeed a recent historiographical debate between Hoppen and Michael Hunter has acknowledged the complex situation of alchemy in the Royal Society. Hoppen emphasised the intellectual inclusiveness of the Society, and the variety of interests and approaches that could be found within its ranks.[36] Hunter argued against this thesis.[37] He claims that the Society strove to promote a corporate image, and as a result members' interests in alchemy and magic were, for the most part, kept private. Hunter's position can be supported by Dickson's evidence concerning Henshaw. Dickson argues that Henshaw's joint pursuit with Sir Robert Paston for the so-called 'red elixir' demonstrates that for some more typically alchemical endeavours, Henshaw worked in private.[38]

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32 Samuel Hartlib, *Ephemerides* Part 3 (1650), in *The Hartlib Papers Online,* Ref: 28/1/65A. Also in: Donald R. Dickson, *Thomas and Rebecca Vaughan's Aqua Vitae: Non Vitis* (Tempe, Az: Arizona Center for Medieval and Renaissance Studies, 2001)*,* xvi.

33 Hoppen, "Nature of the Royal Society, Part II," 244.

34 Hoppen, "Nature of the Royal Society, Part II," 246.

35 Dickson, "Red Elixir," 58.

36 Hoppen, "Nature of the Royal Society: Part I"; *idem.,*"Nature of the Royal Society: Part II."

37 Michael Hunter, "The Royal Society and the Decline of Magic," *Notes and Records of the Royal Society* 65 (2011), 103-119.

38 Dickson, "Red Elixir," 67-68.

Golinski, however, has claimed that chemistry was 'an essential part of what the Royal Society intended to achieve'.[39] He argued that the Royal Society was aware of perceptions of the discipline, a close relative of alchemy, but sought to change these perceptions. It was the Society's aim, Golinski claims, to take the more 'honest' parts of chemistry, and turn these into a valuable feature of its new natural philosophy.[40] Indeed this endeavour to refine and raise the status of chemistry has already been seen in Chapter 2.

Regardless of efforts to purge chemistry, the approach taken in Henshaw's gunpowder essay is not far removed from his earlier researches in alchemy. Yet at the same time, it does meet some of the requirements of Royal Society Baconianism. It has been demonstrated by Alan Taylor that Henshaw's experiment to extract nitre from may-dew, conducted in front of the Royal Society in 1661 and subsequently reported in the *Phil Trans,* is representative of a blend of alchemical theorising and Royal Society Baconianism.[41] The focus on may-dew and the procedures employed fulfilled the alchemical dimension. The experimental effects were explicated through the notion of the 'universal' or 'aerial nitre', which we analysed in chapters 2 and 3, in mind.[42] He conducted the experiment in front of the Society, and repeated it in order to verify his assertions. Most importantly, this experiment was 'an examination of the belief systems of the day to ascertain if there was any empirical evidence to support the assertions made.'[43] The Society prided itself on using practical experience and probing investigations in order to verify questionable claims as well as for the production of new knowledge. The may-dew experiment provided the fellows with precisely these opportunities.

Henshaw's extraction of nitre from may-dew was among the first experiments published in the *Phil Trans,* which was always reviewed by the council

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39 Golinski, "Noble Spectacle," 13-16, on 15.

40 Joseph Glanvill, *Plus ultra: or, The Progress and Advancement of Knowledge since the Days of Aristotle* (London: 1668), 11-12, cited in: Golinski, "Phosphorus," 13. See also: Dickson, "Red Elixir," 57. Dickson explains attempts of seventeenth-century scholars to refine alchemy, claiming that the position of alchemy changed in the period 'because more rigorous experimentation proved the alchemist's claims to be unverifiable, not because any underlying theories had been altered.'

41 Alan H. Taylor, "An Episode with May-Dew," *History of Science* 32 (1994), 163-84, on 163, 136; The Royal Society, "Some Observations and Experiments upon May-Dew," *Phil Trans* 3 (1665), 33-36.

42 Taylor, "May-Dew," 167-71. Further, Taylor explicates that may-dew itself had a presence in folklore, believed to be connected to birth, youth, and rejuvenation.

43 Taylor, "May-Dew," 179.

—they did not publish just anything.[44] Yet although Taylor shows that the experiments epitomise the Royal Society's ideals, Hunter claims that the Society was picking and choosing from Henshaw's efforts in order to present a particular corporate and public face.[45] Some alchemical activity did filter through into the Society's public life, but this was not a typical phenomenon. Hunter even claims that the may-dew experiment making it into the *Phil Trans* was an exceptional instance of alchemy penetrating the Society's corporate Baconian façade.[46] Dickson confirms Henshaw's peculiar status. He states that the fellow was 'in many ways the typical Baconian who empirically tested all hypotheses', although he did not reject his alchemical leanings.[47]

The instance with may-dew is telling because we see appeals to similar alchemical theories in *HM*—a document that was supposed to typify a particular aspect of the Society's wider Baconian project. Henshaw's alchemical influences are evident in his explanations of how saltpetre is formed. He drew again on the universal nitre. He proposed in *HM* that 'it be likely, that the Air is every where full of a volatile kind of *Nitre'*, which in the right conditions, can be extracted from the earth as saltpetre.[48] Just as the supposed universal nitre allowed him to extract saltpetre from may-dew, it would allow him to extract it from the earth and other living things. The universal nitre, Henshaw claimed, was thought necessary for the generation and sustenance of life: 'if [the earth] were not impregnated with this salt, [it] could not produce vegetables; for salt (as the Lord *Bacon* says) is the first Rudiment of Life; and *Nitre,* is as it were the life of Vegetables'.[49]

HM provides further use of the old alchemical theory with a reinterpretation of Boyle's 'redintegration of nitre.'[50] For Henshaw, the redintegration 'raised such

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[44] Taylor, "May-Dew," 166.

[45] Hunter, "Magic and the Royal Society," 105. Hunter argues that the Society's presentation of their corporate efforts took precedence over individual interests. He emphasizes how rare such studies were in the early Royal Society.

[46] Hunter, "Magic and the Royal Society," 105.

[47] Dickson, *Red Elixir*, 65.

[48] Henshaw, "History," 266.

[49] Henshaw, "History," 264-65. For more on the significance of salts, and their role as a 'principle' in early modern science, see: Roos, *Salt of the Earth,* 10-107.

[50] Boyle, *Certain Physiological Essays, Works*, II, 93-113.

important Observations, as never before were raised from one Experiment'.[51] It could unlock 'many noble Secrets in Nature; [and lead] to a great improvement in the Art of making salt-peter'.[52] Whereas Boyle's motivation to work with saltpetre in this way was the acquisition of knowledge of matter, in an experiment of light, Henshaw pursued an experiment of fruit. He proposed that via the process of redintegration, the salts extracted from animal body parts might be transformed into saltpetre. The proposal promised other means of generation and procurement of this much sought after substance. In Henshaw's saltpetre research then we see the adaptation of old alchemical theories to the demands of a Baconian vision to always aim at something potentially practically useful.

Moreover, Henshaw's research offers further insight into the Royal Society's expectations of gunpowder research. If more saltpetre is generated, then this could solve a problem observed by Henshaw. He claimed that powder-makers were increasing profits by bulking out their product with more coal, and less of the more expensive saltpetre.[53] More widely however, gunpowder was seen as the ideal substance through which to fulfil both experiments of light and experiments of fruit—even if in reality, it was mostly the latter category that the Royal Society pursued. Henshaw called saltpetre and gunpowder a 'darling of nature' and 'the most fatal Instrument of Death that ever Mankind was trusted withal' respectively.[54] Understanding the basic composition of gunpowder had already led to its explosive power being harnessed. Investigations into the nature of saltpetre and gunpowder could further increase its utility. *HM* combined military-technology needs with Henshaw's natural philosophical and alchemical interests. A history of gunpowder was the ideal way through which to achieve the Baconian ideal of combining knowledge with power. Saltpetre and gunpowder show how Henshaw united his alchemical background with his Baconian projections.

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51 Henshaw, "History," 275.

52 Henshaw, "History," 274.

53 Henshaw, "History," 278.

54 Henshaw, "History," 274.

Henry Stubbe

Providing the alternative viewpoint in the gunpowder controversy is Henry Stubbe. In many ways Stubbe is a comparable case to Hobbes. *Leviathan* surprised historians with a fair and in-depth analysis of Hobbes' natural philosophy, which had typically been marginalised as inconsequential by those historians who considered him solely as a radical political philosopher.[55] Stubbe was also surrounded by a certain amount of notoriety, and his radical views meant that his credibility as a natural philosopher was not always appreciated.[56] Like Hobbes, Stubbe published very radical views. Stubbe embedded his more radical opinions in natural philosophical treatises, using gunpowder to get his points across.

Stubbe was primarily a physician by trade, but his background and career were complex. He was educated under the charity of Sir Henry Vane, who had been in the Parliamentarian army during the Civil War.[57] Stubbe soon found that his sharp tongue got him into trouble. In 1659 he was expelled from Christ Church for his writings on universities and religion, before settling as a physician in Stratford upon Avon. He worked in Jamaica in 1665 as Royal Physician, before returning to Warwick. He often wrote pamphlets expressing extreme views on matters of the time, later claiming he wrote for his patron Vane. Stubbe seems to have acted as a mercenary pamphleteer, frequently becoming involved in controversy leading to accusations by members of the Royal Society that he was a hired hand for doctors or clergymen opposed to the new science. Yet Stubbe maintained that his intentions were honest.[58]

Jacob maintains that Stubbe stood out amongst English writers and pamphleteers of the period, claiming that whilst Stubbe was not a 'major thinker […] he was certainly a very exceptional one'.[59] In his onslaught against the Royal

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55 Shapin and Schaffer, *Leviathan and the Air-Pump.* See especially Chapter 4 'The Trouble with Experiment: Hobbes versus Boyle,' 110-54.

56 Anthony à Wood, *Athenae Oxonienses* (London: 1691). Wood speaks favourably of Stubbe's intellect, but indicates his contemporaries saw him as a nuisance, thus they would not take his natural philosophy seriously, claiming that: 'He was a person of most admirable parts, had a most prodigious memory, tho his enemies would not acknowledge it,' 414.

57 R. H. Syfret, "Some Early Critics of the Royal Society," *Notes and Records of the Royal Society of London* 8 (1950), 20-64, on 24-25; Jacob, *Henry Stubbe,* 9-10.

58 Syfret, "Early Critics," 25-26.

59 Jacob, *Henry Stubbe,* vii.

Society, Stubbe certainly made an impact. Jacob describes the attack as 'the most sustained and vociferous polemical challenge that the society has ever faced.'[60] R. H. Syfret claims that Stubbe was the Society's 'most voluble and outspoken' opponent, and although 'he does not appear to have been original in his criticism; he concerned himself with all the charges which, to judge from the implications of Sprat's [*HRS*], had already been brought against the Royal Society.'[61] Syfret notes how Stubbe attempted to show the harm of the Royal Society to religion, society, and knowledge.[62]

Stubbe began his tirade at a critical point in early modern natural philosophy. The new experimental philosophy was still developing. Yet I agree with Jacob that this conflict was not 'ancients versus moderns', but rather, it came down to different 'views of how to achieve progress and reform.'[63] Both sides were progressive in their own way, seeking to improve natural philosophy in one way or another. Stubbe defended aspects of the 'ancient' learning, but he was not an 'ancient' strictly speaking. It is the case, as Jones has shown, that Stubbe in his wider conflict found himself defending some scholastic traditions.[64] Stubbe's 'unqualified praise of the ancients was worthy of the blindest admirer of antiquity; his admiration of Aristotle was unbounded […] he was incited to the controversy by the irreverence which Glanvill showed the ancients.'[65] Yet it was not black and white. Stubbe was not opposed to experiment.[66] He 'indignantly repudiated some of the most representative theories of the past, such as nature's abhorrence of a vacuum and the Ptolemaic system, and refused to defend the truth of Galenical and Aristotelian principles.'[67] Times were moving forward and positions were more complex. The debate cannot simply be categorised as one idea against another.

Complicating Stubbe's natural philosophical stance, and moving him further from the 'ancient' camp, is his connection with Boyle. In the 1650s he translated

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[60] Jacob, *Henry Stubbe*, 1.

[61] Syfret, "Early Critics," 20.

[62] Jacob, *Henry Stubbe*, 1.

[63] Jacob, *Henry Stubbe,* 4-5.

[64] Jones, *Ancients and Moderns*, 245.

[65] Jones, *Ancients and Moderns*, 262.

[66] Jacob, *Henry Stubbe,* 43.

[67] Jones, *Ancients and Moderns*, 262.

Boyle's redintegration essay into Latin, and from 1662 Boyle was a patron of Stubbe.[68] They were in contact and seem to have shared some religious views. For example, both opposed the church governing by divine right.[69] Stubbe did spend time in Oxford, and claims to have been enthusiastic about the experimental philosophy during that time—primarily because he saw it as a way to challenge 'conventional Christianity.'[70] Stubbe clearly held Boyle apart from the virtuosi that surrounded him. In his correspondence with Boyle, Stubbe praised that '[he] never doubted but that Mr Boyle would never swerve from the rules of honour and strict virtue, whatever the other virtuosi might do. [Boyle is] still constant to [himself] and worth, but so are not they.'[71] He further proclaims that to have supported the Royal Society would be to have 'betrayed religion'.[72]

Stubbe was unhappy that Boyle and 'several persons of honour […] should ever mix with such insignificant talkers, as the generality [of the Royal Society] are; for [Boyle] could get no credit by them and their arrogance and folly would unavoidably run [them all] into quarrels if not contempt.'[73] A month later he expressed his 'sorrow to find that [Boyle] still adhere[s] to the Royal Society'.[74] Given his admiration for Boyle (and his admission of having practiced experiment), his later repulsion for the Society latter cannot simply be explained as an 'ancient' having distaste for the 'moderns.' This conflict has deeper religious and philosophical roots.

In understanding Stubbe's motivations for attacking the Royal Society, his treatise in *Legends* can be more fully understood. The conflict resulted from Stubbe's severe religious opinions and concerns over the nature of the connection of religion to natural philosophy. Such connections, Stubbe thought, could be dangerous.[75] Stubbe was a notorious radical, famous for his scathing political and

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68 Frank, *Oxford Physiologists*, 238-39.

69 Jacob, *Henry Stubbe,* 48.

70 Jacob, *Henry Stubbe,* 49.

71 "Letter Henry Stubbe to Boyle," 18 May 1670, in *Boyle Correspondence,* IV, 175-76.

72 "Letter Henry Stubbe to Boyle," 18 May 1670, in *Boyle Correspondence,* IV, 175-76.

73 "Letter Henry Stubbe to Boyle," 18 May 1670, in *Boyle Correspondence,* IV, 177.

74 "Letter Henry Stubbe to Boyle," 4 June 1670, in *Boyle Correspondence,* IV, 180.

75 Jones, *Ancients and Moderns,* 262. Jones writes 'State, Church, and School were so involved with ancient learning that an undisguised attack upon it, without even the semblance of perfunctory

religious writings directed against the monopoly of the clergy.[76] As demonstrated by Jacob, the turbulence in the aftermath of the English Civil War meant that Stubbe had to present his radical opinions in a less obvious manner.[77] He could do this through his natural philosophical treatises, such as his onslaught against the Royal Society in 1670-71.[78] Stubbe certainly was one of the most vocal opponents to the young organisation, and his covert motivations on the whole seem to be, as Jacob rightly claims, anti- religious ones.[79]

Stubbe's favoured civil religion was anti-clerical, calling for an abandonment of the clergy in favour of secular governance over religion.[80] His main problem with the Royal Society was its membership. A good number of natural philosophers, 'probably most' says Shapin, were clergymen or somehow affiliated with the church.[81] Stubbe resented the control of the clergy over religious matters. In the Royal Society, he saw the clergy as trying to exert further control into domains that did not concern them, namely, natural philosophy:

> if we look de facto upon these experimental philosophers, and from too fatal trials judge how little they are fitted for those trusts and management of business by that so famed mechanical education, by complying with these novel projects for the breeding up of youth, we deprive out selves of all our hopes to see such persons either in church or state; we must rise as high in our resentments against the authors of this history.[82]

He saw the Royal Society's membership as unqualified to implement such dramatic changes to natural philosophy. *HM* was the perfect example of this. The Society was

respect, seemed to his conservative spirit, with its genuine fear of change, about to undermine all established things.'

[76] On some of Stubbe's more controversial religious views, see: Henry Stubbe, *A Light Shining out of Darkness* (London: 1659).

[77] Jacob, *Henry Stubbe,* 3-4; 101-02.

[78] Jacob, *Henry Stubbe*, 4.

[79] Stubbe, *Censure*; *idem., Campanella Revived.* These tracts are more explicitly devoted to exposing the Royal Society's as dangerous to religion, despite Stubbe being anti-religious himself. Such tracts may be seen to have had a purpose of fear-mongering, to dissuade others from the Royal Society.

[80] Jacob, *Henry Stubbe*, 96.

[81] Shapin, *Scientific Revolution*, 126.

[82] Stubbe, *Legends,* 4-5.

indeed religious, seeing its study as a way to understand God's creation.[83] Its work would also be a 'vehicle for practical divinity and ethical reform, in that it was concerned with works and that it presupposed those virtues Christ had taught by his own example.'[84] Wood argues that *HRS* was in a large part written to defend the Royal Society from religious critique and to show how it could be of value in that regard by helping to eliminate atheism and enthusiasm.[85]

Legends was intended not only as an attack on the Royal Society. It was a means for Stubbe to publish his own views. In ignoring the substance of Stubbe's conflict with the Royal Society, historians are losing a valuable source revealing his natural philosophy. It is true that Stubbe's attack may have been about his anti-religious views and distaste for the Royal Society's membership,[86] but it is also true that his attack highlights his expertise on gunpowder. If Stubbe had made any errors in his essay he would have been humiliated, and the wider anti-religious sentiment and natural philosophy that he espoused would be undermined.

Through *Legends* Stubbe emphasises his practical experience and experiments with gunpowder and saltpetre. In particular, he claims to have worked with a 'Mr. Bagnall' and his saltpetremen in Warwickshire.[87] Lastly, as evidenced by his submissions to *Phil Trans,* Stubbe investigated saltpetre when working as a physician in Jamaica in the early 1660s.[88] Not only does Stubbe have practical experience, but he is knowledgeable on relevant literature as well. He draws on well-known authors of gunpowder/ military manuals, such as Nathaniel Nye and Niccolò

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83 Purver, *Royal Society,* 143: 'the impulse behind [The Royal Society] was essentially a religious one, and the Royal Society, as a body, followed [Bacon's] precepts on religion in its relation to science.' See also: Wood, "Methodology and Apologetics," 12-20.

84 Wood, "Methodology and Apologetics," 18.

85 Wood, "Methodology and Apologetics," 18.

86 Jacob, *Henry Stubbe,* Chapters 4 & 5.

87 Stubbe, *Legends,* 35. Jackson I. Cope and Harold Whitmore Jones, *History of the Royal Society; edited with Critical Apparatus* (St Louis: Washington University Press, 1959) suggested in an appendix on Royal Society opponents, that this may be the 'Mr. Bagnal' who was listed as a fellow of the Royal Society. However, research on the fellows of the society by Hunter, *The Royal Society and its Fellows 1600-1700: The Morphology of an early scientific institution* (Chalfont St. Giles: British Society for the History of Science, 1982), 192, lists this fellow as being from Denbighshire, therefore unlikely to be the tradesman with whom Stubbe conversed in Warwick.

88 Henry Stubbe, "An Enlargement of the Observations, Formerly Publisht Numb. 27, Made and Generously Imparted by That Learn'd and Inquisitive Physitian, Dr. Stubbes," *Phil Trans* 3 (1668), 699-709, on 704-05.

Tartaglia, throughout *Legends*.[89] Stubbe's essay is detailed and convincing. He was extremely well versed in gunpowder research, and thus able to use the substance to attack his opponents whilst also promulgating his own natural philosophy.

Despite claiming that 'tis an hard thing to write against men that understand nothing',[90] Stubbe devotes over one hundred pages of *Legends* to dissecting, criticising and correcting Henshaw's work. He effectively re-writes the history as he sees appropriate. Stubbe tears apart Henshaw's essay almost line-by-line, highlighting what he perceived to be errors, falsity, and plagiarism:

> it hath so many defects in it, that I wonder any one should offer such an account to [the Royal Society], and am more surprised to see it approved and inserted into their history as a specimen of their narrations for the world to judge how accurate and inquisitive the society and its members are. The narration is not only imperfect but in many parts false.[91]

In exposing Henshaw as an incompetent natural philosopher and a plagiary, Stubbe could attempt to dissuade any favourable opinion towards the Royal Society. Stubbe was perfectly capable of challenging Henshaw on his own terms. Indeed, he seems to have been able to adapt to his chosen battles. Syfret observes that in his virulent exchanges with Glanvill, Stubbe 'could meet Glanvill on equal terms and, moreover, he could speak the same language.'[92] Syfret attributes this to his 'very quick and alert mind, […] retentive memory, [he] had read widely, and was knowledgeable in modern science'.[93]

Stubbe used his essay to present his views on matter theory. We have already seen gunpowder be used in explicating the matter theories of Bacon and Boyle, and now Stubbe can be added to this group. Stubbe strongly disagrees with the aerial nitre, instead believing that saltpetre is generated within the earth, as a result of fermentation.[94] He criticises Henshaw for not going far enough in his research,

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89 See: Nye, *Art of Gunnery*; Niccolò Tartaglia, *Three books of colloquies concerning the arte of shooting* (London: 1588).

90 Stubbe, *Legends,* 3.

91 Stubbe, *Legends,* 35.

92 Syfret, "Early Critics," 24.

93 Syfret, "Early Critics," 24.

94 Stubbe, *Legends,* 50-51. cf. Henshaw, "History," 66-67, for his original account of the nature of saltpetre earth.

saying that he should have investigated the causes behind the different salts that he observed in the refining process:

> this had been a curiosity worthy of a philosopher that understands something more than common forms. To tell us that *nature* acts the geometrician, or that it is done by the agitation of any subtile spirits, or matter, acting in a determinate manner upon the particles of one configuration, whilst the others are agitated and cast off by a different motion.[95]

Stubbe's approach to nature is described by Jacob as 'secular historicism'.[96] Stubbe saw nature's forces as acting on their own, free of supernatural intervention. In criticising Henshaw's approach to gunpowder, Stubbe was able to both strike at the Royal Society and deliver his own more radical approach to natural philosophy. Stubbe attacked the Society's religious membership, aptness, and natural philosophical views. With gunpowder, Stubbe could shoot many birds with one stone.

Baconian Histories

Both Henshaw and Stubbe used their gunpowder treatises to comment on the nature and value of the Baconian history. This is the mode of inquiry that the Royal Society was trying to promote in the *HRS.* Stubbe charged Henshaw with being incapable of effectively carrying out the natural historical programme espoused by the Royal Society. The very title of Stubbe's pamphlet, *Legends no histories?* demonstrates that he thought that the gunpowder 'history' was not done correctly by the Royal Society. Yet Stubbe thought gunpowder to be one field in which the Royal Society could potentially incur great benefits. He wrote:

> I am so great a well-wisher to the *publick good*, that I shall be willing to enquire into any thing, that may advance so *great* & *Staple a commodity* as *Salt-Petre* is, and alwaies wil be as long as the use of *Guns* continues: and since it is the most *plausible pretense* for the establishment of the *Royall Society*, that they *may* and *will* meliorate and *improve* the *Manufactures* and *trading* of our *Nation.*[97]

[95] Stubbe, *Legends,* 61-62.

[96] Jacob, *Henry Stubbe,* 101-02.

[97] Stubbe, *Legends,* 64.

When Stubbe read what he considered to be a gross mistreatment of gunpowder, he decided to write his own essay which would give the substance the analysis it deserved, and expose the perceived flaws in the Royal Society's Baconian programme.

What is a Baconian History?

Stubbe and the Royal Society had different understandings of what a history should be. The 'History of Trades' project was the Society's interpretation of Bacon's proposal for a programme of natural and experimental histories. Owing to his dissatisfaction with what he perceived to be a corrupt and erroneous state of natural philosophy, Bacon devised the 'histories' programme in his *great instauration.*[98] The *instauration* aimed to demolish scholasticism and rebuild natural philosophy on new foundations. These foundations were to be the natural and experimental histories. Bacon in his instructional 'preparative' for natural history, wrote:

> For [natural histories are] used either for the sake of knowledge of the actual things assigned to history, or as the primary matter of philosophy, and the basic stuff and raw material of true induction.[99]

A history was an inquiry on a particular subject in nature. For example, Bacon's own specimen histories included the 'History of the Winds' and the 'History of Life and Death'.[100] Bacon encouraged his followers to write histories covering as many natural phenomena as possible, and these histories fell into three categories: generations (nature in a state of liberty), pretergenerations (nature in a state of error) and arts (nature's bonds, or captive).

Bacon envisaged the individual histories as eventually coming together in a storehouse of sorts.[101] The histories would be the tools needed for future generations of natural philosophers to properly investigate nature, and maximise its productive

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98 Bacon, *Parasceve ad historiam naturalem, OFB*, XI; *idem., Historia Naturalis, OFB*, XII.

99 Bacon, *Parasceve, OFB,* XI, 455.

100 Bacon*, History of the Winds, OFB*, XII, 18-131; *idem*., *History of Life and Death, OFB*, XII, 141-377.

101 Bacon, *Parasceve*, *OFB,* XI, 455.

power. The inquiries would provide the basic practical knowledge of a particular topic, upon which experiments of light and experiments of fruit would eventually be based.[102] They were to be an important step towards gaining real knowledge over nature, and maximising its productivity.[103]

It is no surprise that the Royal Society chose to undertake the Baconian histories so soon after its foundation. Owing to Bacon's positioning of the histories as the base for the theoretical and inductive part of his project, they provided a natural starting point for the virtuosi. Yet as Kathleen Ochs has successfully demonstrated, the Royal Society's 'Histories of Trades' project was undertaken with the intention of making improvements in industry, rather than the eventual production of knowledge.[104] Wood notes that Sprat encouraged the writers of the histories to concern themselves less with theoretical hypotheses, and instead to keep 'an eye to utilitarian benefit.'[105] Bacon himself, as we have seen in Chapter 1, said that histories of arts were the most useful. In addition to the obvious utility of the arts, they would also provide great insight into nature's workings.

Bacon wrote of the productive potential of crafts that work with gunpowder, dyeing and chemistry more generally. These arts represent nature being controlled to powerful effect. He also emphasised that all substances should be explored, no matter how basic or mundane, no matter how 'vile, illiberal, and repellent'.[106] Gunpowder was, to some, all three of these. Yet its utility and power meant that it was fundamentally important to the early moderns, and more than deserving of a thorough natural-philosophical analysis. Through a collaboration with the labourers and the skills associated with gunpowder production, greater insight could be gained into its hidden forces, and its power could be increased yet further.

That two of Bacon's suggestions for histories were included in Sprat's book, Henshaw on gunpowder and William Petty on dyeing,[107] underlines the reverence

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[102] Sprat, *History,* 245, wrote that 'It is stranger that we are not able to inculcate into the minds of many men, the necessity of that distinction of my Lord Bacon's, that there ought to be experiments of Light, as well as of fruit.'

[103] Sprat, *History,* 245.

[104] Ochs, "Histories of Trades," 129-30.

[105] Wood, "Methodology and Apologetics," 12.

[106] Bacon, *Parasceve*, *OFB,* XI, 465.

[107] In addition to Henshaw's *HM,* is William Petty's "An Apparatus to the History of the Common Practices of Dyeing," 284-307, and Sprat's "The History of the Generation and Ordering of Green-Oysters called Colchester-Oysters," 307-09.

the Society held for its intellectual founder and his programme. The histories are written in a way that points toward a potential improvement of the trades, and they both take pains to emphasise the importance of practical research to understand nature's workings. Sprat's *HRS* stated the Baconian methods and goals of the project:

> The histories they have father'd are either of nature, arts or works. These they have begun to collect by the plainest method, and from the plainest information. They have detch'd their intelligence from the constant and unerring use of experienc'd men of the most unaffected, and most unartificial kinds of life. They have already perform'd much in this way and more they can promise the world to accomplish in a very short space of time.[108]

In following Bacon's instructions to collaborate with skilled workers in the writing of the histories, the Royal Society used their histories to demonstrate their potential to advance natural philosophy. Bacon declared that if these instructions are followed, 'the work of history will go straight to its proper destination'.[109]

Bacon outlined the rules for writing natural histories in the *Parasceve.* The primary emphasis of Bacon's instructions is reliability. The histories must provide a solid base on which to build a new natural philosophy. To ensure the credibility of the works, according to Bacon, philosophers should start again in their approach to nature. The descriptions should be based, as far as possible, on practical experiment, so as to avoid including pre-existing superfluities or superstitions existing in the scholastic philosophy. Importantly, they should write plainly and descriptively, free of speculation—that comes later in the project.[110] The writer should not worry about 'pleas[ing] the reader' as the goal is a 'granary and store-house of things, not comfortable accommodation for living in'.[111]

As Weeks has argued, it is important to distinguish the instructions in Bacon's *Parasceve,* from 'The Rule of the Present History', which precedes his own

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108 Sprat, *History,* 259.

109 Bacon, *Parasceve*, *OFB,* XI, 471. These instructions were set out in Bacon's *Preparative to a Natural History*, which follows from his *Novum Organum,* and in a briefer and more concise 'The Rule of the Present History' in the third part of the instauratio magna, *OFB,* XII, 2-17.

110 Bacon, *Parasceve, OFB,* XI, 467.

111 Bacon, *Parasceve, OFB,* XI, 459.

example histories.[112] This is a potential source of confusion. Bacon's own specimen histories were, of his own admission, not up to his own standards.[113] Rather, the specimens were intended to give indications of what Bacon wanted from the project. He warned:

> Since I very often lack history and experiments, especially experiments of light and crucial instances which can inform the mind about the true causes of things, I give directions for new experiments suitable, as far as I can tell at present, for the subject under inquiry. These directions are like history in embryo, for what other alternative is left to me who is just setting out on the road?[114]

It was a matter of 'do as I say, and not as I do.' Bacon's project was long term, and in his short lifetime, he would not be able to complete the library of histories in the precise manner that he would prefer.

Rees and Weeks have both commented on the complexity of Bacon's natural histories, which occupied a place in the early practical levels of induction.[115] Yet some commentators connect natural histories to the theoretical stages of the *great instauration.*[116] As we have seen, Bacon was adamant that natural histories were not a place for theorising. He clearly explains that in his own history, he had to take shortcuts and make deviations that should not be undertaken by future scholars taking on the project. On the other hand, however, Ochs holds that 'Bacon's ideas that merely describing trades could change them was incorrect.'[117] This was not in fact Bacon's suggestion. Rather, the focus on providing more immediate benefits to industry was a goal specific to the Royal Society. In Bacon's projections, the histories were a long-term project geared toward accumulating as much knowledge as possible about nature and art. Once sufficient amounts of knowledge had been

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112 Sophie Weeks, "'Historia vitae et mortis' or 'The Book of the Prolongation of Life'," manuscript in preparation.

113 Rees, *OFB,* XII, xviii-xix.

114 Bacon, *Rule of the Present History, OFB,* XII, 15.

115 Weeks, "The Book of the Prolongation of Life"; Rees, "Introduction," *OFB,* XII, xvii-lviii.

116 For example: Peter Anstey "Francis Bacon and the Classification of Natural History," *Early Science and Medicine* 17 (2012), 11-31; Dana Jalobeanu, "Core Experiments, Natural Histories and the Art of *Experientia Literata*: The Meaning of Baconian Experimentation," *Society and Politics* 5 (2011), 88-103; *idem., The Art of Experimental Natural History: Francis Bacon in Context* (Bucharest: Zeta Books, 2015), 199ff.

117 Ochs, "Histories of Trades Programme," 129.

gathered, it would be time to move onto experiments of fruit and experiments of light.

There evidently was confusion concerning how exactly to proceed with natural histories. This becomes abundantly clear when we study Stubbe's and Henshaw's conflict, as both had different ideas about what a history should be. *HM* would be one of the first undertaken. However, as is evident in Henshaw's history, following Bacon's instructions closely was not straightforward. *HM* draws upon elements of Bacon's proposals, but he also disobeys some of these rules. As advised by Bacon, Henshaw emphasised the reliability of his efforts in stating that the *HM* was formed from his own practical experience. He takes pains to emphasise that his experiments were his own, and that he had spent (an undisclosed amount of) time 'in the practice of *Salt-peter men* and Refiners of *Salt-Peter*'.[118] Further, his descriptions of the making and refining processes and skills are written in a straightforward and descriptive manner. However, as was the case with Bacon, Henshaw often was not able to conduct his own experiments in the way he would have wished, so he had to resort to using other authorities to supplement his own work.[119]

Stubbe had his own ideas of what a history should comprise. It is evident that he was not a particularly enthusiastic follower of Bacon's method. Stubbe declared that Henshaw should have focused on variations in different types of nitre, the 'many little differences in the petre'.[120] Bacon advised against this, arguing that most bodies and practices have an abundance of minor variations, and that focussing on these tiny details are often of little significance to the advancement of knowledge pertaining to the larger subject.[121]

Stubbe further criticised Henshaw for not pursuing the knowledge of nature's hidden processes that Bacon himself would have sought. He refers in particular to Henshaw's revival of the redintegration experiment, claiming that if done properly, this experiment could have been used to expose the 'true signatures of saltpetre'.[122]

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118 Henshaw, "History," 261.

119 Henshaw, "History," 260-61. Henshaw claims that he could have quickly solved the issue of whether ancient and modern nitre were the same if he had been able to obtain nitre from Egypt, which was said to be the same as that written about by the ancients. He had to draw on other accounts because it was not possible to obtain this nitre.

120 Stubbe, *Legends,* 37.

121 Bacon, *Parasceve*, *OFB,* XI, 457-59.

122 Stubbe, *Legends,* 69-72.

This would not have been properly Baconian, however, because Bacon's histories were to be free of speculation. Stubbe thought his way was more useful. Although he believes he has 'given a real insight into the nature of saltpetre,' he claims that he 'could have added more, had I designed an history, and not mere animadversions.'[123]

Plagiarism

Stubbe's largest charge against Henshaw and the Society attacked their supposed devotion to Bacon directly. Henshaw was shown by Stubbe to have plagiarised some of his material. Stubbe proclaims:

> I should here conclude my Animadversions upon this *History of Salt-Petre,* but I think it is necessary to show the world what a *Plagiary* this *Virtuosi is.*[124]

Stubbe discovered that Henshaw based much of the *HM* on Johan Glauber's 'Prosperity of Germany' (which included a translation of Ercker's description of saltpetre-making).[125] In addition, Stubbe points out that Henshaw's descriptions of making saltpetre and gunpowder are remarkably similar to those of Ercker. He demonstrated that Henshaw made the same 'errors' as Ercker, for example, using wooden trays to contain the boiled lixivium. [126] These are liable to break, Stubbe claims. Stubbe's accusations were accurate. Glauber's works, and Ercker's publication within it, evince a remarkable similarity to Henshaw's paper, particularly the description of making saltpetre. Owing to its plagiarism, claims Stubbe, the Society was not as genuinely Baconian as it claimed to be. Stubbe's familiarity with literature on gunpowder and nitre allowed him to deliver this striking blow to the Royal Society.

Had Henshaw had genuine experience with saltpetre-men and powder makers, Stubbe argues, 'he would not have committed so many errors'.[127] The

[123] "Letter Henry Stubbe to Boyle," 18 May 1670, in *Boyle Correspondence,* IV, 174.

[124] Stubbe, *Legends,* 86.

[125] Lazarus Ercker, *Treatise on Ores and Assaying* 1580, trans. Anneliese Grünhaldt Sisco and Cyril Stanley Smith (University Chicago Press, 1951); Johan Rudolph Glauber, *The Works of Johan Rudolph Glauber,* trans. Christopher Packe (London: 1689).

[126] Stubbe, *Legends,* 88.

[127] Stubbe, *Legends,* 87.

charge of plagiarism is not strictly about intellectual piracy. Plagiarism was not Baconian. The object of the history was to ensure reliability based on the author's own experience, and when such experience is not possible, the outside authorities used should be cited accordingly.[128]

> [Henshaw] pretends to a practical knowledge of the subjects! how little of accurateness is there in those scrutinies which ought to be so criticall and severe? where is that certainty which we are to have from them…?[129]

The non-reliance on ancient authorities, and the grounding of knowledge in the practitioners' own experiences, was a crucial part of what Bacon and his followers envisaged.[130] This is Stubbe's attempt to highlight a major flaw in the Royal Society's Baconianism. Stubbe may even have been aware of accusations of plagiarism against Bacon himself.[131]

The plagiarism accusations make it evident that Bacon's project was not necessarily an easy one to follow. It may be the case that Henshaw did not have the means to spend much time with saltpetre-men and gunpowder makers, or that he was unable to take everything in when he did. We saw in Chapter 3 that to become fluent in a craft, it could take a very long time. It requires tacit knowledge built up with experience. Eamon and Ochs have both investigated the potential problems faced in the proposed collaboration between scholars and craftsmen.[132] Based on their speculations, it is possible that perhaps Henshaw and the artisans he claimed to consult were unable to make a genuine Baconian collaboration work. Indeed it is possible that the artisans were unwilling to part with the secrets of their trade that comprised their livelihoods. Henshaw does comment that the gunpowder makers

[128] Bacon, *Parasceve, OFB,* XI, 467-469.

[129] Stubbe, *Legends,* 44-45.

[130] Peter Dear, "Totius in Verba: Rhetoric and Authority in the Early Royal Society," *Isis* 76 (1985), 144-61, on 150-53. Dear comments on the Society's effort to use experiential knowledge to challenge the scholastic reliance on ancient authorities. The scholastics had no way of verifying or disproving their sources, whereas the experimental philosophers did.

[131] On accusations of plagiarism against Bacon, see: Graham Rees, "An unpublished manuscript by Francis Bacon: *Sylva Sylvarum* drafts and other working notes," *Annals of Science* 38 (1981), 377-412, on 387-92.

[132] Eamon, *Secrets,* 342-45. Eamon holds that it was not only the craftsmen who were unwilling to give their secrets away. The virtuosi themselves were reluctant. See also: Ochs, "Histories of Trades," 146-50.

swore him to secrecy, although he claims that the only secret was their use of more coal and less nitre in the mixture in order to secure a greater profit, as mentioned above.[133] It is likely that they would not give up their secrets for publication, and Henshaw seems resentful of this.

There were social and intellectual boundaries between the scholars and the craftsmen, and these would be difficult to transcend in reality. These labourers had spent years in their trades, so it is unlikely that a natural philosopher could so quickly equal or transcend them in terms of knowledge and skill. Stubbe recognised this potential challenge, and believed that a fruitful union between the scholar and the craftsmen would not be an easy thing to achieve. He lamented:

> How will they be abused by Artisans, as Pliny by his authors? how much knowledge and skill is requisite to enquire into the circumstances of mechanicall productions? how much more to relate them?[134]
>
> the *History* of *Nature* which they propose to themselves, will not merit any more Credit (if so much) then that of *Pliny:* and these *Philosophers* instead of undeceiving the age as to *inveterate Errors* will *multiply new ones*.[135]

Ochs holds that the histories programme did not have success immediately, but that it took several more decades for the boundaries between the craftsman and scholar to break down.[136] As we have seen in the previous chapter, these boundaries were both physical and metaphorical. Royal Society scholars could spend a few weeks in a trade and come away with some valuable knowledge and experience, but this would not be enough time to build up genuine tacit understandings of the craft. They would also need to negotiate the boundary between the craft setting, and the laboratory or inquisitional setting to which the craft knowledge would need to be transferred.

In the gunpowder controversy, we see that the Royal Society's Baconianism was complicated. It was not strictly Baconian, in the sense that its writers did not adhere fully to Bacon's proposals. Henshaw was not being completely honest about

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[133] Henshaw, "History," 278.

[134] Stubbe, *Legends,* 47.

[135] Stubbe, *Legends,* 36.

[136] Ochs, "Histories of Trades," 151-52.

his experience, and Stubbe discovered and exploited his dishonesty. The Royal Society tried to write genuine Baconian histories, but was on the whole unsuccessful. Gunpowder provides the window through which we can see some of the complications in the Baconian project. It was liable to varying interpretations, and the Royal Society interpreted it in a way that would be conducive to utility and experiments of fruit.

Conclusion

Material substances are an invaluable resource for the historian, as are the controversies that often surrounded them. I have argued that Henshaw's and Stubbe's gunpowder debate has been overlooked by historians. This conflict tells us not only about the role that gunpowder played in the early Royal Society's public attempts to define its identity. It also highlights some of the challenges that the Society faced in implementing the Baconian programme. I have argued that historians should not overlook the details of historic controversies. Gunpowder's place in Stubbe's tirade against the Society had been mostly lost in the wider historiography. Yet we have seen just how critical it was—not just to Stubbe's attack, but also to the public image of the early Royal Society.

Gunpowder was employed by the Society to show how serious it was as an institution. It was an organisation that sought natural knowledge, but it also wanted to appear relevant. It wanted to separate itself from the scholastics and the alchemists, whose endeavours were often looked upon as fruitless, dilettantish, or superstitious. Gunpowder was a serious subject, and understanding it could have serious consequences, particularly for the government that gave the institution its charter.

Gunpowder's utility is something that could be agreed upon by seventeenth-century scholars. However, the ways of handling and interpreting the substance were far from standardised. This chapter consolidates some of the claims in Chapter 3. Making saltpetre according to early modern instructions was difficult because different social and physical environments demand different approaches. The controversy highlights the fact that there was more than one way to make and understand saltpetre and gunpowder.

The Royal Society used gunpowder to present its Baconian histories project to the world. Owing to Stubbe's in-depth knowledge of the material and the literature that accompanied it, however, gunpowder could also be used to expose the flaws in the Society's membership. Stubbe argued that if the Society was going to embark on this ambitious project in Bacon's name, it should at least do it correctly. The difficulty of producing genuine Baconian histories is evident in the case of Henshaw. Gentlemen scholars would need to travel and dirty their own hands in order to properly engage in Baconian history.[137] It is unlikely that many of the gentlemen scholars would be enthusiastic about doing this. Indeed, Peter Dear characterises the Society's histories of trades as 'half-hearted attempts' that 'bore little or no fruit'.[138]

Whereas this chapter has focussed on gunpowder's role in the external projections of the early Royal Society, in the next chapter we consider gunpowder's place in the internal world of Royal Society Baconianism. Stubbe's attack demonstrates that there were cracks in the Society's self-presentation. In the following chapter, it will be seen just how divisive were the Society's goals. We shall see that in spite of the pivotal public role that gunpowder played for the Society in its earliest years, their actual experiments using the material did match up to their public proclamations.

[137] Ochs, "History of Trades," 139.

[138] Dear, "Totius in Verba," 147.

Chapter 5

Gunpowder Experiments in the Early Royal Society

> No human invention of which we have any authentic records, except, perhaps, the art of printing, has produced such important changes in civil society as the invention of gunpowder. Yet, notwithstanding the uses to which this wonderful agent is applied are so extensive, and though its operations are as surprising as they are important, it seems not to have hitherto been examined with that care and perseverance which it deserves.[1]

Introduction

Gunpowder was an important player in the early Royal Society's public persona. When we look at the internal dynamics of the nascent institution, however, we find a remarkable contrast to the image that that it endeavoured to present to the world. In the epigraph above, Count Benjamin Rumford in 1797, laments that natural philosophy had not yet provided an appropriate analysis of gunpowder; a material that was more than deserving of scientific scrutiny. This chapter offers supporting evidence for Rumford's scathing statement. We will see that although the Royal Society did conduct several experiments with gunpowder, these experiments were infrequent, scattered, and eclectic. Notwithstanding its central role in Sprat's propaganda, there was no well-defined project to examine gunpowder. Whilst the Society did look with enthusiasm towards gunpowder, they did not treat it with the 'care and perseverance' that Rumford demanded.

This chapter argues that there was a surprising lack of focus on gunpowder from the early Royal Society. Given what we have seen so far in this thesis, one would expect more from this period in the institution's history. In particular, we would expect an exhaustive and detailed investigation into gunpowder. It seems odd

[1] Count Benjamin Rumford, "Experiments to Determine the Force of Fired Gunpowder," *Phil Trans* 87 (1797), 222-92, on 223.

that the material that held such importance in Royal Society propaganda was of relatively little significance in its actual meetings.

In this chapter I will explain the limited attention given to gunpowder, and why that attention declined. I show that, like many of the early Royal Society's endeavours, the interest in gunpowder was too sporadic and eclectic to be considered a research project of any import. The gunpowder experiments seem random, as if resulting from the whims and interests of individuals, as opposed to any collective corporate effort. This is highly surprising because of its evident potential as both an intellectual and utilitarian benefit not only to experimental philosophy, but also to the early modern state.

I argue that to understand the disappointing treatment of gunpowder by the Royal Society in its first four decades, we must look to a blend of internal and external factors that inhibited a more genuinely Baconian investigation of its causes and behaviours. In particular, we must look towards the Royal Society's dynamics and its interpretation of the Baconian project. The Society was less actively pursuing the grander programme set out by Bacon that would utilise experience to discover causes, but rather it sought primarily experiments of fruit. A loftier and more programmatic inquiry into gunpowder's occult causes was neglected in favour of more immediately fruitful and fragmented experiments. As expressed by Eamon, the Society espoused Baconian ideals publically but 'in reality, its commitment to that ideal was only partial.'[2]

I argue that the Society, when it came to gunpowder at least, engaged in the contested aspect of Baconian inquiry known as *experientia literata,* or *literate experience.* Lisa Jardine and Sophie Weeks have both shown that *experientia literata* is a distinct early phase in Baconian inquiry.[3] Briefly, literate experience describes the practice of extending experiments and knowhow solely based on experience and clever artisanal insights. Typically it terminates in modest material gain and utility, and by definition is not concerned with the discovery of causes. Jardine argues that fellows of the early Royal Society were in fact, for the most part, more concerned with utility, and hence were stuck at the early *experientia literata* phase of

[2] Eamon, *Secrets,* 319-20.

[3] Lisa Jardine, "*Experientia literata* or *Novum Organum*? The Dilemma of Bacon's Scientific Method," in *Francis Bacon's Legacy of Texts: 'the Art of Discovery grows with Discovery',* ed. William A. Sessions (New York: AMS Press, 1990), 44-67, on 51-52; Weeks, "Mechanics," 162-73.

induction.[4] A study of gunpowder experiments shows how practitioners proceeded from one experiment to another in precisely the manner of *experientia literata* that is described by Bacon.

The Royal Society's nature was not conducive to long-term projects like that which gunpowder demanded. The gunpowder experiments act as a sort of test case through which to throw light on the nature of the early Royal Society and its putative Baconianism. We will explore the experiments with gunpowder in the meetings and texts of the Society in order to understand why the fellows' successors a century later were so eager to chastise the rather meagre seventeenth-century flirtations with one of the most potent materials known to man.

A few historians have directed limited attention towards the Royal Society's gunpowder experiments. Needham's extensive biography of gunpowder looks at the Royal Society's endeavours to construct a device to test the quality of gunpowder, as we shall see in more detail below.[5] Buchanan draws the connections between the Royal Society and the Board of Ordnance, also founded in 1660.[6] She claims that some of the Society's engagements with gunpowder were of note, particularly Henshaw's and Prince Rupert's, which she notes both acknowledged the precise workmanship required to make good gunpowder in the early modern period.[7] Buchanan's account of the initial decades of the Royal Society suggests that there was not much of a connection between the natural philosophy of the Society and endeavours of the Board of Ordnance to improve upon gunpowder manufacture. That connection, she argues, came much later, and ultimately it was the latter organisation that would prove capable of generating change in the gunpowder industry.

My own approach looks more widely at the Royal Society's engagements with gunpowder from the institution's foundation until the turn of the eighteenth century.[8] In looking at a wider range of experiments and writings on gunpowder, we

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4 Jardine, "*Experientia Literata* or *Novum Organum*," 58-60.

5 Needham, *Gunpowder Epic,* 548-52, 555-59.

6 Buchanan, "Art and Mystery," 254-64.

7 Buchanan, "Art and Mystery," 256-57.

8 At this point I should emphasise that I am concentrating only on the Royal Society experiments that centred on gunpowder, and not those that used gunpowder but were ultimately about other aspects of gunnery and ballistics.

get a better sense of its actual role in the Society. This role, I argue, did have symbolic and inquisitional facets, but ultimately, was relatively minor.

In the first part of this chapter I consider the extent to which the Royal Society's gunpowder experiments focussed on utility. In particular, I address the 'Merton Thesis' and analyse the extent to which military concerns influenced Royal Society approaches to gunpowder. In the second section I argue that the Royal Society had confused notions of Baconianism, and that the internal dynamics of the Society meant that it was not equipped to give gunpowder a focussed analysis. The final section explores the external factors contributing to the relative lack of gunpowder analysis within the early Royal Society. Social and political factors, in addition to gunpowder's inherent properties, meant that it was a very difficult material to work with. There were limitations that meant that as much as all and sundry could comment on its awesome powers and capabilities, for the Royal Society to bring gunpowder in to its domain would be difficult. Whereas Boyle worked with gunpowder in a private laboratory, the same material in the hands of a society could have drawn criticism from those who were suspicious of societies as secretly engaged in political machinations.

Gunpowder and Utility

Gunpowder's potential to satisfy the utilitarian dimension of the experimental philosophy was glaringly obvious. It unleashed devastating waves of energy in the blink of an eye. It is clear to see why scholars concerned with invention would be interested in improving and extending its capabilities. Yet as we have already seen, the very fact that that it provided an instantaneous burst of energy made it theoretically interesting. If understood correctly, it could potentially reveal some of matter's most potent secrets, thus satisfying the real end of the Baconian instauration that sought knowledge of forms above all else.

The Royal Society's efforts with gunpowder were focussed on the category of utility. The concern overwhelmingly lay with extending knowledge and uses of the existing technology. A focus on extending the uses of this already critical material is not surprising. What is surprising, is that the quest for genuine Baconian knowledge and schemes were eschewed for experiments of fruit, which Bacon explicitly stated should not be prioritised over experiments of light.[9] The Royal Society's experiments with gunpowder were not part of any systematic programme. The institution's rhetoric as presented in the *HRS,* did not match its practice. In this section we explore the Royal Society's concern with gunpowder's utility, and in particular, we assess the extent to which this was military oriented.

Military Utility

The Royal Society was granted a royal charter from King Charles II in 1662 so it is natural that the fellows would wish to pursue socially and politically relevant topics in addition to arcana and curiosities.[10] Gunpowder would be the perfect medium through which the Society could prove its value, and through which it could show how philosophy could potentially be useful. I argue that the Royal Society began its efforts with gunpowder seeking to answer military concerns. The military value of gunpowder was not, however, as one might expect, a constant train of thought through the Royal Society's experimental programme.

The influence of social pressures on shaping the Royal Society's programme was explored by Robert K. Merton in what is now known as 'the Merton thesis.'[11] Merton argues that the Royal Society's gunpowder experiments were unsurprisingly the result of pressing military concerns.[12] He places gunpowder experiments in the category of experiments that he claims to be 'directly related' to 'military technology.'[13] Whilst A. R. Hall agrees on some aspects of the Merton thesis, his challenges to it are severe.[14] He agrees that there was of course an influence from contemporary issues on dictating the Royal Society's efforts, but challenges

[9] Bacon, *OFB,* XI, 157.

[10] On the royal foundation of the Society, see: Purver, *The Royal Society*, 137-40.

[11] Robert K. Merton, *Science, Technology & Society in seventeenth century England* (New York: Howard Fertig, 1970). Merton's study drew heavy-handed criticism from historians of science especially for his claim that religion in the form of Puritanism spurred the growth of science and technology. His focus on technological development has been relatively neglected. For a succinct and insightful commentary on the reception of the Merton thesis, see: Steven Shapin, "Understanding the Merton Thesis," *Isis* 79 (1988), 594-605.

[12] Merton, *Science, Technology & Society*, 184-98.

[13] Merton, *Science, Technology & Society,* 202. Merton categorizes experiments relating to particular social or economic issues. Those with no obvious affiliation are labeled 'pure science.'

[14] Hall, "Gunnery, Science, and the Royal Society," 136.

Merton's claim that mining, navigation and war were the pillars on which many of the early Royal Society fellows based their works.

Hall argues that gunpowder (and gunnery) experiments offered little to the science of ballistics, meaning the mechanics and mathematics of ballistics.[15] I argue that we should not assign a military function to the Society's gunpowder experiments unless there is context and documentation to support this claim. Given what we have seen so far in this thesis, we can conjecture that not all natural philosophers saw gunpowder as a strictly military material. Indeed, the transition into the laboratory creates a distinctly new conceptualisation of a powerful compound substance.

The earliest gunpowder experiments in the Society's records do seem to respond to military needs. Whilst this was likely connected to the Society's efforts to live up to its royal patronage, it was also owing to their membership. Prince Rupert of the Rhine (1619-82) provided a direct connection between the military sphere and the natural philosophical efforts of the Royal Society.[16] He was a cousin of Charles II and a royalist commander in the Civil War, and was heavily involved in the Royal Society. Scottish natural philosopher Sir Robert Moray (1608-73) ordered many of the gunpowder experiments in the 1660s. He was a Colonel of the Scottish Guards from 1645-50, and a driving force in the founding of the Royal Society.[17] It is probable that the presence of military commanders in the Society's earliest years was the reason behind the series of military-oriented experiments at this time.

Prince Rupert in 1663 he presented to the Society an account of gunpowder with a 'strength so far exceeding the best English powder, that trial being made with a powder-trier, it was found to be in the proportion of 21 to 2.'[18] The Society's minutes tell us that:

> the same kind of powder being found to differ in strength from the common English powder as about eleven to one, sir Robert Moray

[15] Hall, *Ballistics*; *idem.,* "Gunnery, Science, and the Royal Society."

[16] Sarah Barter Bailey, *Prince Rupert's Patent Guns* (Leeds: Royal Armouries, 2000).

[17] David Stevenson, *Letters of Sir Robert Moray to the Earl of Kincardine, 1657-73* (Ashgate, Aldershot: 2007), 36-51; Alexander Robertson, *The Life of Sir Robert Moray: Soldier, Statesman and Man of Science (1608-1673)* (London: Longmans, Green and co,1922), 62-76.

[18] Birch, *History,* I, 281. He first sent this to the Society in 1661, and the description in high Dutch was subsequently translated by Henry Oldenburg.

> moved that it might be considered how to make such powder in England since it might be carried in far less quantity to perform the same effects, that ordinary powder doth; and the charges of making it would not be so great as to take away the advantages of it.[19]

The description provided is a variation on the processes of making gunpowder in the period.[20] This powder's efficacy seems to rest on the purity of the ingredients, and the careful manner of combining them. It is made up of 2 oz sulphur and 2.5 oz coal to every pound of saltpetre. The high proportion of saltpetre is likely a reason for the powder's apparent efficacy. Such was its power, that it was necessary to caution users of it 'because this powder is pretty strong, you must make your charges somewhat less in all small guns, and especially in pistols, for else they will break.'[21]

The Society was evidently impressed by Prince Rupert's proposal. So much so that in some following gunpowder experiments, his mixture was called in for comparison with regular powders. However, claims of having a 'better' gunpowder composition would need to be substantiated. In 1663 Robert Hooke, the curator of experiments in the Royal Society, was ordered to design and construct a device that could test the strength of gunpowder.[22] This mechanical device, in principle, would be able to assess the relative quality/ strength of different gunpowder compositions.

Hooke was not the only fellow in possession of such a device. One owned by Prince Rupert makes appearances in the Society's minutes concurrently with Hooke's.[23] The fact that the virtuosi describe Hooke's gunpowder-tester as 'new,' suggests that they commissioned Hooke to build such a machine so that they could have one that was distinctly theirs.[24] The precise design of Prince Rupert's machine is not made clear. Based on the observation that 'common powder, with the fixed [ferrule] raised the weight very little whereas the same quantity of the Prince's

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[19] Birch, *History,* I, 338.

[20] Of course there was great variation in practices, as shown by the Stubbe/ Henshaw conflict in Chapter 4. However this account is much more detailed than most others.

[21] Birch, *History,* I, 285.

[22] Birch, *History,* I, 292.

[23] Birch, *History,* I, 295, 332, 338, 365.

[24] Hooke's eprouvette is referred to as the 'new powder engine' three times: Birch, *History,* I, 338, 340, 342.

powder, with the loose [ferrule] struck it up to the top,' [25] it might be safe to speculate that it was a 'vertical ratchet' model similar to the one explained below.

The notion of testing gunpowder mechanically was not novel to the Royal Society.[26] The first known mechanical gunpowder-tester, or 'eprouvette' to use the terminology of R. T. W. Kempers, appeared in William Bourne's *Art of Gunnery* in 1587.[27] Needham designates the century following Bourne's publication as the 'heyday' of eprouvettes.[28] This flurry of activity, argues Needham, was precursory to the invention of the piston and steam engines, which share a technology with these early eprouvettes.[29] He also emphasises the similarity between a cannon barrel and internal combustion cylinder.[30] Several early modern natural philosophers actually used gunpowder as fuel, in an industrial application removed from gunpowder's common home on the battlefield. Leonardo da Vinci used gunpowder to generate an explosion above a piston in order to raise a weight.[31] Christiaan Huygens's gunpowder engine (1673) used gunpowder to create a vacuum in a cylinder that caused a piston to move.[32] A crucial figure, argues Needham, is Denis Papin who built upon the technology of Huygens's gunpowder engine in 1688 when he replaced the energy of gunpowder with steam.[33] This episode tells us that the energy of gunpowder was perceived as much more than a military tool. Efforts were made to use gunpowder as industrial energy.

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[25] Birch, *History,* I, 338.

[26] R. T. W. Kempers, *Eprouvettes: A Comprehensive Study of Early Devices for the Testing of Gunpowder* (Leeds: Royal Armouries, 1998), xiii-xiv. These contrivances went by many names, including 'tryers' or 'testers'. The French term 'eprouvette' is adopted by Kempers. He explains that the term 'eprouvette' is specific to devices intended to test gunpowder, whereas 'tryer' or 'tester' could apply to many things. Prior to Kempers, eprouvettes were discussed in only a few short articles: H.G. Muller, "A Brief History of Powder Testers," in Robert Held ed., *Arms and Armour Annual,* Vol. 1 (Northfield, Illinois: Digest Books, 1973), 206-15; Graham Hollister-Short, "Early Gunpowder Testers," *The Antique Collector* 11 (1984), 104-07. Many thanks to the staff at the Needham Institute in Cambridge for locating the latter article for me.

[27] Kempers, *Eprouvettes,* 19-22.

[28] Needham, *Gunpowder Epic,* 548.

[29] Needham, *Gunpowder Epic,* 544-68.

[30] Needham, *Gunpowder Epic,* 544-47.

[31] Needham, *Gunpowder Epic,* 552-55.

[32] Needham, *Gunpowder Epic,* 556-58.

[33] Needham, *Gunpowder Epic,* 556-59. Papin, who is discussed below, developed this machine after he had moved from England to Marburg.

Eprouvettes appeared in a wide variety of shapes and forms, although most of the early ones operated on similar principles. They were devices that comprised a small powder chamber and some sort of scale. In most cases, the powder would be ignited in the chamber, and its forces would push a lid along the scale to provide a qualitative measurement of power.[34] Hooke's eprouvette was more complex. The powder charge in the chamber on ignition would raise a lid; to which is attached a beam that holds interchangeable weights. This model was novel as it used the premise of raising weights rather than moving a lid along a scale.

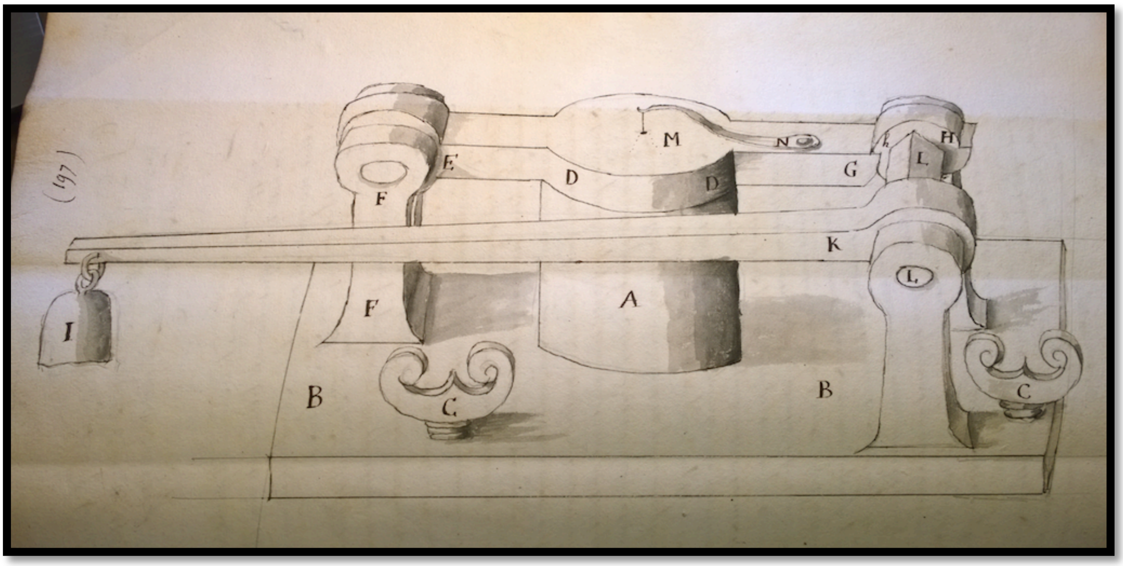


Figure 9: Eprouvette of Robert Hooke

[34] Kempers, *Eprouvettes,* 74-86.

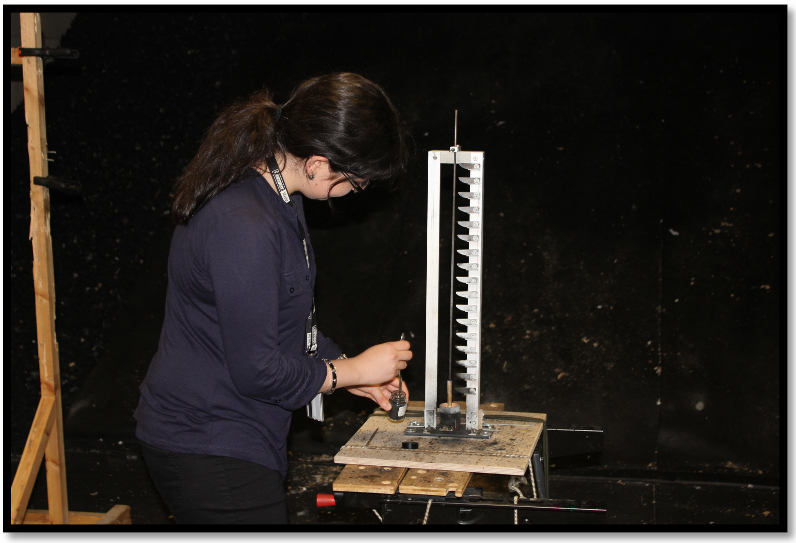
Experiment 3: An Eprouvette to test the strength of gunpowder

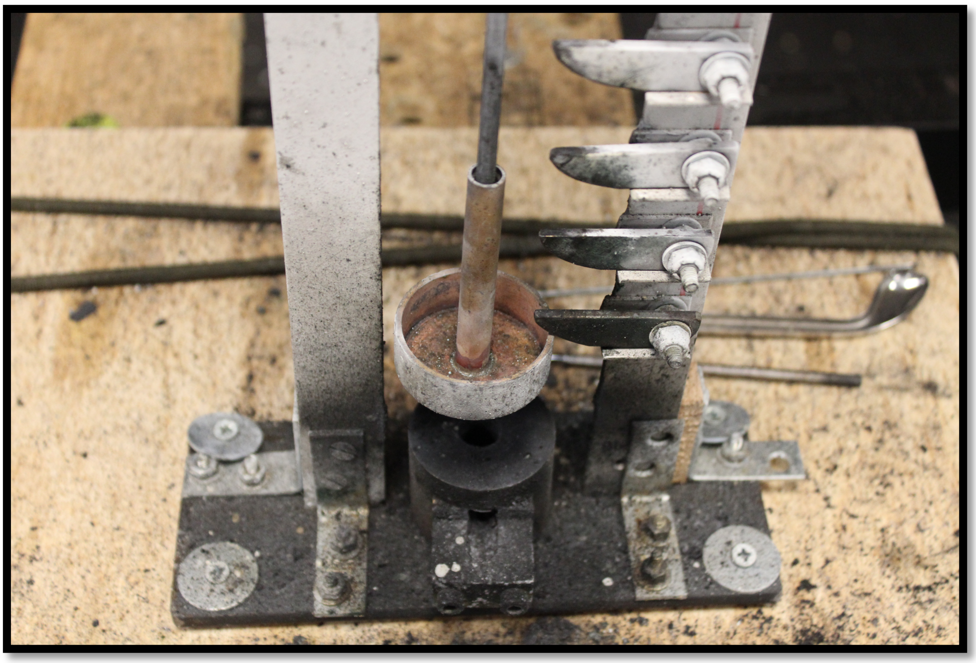
Experiment by Steven A. Walton, Peter Smithurst, Graeme Rimer, Trevor Weston, MGRG, Haileigh Robertson, 2013-14.

Prof. Steven A. Walton built the eprouvette in 2013. It is a proof-of-concept model based on the Joseph Furtennbach eprouvette, seen on the right (Kunsthistorisches Museum Wien, Hofjagd- und Rüstkammer, Inv.-Nr. A 1610).

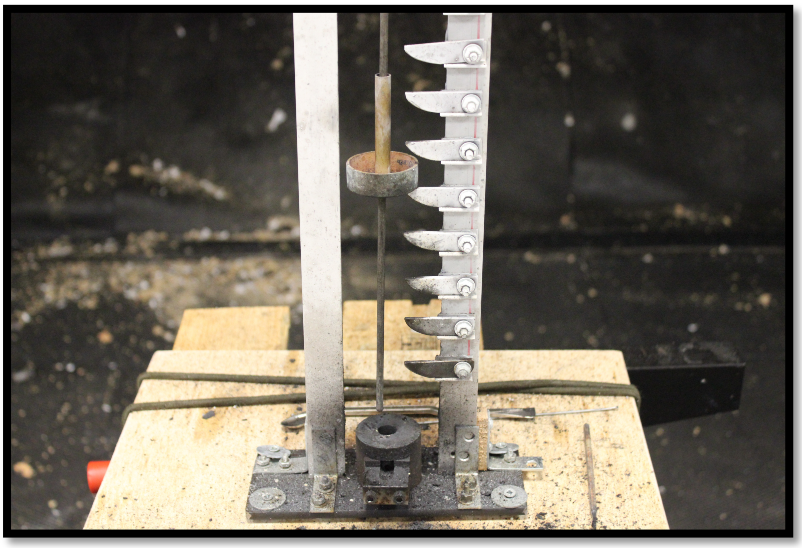
This device appeared in Furtennbach's *Halinitro Pyrbolia* in 1627 as a means to correct the inevitable guesswork associated with the selection of good gunpowder. The Furtennbach model was not the same style as Hooke's, but it worked on similar principles. A charge of gunpowder is contained in a small chamber, and on ignition the force of the explosion pushes the lid, attached to a central wire or rod, up a scale. Employing just one of many models of eprouvettes is sufficient to give insight into their nature. It was our goal to test how these devices operated, and to observe and address the specific questions and challenges posed by gunpowder in seventeenth-century experimental philosophy. Some deviations from the eprouvette upon which ours is based were taken, although functionally the eprouvette is faithful to the Furtennbach original.

Furtennbach's eprouvette is a 'vertical ratchet' model, to use the typology of Kempers (*Eprouvettes,* 74-75). On ignition, the gunpowder's energy pushes the lid upwards on a scale of seventeen pawls (twenty four on the original) spaced approximately 21mm apart. The pawls are on the right hand side, and rotate clockwise. This means that as the lid is blown up the scale, the pawls rotate upwards to allow its passage, until it lands on one of these pawls at its highest point. The base of the eprouvette is bolted onto a wooden base to give the device stability. Initial trials were undertaken in 2013 with the MGRG to gain an insight into how the eprouvette worked. We started off with a tiny amount of powder the chamber, which gave no discernible result. Gradually, the charge was built up until it reached a full chamber, and indeed this proved necessary for the lid to be raised. The same powder, however, gave differing results.





More rigorous testing was undertaken in 2014 at the National Firearms Centre (Royal Armouries). I worked closely with Peter Smithurst, Trevor Weston, and Graeme Rimer on site, and Steven Walton via email, to conduct the experimentation. We used gunpowder made to varying compositions (four corned, four serpentine) to assess their power in the eprouvette. 'Powerful' in this context, corresponds to 'that which raises the lid the highest'. We chose to test gunpowder mixed to different ratios because this might allow us to assess whether higher or lower saltpetre, charcoal, and sulphur contents really made a difference to the strength of the gunpowder.



To make ignition easier, we used standard commercial powder as a primer, whilst the eight sample powders filled the chamber. The results were inconsistent, and as the charge raised a random weight (the lid), the results are purely comparative. The initial test with modern powder raised the lid to fourteen pawls. The serpentine powders failed to burn with enough rapidity to raise the lid at all, producing only a flash in the pan. The corned powders were more successful, but only after significant modifications had been made to the eprouvette and our procedure. These modifications included cleaning the eprouvette between each test, and the enlargement of the touchhole, as the major problem was the build up of residue between each test. Even then, however, repeat tests with the same powders would provide different results. In the end, the corned powder mixed to the ratio 70/20/10 provided the best result, reaching a maximum of eight pawls. The other three corned compositions averaged at five. Thus the eprouvette posed challenges that meant that at best it could be used as a way of loosely comparing different samples of gunpowder.

Experiment 4: Powder Testing by Shooting

From: Thomas Birch, *History,* I, 335.

Experiment by Peter Smithurst, Trevor Weston, Haileigh Robertson 2014.

By way of comparison to the eprouvette experiments, the same powders were tested using another testing-method of the early modern era; firing a musket at a row of wooden boards. The Royal Armories provided a framework into which individual boards were slotted. It was made of wood, as metal would bring the risk of ricochet.

We used a Henrician replica matchlock musket attached to a remote ignition device that kept the musket stable, thus ensuring more consistent results. We measured the strength of the corned powders by calculating how many boards the musket-ball penetrated. Results were by no means consistent—the same powder would perform slightly differently with each test. Yet the results were more stable than with the eprouvette.

These powders also shot the bullet cleanly through ballistic soap before getting stuck in the first board—so we know that they are not weak or defective, as the more meagre results in the eprouvette might have indicated. Three boards was the result of the most successful powders, but the reason for the small number is that the projectile loses more and more energy as it hits each board and travels through the small gaps in between. Like the eprouvette, this method could provide only a means of qualitatively comparing different samples of gunpowder.

With Prof. Steven Walton, the Royal Armouries, and the MGRG, I conducted experiments with a replica eprouvette in order to gain a greater understanding of the technology and the experience of using it.[35] The most striking aspect of the experimentation was the extensive modifications that had to be made to the apparatus and process during the tests. First of all a priming pan was added for ease of ignition. The central wire was replaced with a rod, which is easier to adjust and remove. A new and lighter lid was made with a lip around the edge to allow for the addition of weights if necessary. Mid-way through the experiments on the first day at the Royal Armouries, the touchhole was enlarged to prevent it becoming blocked with powder residue.

Eprouvettes were not the only means of assessing gunpowder employed by the Royal Society. Another method was to simply shoot a bullet through a series of aligned wooden boards to see how far it travels.[36] In an experiment of Sir Paul Neile it was observed 'that trial being made of Prince Rupert's powder, and common English powder, it was found, that whereas a charge of the English powder shot through three boards, and stuck in the fourth, Prince Rupert's powder passed through four boards, and stuck in the fifth.'[37] We also tested this method of the Society, using the same powder.

Reworking these experiments illuminated some of the challenges and experiences associated with eprouvettes that are not fully portrayed in the salient literature. For example, difficulty with ignition seems to be a likely problem presented by eprouvettes, yet it is not one that makes it into the records. The Royal Society does not even mention how Hooke ignited the eprouvette. Whilst these devices are safe to operate, they do produce a small explosion that would make

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[35] Steven Walton, "A Replica Eprouvette for the Danish Medieval Centre" (unpublished draft report, 2013). It is not an exact replica, but rather a 'proof-of-concept' working model. I am grateful to Dr. Stefan Krause at the Kunsthistorisches Museum (Vienna) for allowing me to examine and photograph the Furtennbach eprouvette.

[36] In yet another instance Lord Brouncker was ordered by the Society to unveil the causes of gun-recoil. Whilst this experiment ventures from the strictly gunpowder category into the ballistics one, it is worth mentioning as it relates to the strength of the varying powder charges employed in the experiment. See: Sprat, *History,* 233-39. France maintains that this experiment had the aim of using the results 'as a basis for achieving the mathematical precision in modeling the behavior of the bullet inside the gun, according to the velocity of the bullet and the radius of the bore of the gun,' *Gunnery and the New Science,* 263.

[37] Birch, *History,* I, 335.

direct ignition risky. Our solution was to attach a piece of lit slow-match on a 1.5 metre stick to allow for remote ignition.

We have also been able to shed light on the nature and efficacy of eprouvettes. Whilst the commercially mixed powder used first in our eprouvette performed well, the varyingly mixed compositions barely moved the lid up the scale. This was partially because, as mentioned above, the touchhole kept becoming blocked with residue. It must also be noted that the custom compositions had a slower burn rate than the commercial powder. After enlarging the touchhole, and cleaning between applications, the results improved. It took many tests to indicate the 'winner,' but the powder mixed to 70/20/10 (Saltpetre/ sulphur/ charcoal respectively) did perform slightly better than the others after the modifications were made.[38] Ultimately, however, there was a lack of consistency in the eprouvette's performance. The same powders produced differing results. Only relative estimates could be obtained based on the powders that tended to perform better.

These results seem disappointing on the surface, but they are not far removed from the experiences of the virtuosi. Regarding Prince Rupert's eprouvette, it is simply said that one powder performed better than another—no quantitative measurement is given. Furtennbach himself did not report any powders reaching high levels on the device. He rather talks about different types of powder reaching four, five, nine and twelve inches.[39]

We do know that Hooke faced similar problems with his eprouvette. It was 'found imperfect, by reason of the noncontinuance of the first impulse', so 'he offered to complete it, by the addition of a rammer.'[40] By adding a rammer, a ramrod as found in a musket, the powder could be compacted to ensure that the charge burns evenly thus preventing these 'impulses.'[41] A rammer was added to Hooke's eprouvette, but his problems were not so easily solved:

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[38] The serpentine (fine, dry mixed) powders were soon discarded as they all failed to raise the lid to even one pawl. The powders mentioned above are all corned (wet-mixed and then powdered)..

[39] Kempers, *Eprouvettes,* 24. Powders are made for different types of gun, for example, cannon powder is coarser and designed for a much larger space than an eprouvette or even a musket can provide.

[40] Birch, *History,* I, 335.

[41] The following explanation is based on Peter Smithurst's explanation of the process. The impulses may owe to both the powder used and the design of eprouvettes. Serpentine powder has a perceptible but slow burn rate, and indeed performed very poorly in our experiments. Corned powder has a faster burn rate as the ingredients are more intimately mixed owing to the corning process that wet-mixes the powdered ingredients into a paste before powdering them again. The barrel of a musket allows the

> The experiment of trying the force of powder by weight in the new powder engine contrived by Mr Hooke was made twice, but without success both times, once by reason that the barrel broke in pieces, the second time because the cover of the barrel bent. It was referred to Mr Hooke to think of a way to prevent these inconveniences.[42]

It seems that Prince Rupert's efforts were marginally more successful than those of Hooke. The Society mainly modified Prince Rupert's eprouvette by experimenting with loose and fixed 'ferrels' (ferrules). The experiments confirmed to the Society that Prince Rupert's powder (as mentioned above) was indeed stronger than 'ordinary powder' as it was capable of lifting the weight higher, but it was only strong when the ferrule was left loose. The observation inspired Moray to propose, in the style of *experientia literata* that will be explicated more thoroughly in the next section, two suggestions for future experiments. Firstly, he proposed that it would be useful to make Prince Rupert's powder in England 'since it might be carried in far less quantity to perform the same effects, that ordinary powder doth.'[43] Secondly, he asked Prince Rupert 'to prosecute these experiments by putting loose ferrels into guns.'[44]

We are provided with a means of comparing gunpowder in the eprouvette so we can see why military-men and natural philosophers alike were drawn to these instruments. Yet we can also understand the frustrations of working with eprouvettes; the sort of frustrations that Hooke and his colleagues faced in 1663. In an era when gunpowder was in high demand, a device that could eliminate the poor powders from the strong powders in a seemingly mechanical way would be valuable. In using gunpowder in a controlled manner, we can see how its power could be put to non-military applications—and this is a key reason why natural philosophers were interested in the testing of gunpowder. Not only could they benefit the military sphere by potentially eliminating poorer powders (should the eprouvettes work), but

ignited powder's energy to reach full power before expelling a projectile. The chamber of the eprouvette is too short for the amount of serpentine power it contains, thus instead of raising the lid the powder is dissipated to burn in the open air. It may also be the case that unevenly mixed corned powder, where the ingredients clump together, could exacerbate the problem by producing an uneven burning process and thus an uneven exertion of the gunpowder's force, causing what Hooke calls 'impulses'.

[42] Birch, *History,* I, 342.

[43] Birch, *History,* I, 348.

[44] Birch, *History,* I, 348.

also they would be able to control a substance that was so famously volatile and powerful, to bring nature under their command.

However, the eprouvettes did prove themselves to be difficult to work with, and they were not actually capable of quantifying gunpowder's forces. We can speculate that the technical problems and the time needed to gain necessary skills were obstacles in the exact quantification of gunpowder's power. We are also reminded of Bacon's 'negative instances', as encountered in Chapter 3, wherein failure can be instructive. Our constant modifications were the result of our initial failures. The same can be said for the many modifications that Hooke made to his gunpowder tester.[45]

The efforts with the eprouvettes, especially Prince Rupert's, make it blatant that the knowledge acquired had the potential to be adapted for military innovation. Yet even an early focus on military questions was not enough to embark on a serious inquiry into gunpowder. In 1663, after numerous repetitions of the eprouvette experiments, these tests were abandoned for no apparent reason.

Expansion experiments

Despite the Royal Society's problems with the eprouvette, it raised an interest in the nature of gunpowder's expansion, and the experiments were extended in order to analyse this phenomenon. Whilst thematically the Society's efforts to study gunpowder's expansion seem similar to the eprouvette experiments by virtue of their focus on the strength of gunpowder's forces, there is no evidence to suggest that they were part of the same research programme. It is more likely the case that an experiment would raise a particular question leading to a related experiment. This is an extension of existing knowledge and practice, rather than attempt to build knowledge anew. So whilst it would be a leap to suggest that the expansion experiments were unrelated to military technology, it cannot be said that they fit neatly into this box. Hall is correct to observe that in the manner they are reported by the Society, these experiments have no obvious purpose.[46]

In a series of experiments concurrent with the eprouvettes, the Society aimed

[45] Hooke's eprouvette was tried at least four times (twice in front of the Society, twice behind the scenes). See: Birch, *History,* I, 335, 338, 342, 346.

[46] Hall, "Gunnery, Science, and the Royal Society," 125.

to test gunpowder's forces and behaviours by igniting explosives in closed iron containers.[47]

> Sir Robert Moray was desired to get two hollow iron-balls made for the putting of gunpowder into one, and aurum fulminans into the other and to make them red-hot, in order to see, whether the gunpowder would melt in one, and the aurum fulminans fire in the other.[48]

They were testing if the powder was strong enough to break its bonds, but also paying attention to what happened to the powder—whether it detonated, or whether it did something else. Gunpowder propels bullets with such power because the energy seeks one way out, through the barrel of the weapon. These experiments asked what happened when the forces of explosives had nowhere to go.

In the first instance the gunpowder did 'fire and burst' but the aurum fulminans did nothing more than stick to the sides of the cavity. As such it was ordered for the experiment to be adapted to use stronger containers that are more tightly screwed together.[49] However, the experiment continued to give curious results:

> The experiments of closing up of gunpowder, aurum fulminans and water in three balls of steel severally being again made; and that with gunpowder alone being fired and broken, it was debated, what might be the cause, that the gunpowder should fire and not the gold powder, the latter being the stronger of the two? Some conceived that a sulphurous matter might exude out of the heated steel and be communicated to the gold powder whereby its fulminating virtue might be deadened. Others thought that this powder might fire within the ball (having left some air in it, because not filled full with the powder) and the noise not be heard at a distance. Others were of opinion, that the penning it in, and giving it but a slow heat might make it melt it being found sticking to the sides of the ball upon the cutting it asunder. It was ordered hereupon that the operator should bespeak two balls with cavities no bigger than a pea to fill them full severally with aurum fulminans and gunpowder.[50]

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47 These experiments, with their subtle variations each time, were numerous. See: Birch, *History,* I, 292, 293, 295, 296, 299, 300, 306, 310, 335, 424, 425, 427, 432, 440, 445, 446, 448, 450, 452, 455, 464, 465, 468, 469, 474.

48 Birch, *History,* I, 292-93.

49 Birch, *History,* I, 295.

50 Birch, *History,* I, 299. This was followed by another batch of experiments where gunpowder would fire and give off some noise, but the gold powder did not react at all, 310.

These three substances expand when heated. Two to explosive effect, and water generates steam. There is a clear attempt to theorise on the nature of expansion and energy by comparing three substances.[51] Yet this attempt does not go beyond more immediate observations of the experiments at hand. The fellows posit an investigation into the causes, but their explanations are varied and lack cohesion, and ultimately go no further.

The expansion experiments and the eprouvette experiments were often conducted in the same meetings. Yet there was no attempt by the fellows to connect the two. The experiments of igniting gunpowder in spherical and cylindrical cases were far more numerous than the efforts with the eprouvette. The Society tried this experiment week after week making minor modifications either to the apparatus or to the weight of powder used. Hooke, who was conducting most of these experiments, was aware of the emphasis on practice. His lamentations were read to the Society, as he proclaimed that he 'shall yet again make some more trials of [gunpowder's detonation within an iron case] before we leave it, that so we may bring to it some certainty and theory.'[52]

The observations gradually became more detailed. After a gunpowder explosion broke the case, the operator examined the case to find that some of the powder remained inside. Held on a piece of paper over a fire, this powder burned without rapport. The fellows speculated that the gunpowder left behind after the explosion had been calcined and converted into an alkali, with the nitre destroyed by the explosion.[53] Thus the Society did make small efforts to theorise, but ultimately it was practice that was favoured. The experiments did not entail any prolonged or meaningful discussions on why gunpowder and the related materials would behave in this way. Like the eprouvette, these experiments were abandoned without being brought to a close. The abandonment may owe to frustration from not achieving the desired results, or the virtuosi may simply have lost interest. Nonetheless, these experiments and their peremptory abandonment deserve further consideration by historians. Such instances could tell us a great deal about the Society's attitude to

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[51] Birch, *History,* I, 425, 427. This batch of experiments continued, next using cylindrical, as opposed to spherical, steel containers. They continued to vary the strength of steel and amount of gunpowder used.

[52] Birch, *History,* I, 468.

[53] Birch, *History,* I, 414.

experiment and its claims to be Baconian.

The notion that gunpowder's energy could be quantified raised the possibility that it might also be contained and harnessed. In 1666, the Society ordered 'an instrument to apply the strength of powder to the bending of springs securely and certainly.'[54]

> The experiment of bending a spring by the force of gunpowder was tried three times without success, and the fourth time it succeeded. It was ordered that it should be repeated at the next meeting, and that particularly a weight should be wound up by a shot of gunpowder, to see for example, what force would wind up a hundred pounds weight. It was observed that the stroke of gunpowder was so brisk and sudden, that it would break anything; and that therefore little powder should be used.[55]

Hooke found that one and a half grains of powder could wind up a four-foot long spring. He remarked that if it were possible to 'communicate the force of gunpowder to a spring he might then command as much strength as he would.'[56] The spring experiments aimed to discover ways of storing and applying the huge waves of gunpowder-produced energy. This would be no small feat.

It was almost ten years before the Society returned to this idea. In 1674 the virtuosi conjectured that an understanding of gunpowder's motions could be applied to mechanical devices:

> Sir William Petty mentioned that perhaps it might prove of use to consider whether gunpowder being of so great and quick a force might not be slackened to give a slower motion as in the mortar piece the shell is much more slowly carried through the air than a bullet of a musket. Some said that it would be of real use to contrive something for flying if it were to raise a man so high as to fly over a wall and the besiegers of a town to carry and bring back intelligence.[57]

The Society's projections for a gunpowder-operated flying machine unfortunately never reached fruition. Yet the very idea of such a device tells us that the virtuosi saw gunpowder as a fuel or energy source. This energy need not be reserved only for projectiles. The Society understood that to use gunpowder in this way, its motions

54 Birch, *History,* II, 137.

55 Birch, *History,* II, 146.

56 Birch, *History,* II, 156.

57 Birch, *History,* III, 181.

had to be somehow slowed down, and at that stage this was knowledge that the virtuosi did not possess.

The experiments outlined above show a seemingly natural progression from quantifying gunpowder to harnessing its expansive energy. Through these experiments, Merton claims, 'the definite relation between military technology and pure science is made explicit'.[58] Likewise, he groups them all into the category of 'interior ballistics' and cites this as the reason that Boyle was interested them.[59] I argue that the expansion experiments, excluding the eprouvette, evince no real connection to the military sphere. Indeed it is possibly the case, as Buchanan has argued, that the Royal Society faced less pressure to make military minded inventions owing to the presence of the Board of Ordnance that was explicitly set up to deal with such matters.[60] Moreover, given the evidence presented in Chapter 2, a military motivation cannot be said to be the reason of Boyle's attendance. It was at this point that Boyle asked 'what is really the expansion of gunpowder, when fired'.[61] The Royal Society's motivation was unclear but for Boyle, this was *experimenta lucifera.*

It is not military improvement that holds these experiments together as Merton suggests. It is the common theme of gunpowder's expansive energies. The experiments with the eprouvette and the steel containers aimed to quantify or measure this energy; the spring experiment endeavoured to contain it, and the flying machine proposed a way to use it. It must be noted, however, that we can tie these experiments together under this umbrella only in hindsight. Apart from Hooke, whose efforts to marry theory and operation into a single enterprise stemmed from his deeper understanding of the Baconian programme,[62] there is no evidence to suggest that the Society viewed them as one long-term project. The fact that we do have this expansion track to trail, however, does remind us that over its first two decades, the Royal Society's intentions with gunpowder were utilitarian and

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[58] Merton, *Science, Technology & Society*, 192.

[59] Merton, *Science, Technology & Society*, 188.

[60] Buchanan, "Art and Mystery," 256-69.

[61] Birch, *History,* I, 455.

[62] Hooke's *General Scheme* shows his clear conception of Baconian protocols, and the power of analogy. Hooke is famous for his physics of the spring and here he is linking the energy of the spring and the energy of black powder. This shows the Baconian aim to see similarities in disparate phenomena.

focussed on the appropriation of gunpowder's power for immediate fruits.

Baconianism and Experientia Literata

Hall is correct to point out that the Society's experiments with gunnery were 'sporadic, slight, and ineffective investigations'.[63] He is right about this but for the wrong reasons. It is not Hall's aim to scrutinise the Baconian commitments of the Royal Society, but rather he argues that these gunpowder experiments contributed little to ballistics. In this section I argue that owing to the nature of the early Royal Society, which was mainly focused on fact gathering and experiments of fruit, it was not possible for gunpowder to become the topic of study in the Baconian sense. Following Jardine, I suggest that, for the most part, fellows of the Royal Society were concerned with *experientia literata* and immediate utility,[64] as opposed to the larger Baconian programme. I explore the extent to which some fellows attempted to understand gunpowder in accordance with Baconian principles, but conclude that ultimately the internal dynamics of the Royal Society could not support such a project.

Experientia Literata

Experientia literata was one of three stages in Bacon's programme for discovery. It came after discovery by chance, and anticipated 'philosophical mechanics' that would invent works based on knowledge of causes achieved via the inductive method.[65] Literate Experience was concerned with extending existing knowledge, as opposed to using the full range of Baconian procedures in order to understand matter and forms as the foundation for inventing novel things. It contributes to Baconian inquiry by both generating experiments of fruit, and by providing aids to the memory in advance of the philosophical interpretation to which the programme is building towards.[66] By arranging mechanical history in tables,

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[63] Hall, "Gunnery, Science, and the Royal Society," 136.

[64] Jardine, "*Experientia Literata* or *Novum Organum*," 47.

[65] Weeks, "Mechanics," 162; Jardine, "*Experientia Literata* or *Novum Organum*," 52.

[66] Weeks, "Mechanics," 163-64.

literate experience facilitates an expansion of knowhow that extends beyond the tacit and habitual technical abilities of the arts and crafts.[67]

Experientia literata is a low-level sort of knowledge. It is based on the abilities of artisans to observe similar effects across a range of diverse procedures. It involves the extension of knowledge and practice via this power of observation. Literate experience moves from procedure to procedure. What is observed in one experiment or activity is the inspiration for the next. One effect may give rise to an idea that a particular effect or process could be extended beyond its customary application or domain. However, it is in no way a novel effect in the Baconian sense. Bacon's idea was that erudite scholars would be able to notice trends and variations in crafts and procedures, and use their intellect to suggest changes and improvements. *Experientia literata* does not contribute to philosophical mechanics. It does not entail knowledge of causes, yet several treatments position this aspect of Baconian inquiry as a contributing stage in the wider causal investigation.[68] For example, Eamon conflates *experientia literata* with the higher phase of induction.[69] As Weeks shows, Bacon is emphatic about literate experience not being connected to inquiry.[70] Bacon states that none of the eight modes of experimenting or 'extending the mechanical history' will generate axioms; that is the domain of the higher stage which Weeks calls 'philosophical mechanics' and the aspect of inquiry dealt with in the *Novum Organum*.[71]

So far I have argued that the gunpowder experiments carried out by the Royal Society were in Baconian terms literate experience rather than the pursuit of causes. The experiments outlined in the previous section support this thesis. They tread

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67 Weeks, "Mechanics," 164; Jardine, "*Experientia Literata* or *Novum Organum*," 52-54.

68 Although acknowledging that Bacon said that literate experience was not part of the grander interpretive scheme, the following accounts ascribe a semi-elevated role to *experientia literata,* focussing particularly on its role in generating natural histories: Jalobeanu, "Core Experiments," 96 ff; Guido Giglioni, "Learning to Read Nature: Francis Bacon's Notion of Experiential Literacy (*Experientia Literata*)," *Early Science and Medicine* 18 (2013), 405-34; Laura Georgescu, "A New Form of Knowledge: Experientia Literata," *Society and Politics* 5 (2011), 104-20.

69 Eamon, *Secrets,* describes experientia literata as 'an inductive methodology,' 286-87. The approach of Weeks and Jardine is concerned with the various stages of Bacon's method, whereas others are concerned with a more general and at times imprecise understanding of the inductive programme.

70 Weeks, "Mechanics," 165-66.

71 Weeks, "Mechanics," 164-65. Weeks quotes *De Augmentis Scientarum* (*SEH*, IV, 443) where Bacon states that these eight ways of experimenting 'extend so far as to the invention of any axiom. For all transition from experiments to axioms, or from axioms to experiments, belongs to that other part, relating to the New Organon'.

along the shared path of gunpowder's expansion, yet branch out owing to lessons learned and questions raised at each stop along the way. The eprouvette experiments failed in their goal of reliably quantifying gunpowder's strength. Yet they instilled the idea that the energy of gunpowder could be contained and possibly harnessed. This led to another idea to compare the strength of explosive and expansive substances by examining which would break the strongest bonds. This led to the notion that the energy of these materials could somehow be stored and put to use. This series of experiments do not exhaust the full range of a genuine Baconian examination that required a constant back and forth between operation and contemplation. They were mostly operative, with practical goals in sight. Gunpowder shows us how the Society moved between experiments based on existing knowledge and observations in the style of *experientia literata*.

The case of the Royal Society thus far helps to demonstrate the gulf between Bacon and Baconianism. Jardine is correct to point out that the *Novum Organum* 'rapidly became the subject of two entirely distinct types of reading'.[72] Boyle embraced experiment and united theory and practice in a genuine attempt to pursue knowledge. In contrast, the Royal Society, by and large, was not engaged in the procedures as laid out in the *Novum Organum.* The Royal Society's brand of Baconianism sought utility, and thus was far removed from the grand systems envisaged originally by Bacon.

William T. Lynch provides an alternative reading.[73] He argues that part of the reason for the seemingly dilettantish utilitarian interests of the Society is owing to their self-imposed embargo on 'premature theorizing'.[74] In Lynch's view, the Society was focussing on the gathering of enough factual material, as Bacon did suggest, before moving onto the speculative stage. Be that as it may, Bacon's project was to be highly systematised and organised in a way that the early Royal Society was not. The Society pursued immediate gratification. This was not how Bacon envisaged his project.

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[72] Jardine, "*Experientia literata* or *Novum Organum*," 50.

[73] Lynch, *Solomon's Child*; *idem.*, "A Society of Baconians?: The Collective Development of Bacon's Method in the Royal Society of London," in *Francis Bacon and the Refiguring of Early Modern Thought,* ed. Julie Robin Solomon and Catherine Gimelli Martin (Aldershot: Ashgate, 2005), 173-202.

[74] Lynch, *Solomon's Child,* 29-30.

Michael Hunter and Paul B. Wood have demonstrated that the Society itself was aware of the varying interpretations of Baconianism to be found within its ranks.[75] A fellow using the pseudonym 'A. B.' wrote to the Society in 1674 challenging the Society's membership and organisation.[76] His letter, as explained by Hunter and Wood, describes the tension between these contrasting utilitarian and theoretical interpretations of Baconianism in the Society.[77] A. B. was in favour of gathering facts and knowledge with a broad and inclusive membership, whereas Hooke, for example, pursued a more theoretical inductive approach and desired a more elite and specialised membership.[78] Expertly put by Hunter and Wood:

> [t]he vulgar Baconians confined the philosopher to the co-operative collection of empirical data. Theory was to be eschewed, but utility was not. Fellows such as Hooke accepted these cooperative and utilitarian aspirations, but insisted on the validity of causal inquiry.[79]

As a result of the early Society's voluntary membership, a huge range of specialities and preferences could be found within the institution's ranks. Indeed, a desire for specialism led to an attempt to implement a policy change in 1680 whereby the fellows would decide on the topic for discussion prior to the meetings.[80] The nature of the Society that was eclectic and being engaged in *experientia literata* meant that the range of subjects studied by the fellows was far too broad and unprogrammatic. Gunpowder was a victim of the sporadic eclecticism exhibited by the Society.

Eclectic Experimentation

The style of research that prevailed in the early Royal Society aimed to gather facts and concentrate on a huge breadth of topics. This means that we certainly see a variety of bases covered by the Society, but very few have the

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[75] Michael Hunter and Paul B. Wood, "Toward Solomon's House: Rival Strategies for Reforming the Early Royal Society," *History of Science* 24 (1986), 49-108.

[76] Hunter and Wood, "Toward Solomon's House," 57-58.

[77] Hunter and Wood, "Toward Solomon's House," 65-66. This view is supported by Eamon, *Secrets,* 345-50. Eamon describes one Hartlibian style Baconianism inspired more by the fact gathering of the *Sylva Sylvarum,* and another more systematic version akin to the *Novum Organum.*

[78] Hunter and Wood, "Toward Solomon's House," 67, 77.

[79] Hunter and Wood, "Toward Solomon's House," 78.

[80] Hunter and Wood, "Toward Solomon's House," 58-63.

attention of a Hooke or a Boyle to see them turned into a more cohesive research interest. Peter Dear argues that '[s]hared ideals among the early Fellows did not, as a rule, translate into shared projects or programs of research'.[81] As Walter E. Houghton put it, the virtuosi were 'men of a thousand interests'.[82] Gunpowder was just one of many curiosities that made it into the minutes, notes, and *Phil Trans.* As shown above, even when there seems to be a common theme of research (gunpowder's expansion), there seems to be little cohesion or sense of the fellows investing in a shared endeavour of any note.

The eclectic range of interests was part of the internal dynamic that meant that gunpowder did not get the focus that it merited given its universally acknowledged importance and more especially its strategic placement in Sprat's *HRS*. In fact, many of its experiments with gunpowder seem to be isolated and random instances. The following experiment, conducted in 1661, is a paradigmatic example of this unsystematic eclectic approach to experimentation. It appears in Thomas Birch's minutes with no context or discussion to follow:

> A circle was made with powder of unicorn's horn, and a spider set in the middle of it, but it immediately ran out.
>
> The trial being repeated several times, the spider once made some stay on the powder.[83]

Gunpowder experiments too seem random and isolated in the records of the early Royal Society. As early as 1661 it was proposed that the Society 'fire powder in a fuse, or otherwise' in order to 'observe the manner of firing, the force of the powder, the motion of the smoke, and the duration of it: the like of other combustible things, as to flame, smoke, etc.'[84] In another effort, Henshaw proposed that he wanted to test 'whether any use of gunpowder would change the polarity of a needle.'[85] The Society then placed a needle in its box, and 'shot upon [it] with a small gun charged

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[81] Dear, "Totius in Verba," 147.

[82] Houghton, "History of Trades," 60.

[83] Birch, *History,* I, 35.

[84] Birch, *History,* I, 9.

[85] Birch, *History,* I, 267.

with powder but the needle was not altered in its polarity.'[86] These are isolated instances; just two of the many in which gunpowder is mentioned and the suggestion is not followed up or brought to a conclusion.

Eamon claims that 'it is misleading to regard the Royal Society's activities as involving merely random experimentation and indiscriminate collection of 'curious facts.'[87] He suggests that a good deal of the seemingly random experiments were actually pursuing knowledge of occult qualities and hidden causes. To an extent this is true. For instance, as shown in Chapter 2, gunpowder's expansion was perceived as an occult property. The Royal Society's experiments on this topic did allude to the acquisition of experimentally produced knowledge on gunpowder's instantaneous and powerful expansive energies. But allude is all they did. The issue here is not to deny that there was theorising and genuine causal investigation in amongst the wide range of utilitarian concerns. Rather, I argue that the Society was not actively engaged in defined research programmes. I have already shown that many topics and experiments make fleeting appearances, never to be returned to again. Gunpowder, a prime candidate for a centralised research project, is explored in a range of mostly unconnected and isolated instances. This would not be enough to engage in a real journey towards understanding its causes in the way that Bacon would have sanctioned.

A possible reason for the Society's gunpowder experiments not being exhaustively analysed is the tension between the public and private interests of the fellows. Eamon has shown how the fellows were not always willing to publish their knowledge for fear of its making its way into 'vulgar' hands.[88] Although the early momentum to gather histories of trades was directed towards the publishing of private or secret craft knowledge, the work conducted by natural philosophers could potentially be applied to personal profit and so in some cases the Society's members were equally unwilling to give up their wares.

Golinski has shown how the one-time rarity phosphorus piqued the interest of philosophers seeking to profit from their knowledge.[89] German natural

[86] Birch, *History,* I, 369.

[87] Eamon, *Secrets,* 298-99.

[88] Eamon, *Secrets,* 344-45.

[89] Golinski, "Phosphorus," 19-20.

philosopher Johann Daniel Krafft visited Boyle in 1677 and impressed him greatly with his homemade phosphorus. Rather than imparting his skills to the Society, however, he attempted to sell his phosphorus for private gain. This inspired others to embark on the business of phosphorus, including Boyle, whose findings on the manner of preparing phosphorus were published posthumously in the *Phil Trans*.[90]

There was a similar motivation to work with gunpowder. Indeed the Hartlib Circle, as we saw in Chapter 3, were motivated by economic, social, and political means to investigate saltpetre and gunpowder. To generate significant improvements to gunpowder's procurement or use could be a profitable enterprise indeed. It is the case that Prince Rupert, as shown by Sarah Barter Bailey, was engaged in the business of cannon founding; the secrets of his methods kept even from the granters of his 1671 patent.[91] The Prince did engage in experimentation and research, funded by the government's Ordnance Office, but this was done privately with the goal of generating profitable instruments.[92] With this in mind, we can tell that Prince Rupert was selective of what matters he brought to the attention of the Society.

To focus on the profitable potential of gunpowder is not Baconian. Bacon spoke against the misappropriation of natural philosophy for the purpose of gaining a quick profit.[93] This example shows how private interests did penetrate the corporate façade of the Society. The military men, as shown in the first section, sought military improvements and profitability. Yet it was not just the potential for profit that caused some fellows to distance their private interests from corporate ones. It is the case that the most Baconian analyses of gunpowder within the Royal Society manifest themselves as the work of individuals, rather than the institution as a whole.

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[90] Golinski, "Phosphorus," 19; Robert Boyle, "A Paper of the Honourable Robert Boyl's, Deposited with the Secretaries of the Royal Society, Octob. 14. 1680. And Opened Since his Death; Being an Account of His Making the Phosphorus, etc.," *Phil Trans* 17 (1693), 583-84.

[91] Bailey, *Prince Rupert's Guns*, 1.

[92] Bailey, *Prince Rupert's Guns,* 12. Bailey further outlines the gun-founding experiments, which she shows were conducted in four different operations, but all focused on the improvement of iron guns, 16-20.

[93] He was not necessarily opposed to *experimenta fructifera* generating profit, but rather he saw that the quest for immediate personal profits could distract from more genuine philosophical pursuits: Weeks, "Mechanics," 170-71. In the fable of 'Atalanta' Bacon cautions on the dangers of being distracted by immediate fruits (in this case the fruits are both literal and metaphorical—Atalanta was distracted by golden apples): Bacon, *De Sapientia Vetorum, SEH,* VI, 743-44.

The Search for Causes

We have seen how utility was the priority when it came to gunpowder in the early Royal Society, but we do see some attempts to engage with the material in a properly Baconian framework. In 1678-79 Henshaw, who we know to have a strong interest in gunpowder, chaired several Royal Society meetings. In these meetings, there was great attention devoted to gunpowder after a considerable silence. The first meeting began with a brief discussion between two fellows on the cause of gunpowder's expansion, said by Hooke to be 'the operation of the alcalizate salt in the charcoal, that served to compound the powder.'[94] Sir John Hoskyns disagreed, arguing that a negligible amount of an alkaline salt could be extracted from coal 'and so it was not likely to be the cause of so great an effect'.[95] This discussion soon terminates and gives way to a discussion on gunpowder's origins.

The Royal Society looked back to Roger Bacon who centuries earlier had made an 'enigmatical description […] that he well understood how to make gunpowder, or a composition which would perform the same effect.'[96] The following discussion was a debate over whether Berthold Schwarz was indeed the inventor of gunpowder, or whether he was simply the first to use it in guns.[97] Following this 'it was therefore desired that inquiry might be made into the times of [Roger Bacon's and Berthold Schwarz's] living.'[98] Yet at this point, these meetings that had begun to focus more on the causes of gunpowder's energy, petered out just as the more obviously fructiferous experiments had done years earlier.

Thus in the 1670s we see a hint of a more theoretical turn, but ultimately it is specific fellows following particular threads that present us with more causal analyses. In particular we see a reprise of the role of gunpowder in meteorological research. Eamon is correct to observe that 'much of Bacon's scientific program was predicated on the assumption that by imitating nature, we come closer to understanding natural processes.'[99] Analogy played an important role in Bacon's

[94] Birch, *History,* III, 469-70.

[95] Birch, *History,* III, 470.

[96] Birch, *History,* III, 470-71.

[97] Birch, *History,* III, 477.

[98] Birch, *History,* III, 477.

[99] Eamon, *Secrets,* 310.

programme, as we have already seen in Chapter 1, and is probably best illustrated in the incredible range of Hooke's interests and in his ability to see connections among them. Analogy helps dissolve the division between art and nature, and provides a medium to investigate phenomena comparatively. For example, Werrett describes how gunners imitated natural phenomena and meteors in their fireworks.[100] Part of the marvel is being able to produce a seemingly magical effect from basic natural causes.

John Wallis in 1695 wrote to the *Phil Trans* about the connection between gunpowder's effects and meteorological phenomena.[101] He says that gunpowder is so like thunder and lightning, 'that we may reasonably judge them to proceed from like causes.'[102]

> the violent Explosion of Gun-powder, attended with the Noise and Flash, is so like that of Thunder and Lightning, as if they differed only as natural and Artificial; as if Thunder and Lightning were a kind of Natural Gun-powder, and this a kind of Artificial Thunder and Lightning.[103]

Gunpowder shows that the boundaries between art and nature can be torn down, and the power that man can achieve over nature. To explore the causes of meteors was to explore the causes of gunpowder. Wallis suggests that the air contains 'a convenient Mixture of Nitrous and Sulphurous Vapours, and those by Accident to take Fire' followed by an explosion resembling fired gunpowder.[104] The explosion if 'high in the Air, and far from us, will do no mischief' such as if 'a parcel of Gun-powder is fired in the open Air, where is nothing near to be hurt by it.'[105] Of course if there are bodies near to it, it will do something very different. Wallis says that lightning has both sulphurous and nitrous vapours 'because we do not know of any Body so liable to a suddain and violent Explosion.'[106]

Wallis theorises, in Paracelsian fashion, a cause based on reactions of nitre

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[100] Werrett, *Fireworks,* 59.

[101] John Wallis, "A Letter of Dr. Wallis to Dr. Sloane, Concerning the Generation of Hail, and of Thunder and Lightning, and the Effects Thereof," *Phil Trans* 19 (1695), 653-58.

[102] Wallis, "Thunder and Lightning," 655.

[103] Wallis, "Thunder and Lightning," 655.

[104] Wallis, "Thunder and Lightning," 655.

[105] Wallis, "Thunder and Lightning," 656.

[106] Wallis, "Thunder and Lightning," 656.

and sulphur in both phenomena. This theory is the same one that we encountered for muscular contraction in Chapter 2. The *aerial nitre* and the *flamma vitalis* reacted to produce a range of natural phenomena, whether bodily or meteorological.[107] The authors in favour of this theory saw that processes involving meteors, earthquakes, thunder and lightning, and muscular contraction exhibited similar properties and could thus be explicated by one cause. It was the case that gunpowder explosions, although an artificial effect, could also be placed in this group with a common underlying cause. This is why these theories came to be known as 'gunpowder theories', and why scholars turned to gunpowder, which unlike earthquakes or thunder and lightning, could be introduced to a laboratory for direct analysis. To understand gunpowder's causes would be to understand the causes of these larger but less tangible phenomena.

A more extensive account on the issue can be found in Hooke's posthumously published exposition on the causes of earthquakes, and thunder and lightning.[108] He did not subscribe to the Paracelsian matter theory like Wallis, but he did draw analogies between gunpowder and meteorological phenomena and propose that they share a cause. Although not a document published by the Royal Society, Hooke's treatise is of relevance when we consider Hooke's important role in the institution. As curator of experiments, it was Hooke who actually constructed the apparatus for the Society's gunpowder experiments, and carried them out. In this job Hooke had, according to Jardine, 'real power and influence.'[109] Yet as we see through his gunpowder research, he published his more theoretical Baconian inquiries separately from the institution within which he worked.

Jardine has previously argued that Hooke exemplifies the Royal Society's engagement in *experientia literata* that was not proper systematic Baconian induction.[110] When we contrast Hooke's efforts with gunpowder within and outwith the Royal Society, however, we see a more complex picture emerge. When working

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[107] Guerlac, "Poet's Nitre," 246-47; Debus, "Paracelsian Aerial Niter," 46-51; Frances Willmoth, "John Flamsteed's Letter concerning the Natural Causes of Earthquakes," *Annals of Science* 44 (1987), 23-70.

[108] Robert Hooke, "A Discourse of the Causes of Earthquakes: July 30 1699," *The Posthumous Works of Robert Hooke,* 2nd edn, in T. M. Brown, ed. (Frank Cass & Co: London, 1971), 424-28.

[109] Lisa Jardine, *The Curious Life of Robert Hooke: The Man who measured London* (London: Harper Perennial, 2004), 97. She discusses Hooke's origins and introduction to the Royal Society, 81-102.

[110] Jardine, "*Experientia literata* or *Novum Organum*," 47-48, 50.

for the Royal Society as the curator of experiments, Hooke did indeed engage in literate experience. We have already seen how the experiments on expansion facilitated the low-level moving between practices. We have also seen how Hooke was often instructed or 'ordered' to make particular modifications, or put into practice the ideas of others. When working on his own accord, however, Hooke was indeed concerned with the Baconian investigation into causes.

This evidence supports Lynch's thesis that 'Hooke himself developed the most explicit attempt to follow Bacon's lead in the *Novum Organum.*'[111] Lynch explains how Hooke was perceived by some of his contemporaries, such as Moray, to engage in premature theorising.[112] Hooke's Baconian tendencies are shown in his *General Scheme.*[113] He places tremendous importance on experiment, and like Bacon, believes that it must be ever-present in the inductive process. He draws on the notion of the application of 'agents to patients' in order to apply knowledge to the benefit of mankind, which as, as we have already seen, the definition of Baconian natural magic.[114]

Gunpowder for Hooke was analogous to many of nature's most powerful effects, not just thunder and lightning. His aim was to explore 'the Ferment or Materials that serve to produce and effect Conflagrations, Eruptions, or earthquakes' as arising from the 'earth grow[ing] old.'[115] These materials, he says, are:

> somewhat analogous to the Materials of Gun-pouder, not that they must necessarily be the very same, either as to the Parts or as to the Manner and Order of Composition, or as to the way of Inkindling and Accension; for that as much as the same Effect may be produced by differing Agents, so the Methods and Order of proceeding may be altogether differing: A clear Instance of this we may find in the Phaenomena of Lightning, wherein we may observe, that the Effects are very like to the Effects of Gun-pouder.[116]

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[111] Lynch, *Solomon's Child,* 29; *idem.,* "A Society of Baconians," 189-93.

[112] Lynch, *Solomon's Child,* 28. Lynch explains that Moray chastised Hooke in spite of the fact that Hooke's 'premature theorizing' was conducted according to the Baconian manner, based on the interaction between hand and mind and the experimental confirmation/refutation/ generation of hypotheses. See also: Peter Anstey, "Philosophy of Experiment in Early Modern England: The Case of Bacon, Boyle and Hooke," *Early Science and Medicine* 19 (2004), 103-32. Anstey argues that Hooke was part of the same experimental tradition as Bacon and Boyle.

[113] Hooke, *General Scheme*.

[114] Hooke, *General Scheme*, 3.

[115] Hooke, "Discourse of Earthquakes," 424.

[116] Hooke, "Discourse of Earthquakes," 424.

He calls earthquakes, and thunder and lightning, 'crises of nature' that have clear differences in particulars yet analogous effects.[117] Even though '[he] cannot possibly prove what the materials are, yet the Effects speak them to be somewhat Analogous to those of Gun-pouder, or *Pulvis Fulminans, Aurum Fulminans* or Lightning.' He conceives of these phenomena as being:

> but one Operation in Nature, and that which causes the effect in one causes the effect in all the rest, and the outward appearances of the differing materials, and the differing way of Operating, are nothing but the Habits, and Dresses, and Vizards of the Actors, and the differing Modes and Dances by which they Act their several Parts, which, when they have done, they are at an end, and have exerted their whole Power, and there must be a new set of Actors to do the same thing again.[118]

Gunpowder, earthquakes, and thunder and lightning share a cause according to Hooke. They are 'materials that make the subterraneous Flame or Fire, or Expansion, call it by which name you please'.[119] They differ only on how they make themselves manifest to us.

The use of gunpowder in addressing meteorological issues is telling. In a similar way to Boyle and Bacon, certain fellows of the Society are interested not only in investigating gunpowder itself, but in using its effects to investigate other aspects of matter. Hooke cannot be described as a vulgar Baconian. He was interested in *experientia literata,* but he was certainly interested in the search for causes too. On his own he made causal investigations, but as part of the institution he conformed to their more utilitarian guise. It might indeed be that Hooke's individual interests were indeed side-lined in favour of corporate policy.

Also engaged in a more genuinely Baconian pursuit was the Society's French technician Denis Papin (1647-1712). From 1675-87, Papin was preoccupied with gunpowder (among other things). Most of his experiments were conducted under the Royal Society's roof. Yet there is also a sense in which he seems to be working on his own. These experiments were deduced, conducted, and interpreted by Papin, and

117 Hooke, "Discourse of Earthquakes," 425.

118 Hooke, "Discourse of Earthquakes," 425.

119 Hooke, "Discourse of Earthquakes," 425.

merely performed in front of the Royal Society and reported in its minutes and transactions.

Papin's project in its earliest stage was shared with Christiaan Huygens.[120] The pair wrote to the *Phil Trans* in 1675 detailing their experiments *in vacuo*.[121] Their primary aim was to confirm the amount of air contained in gunpowder, and to assess this air's contribution to gunpowder's effects. The experiment was conducted by placing eighteen grains of gunpowder in a vacuum receiver alongside a mercurial gage. They used the sunbeams to ignite the charge,[122] and found that the mercury rose 1.5 inches. Papin and Huygens concluded that 'there is a *fifth* part of Air in Gunpowder'.[123] The experiment further led them to posit that 'all the effect of Gunpowder comes from the Air, which is compressed therein, and especially in Saltpeter […] Possibly also we may find in time, that all other Fulminations, Ebullitions and Fermentations, that make such surprising motions, are nothing else but Air compressed expanding it self.'[124] The observations on the centrality of air to understanding gunpowder's expansion and related processes were not new. Boyle had made similar observations just a few years earlier. However, owing to Papin's success in being able to ignite gunpowder in a vacuum chamber, he was able to theorise more deeply on the relationship of gunpowder and the air, and even to propose exact quantifications of the volume of air compressed within the explosive material.

[120] In 1680 Huygens published the account of his newly-invented gunpowder engine. This device worked by igniting small amounts of gunpowder in succession in the bottom of a cylinder, which created a vacuum and moved a piston. On Huygens's gunpowder engine, see: Graham Hollister-Short, "The Formation of Knowledge Concerning Atmospheric Pressure and Steam Power in Europe from Aleotti (1589) to Papin (1690)," *History of Technology* 25 (2004), 137-50.

[121] Christiaan Huygens and Denis Papin, "Some Experiments Touching Animals, Made in the Air-Pump by the Persons Formerly Mentioned," *Phil Trans* 10 (1675), 542-58, on 546-48.

[122] You may recall that Boyle's attempts to ignite gunpowder *in vacuo* with the sunbeams failed. The French climate is evidently more accommodating of gunpowder experiments than the British one.

[123] Huygens and Papin, "Some Experiments," 548. Their complex calculations to reach this result posited that the 18 grains of powder generated enough air to fill 1/18 of the receiver. As the receiver contained 49 drachms of water, the air, which takes up the same amount of space, but is 1000 times lighter than the water, can be said to weigh 1/1000 of 49 drachms which equates to roughly 3 ½ grains. Thus the 18 grains of powder contained over 3 ½ grains of air, which is about 1/5 of the original 18 grains.

[124] Huygens and Papin, "Some Experiments," 548.

By 1686 Papin had moved from France to become a technician in the Royal Society, and then began a flurry of activity concerning gunpowder and the air.[125] He disagreed with Anthony van Leuwenhoeck's calculation that set the expansion of one grain of gunpowder at two thousand times its original size.[126] Papin supposed that the conclusion of Leeuwenhoek was either faulty or 'the air produced by the explosion of gun-powder has a greater elasticity than the common air in a lighter body.'[127] After several experiments, some conducted during Royal Society meetings, Papin would eventually conclude in 1687 that six grains of gunpowder would yield four grains of air.[128]

Having theorised that gunpowder contained roughly ¼ part of air (this calculation is compatible with six grains of powder yielding four of air), Papin moved onto assessing the qualities of this air. He had found that the air made by gunpowder fired *in vacuo* 'will not suffice to maintain fire; for that in a receiver, wherein had fired three grains of powder by the sun, which yielded 1/15 of as much air, as would have filled the receiver […] in a very dark room no sparks of fire were produced upon the trigger of a pistol.'[129] He maintained that the air produced by gunpowder was 'factitious', meaning that it was made through the ignition process. It was not considered to be the same as the common or ambient air. Moreover, this factitious air was compressed in the saltpetre and made to expand on ignition.

Papin left England to become a professor of mathematics in Marburg later in 1687, bringing his illuminating gunpowder experiments with the Royal Society to an end.[130] On reflection, Papin has much more in common with Boyle, than with the Royal Society *en masse.* He engages in both experiment and theorising, displaying a genuine interest in causes, rather than in fruits. Indeed, he hoped that 'such tryalls may also afford some light to discover the true cause of the great effects of gun

[125] See: The Royal Society Archives, "Papin and Hauksbee Papers," Vol. 18i, in "Classified Papers 1660-1741," Ref: CI.P. Several of these papers detail Papin's efforts with gunpowder.

[126] Birch, *History,* IV, 470. In an annotation Papin notes that the air is 1/100 the weight of water, and 'a grain of gun-powder, if it should be turned into air, could take up but 800 times as much space as its own bulk,' 470.

[127] Birch, *History,* IV, 470.

[128] Birch, *History,* IV, 522-23.

[129] Birch, *History,* IV, 531.

[130] Birch, *History,* IV, 553.

powder.'[131] Hall says that 'Papin's ideas represent the culmination of the chemistry of explosives in the seventeenth century.'[132] He reaches this conclusion owing to Papin's recognition that the air compressed in saltpetre was the key to gunpowder's behaviour. I would argue that this idea has earlier origins in Boyle and Hooke. Yet the work of Papin, that continued in the same vein as Boyle and Hooke, was the starting point for mature theories of gunpowder's causes that emerged during the chemical revolution of the eighteenth and nineteenth centuries.[133]

Papin set the ball rolling for future contributions to the *Phil Trans* based on similar principles. In 1693 van Leuwenhoek made a chemical experiment to quantify the rate of gunpowder's expansion.[134] He fired 'one then two then three corns in closed glasses and left them to cool for around five days.' The result, according to Leuwenhoek, was that the compressed air was 'forcibly' thrown out of the glass. To test the amount of air generated, he put the powder in a narrow-necked vessel then filled with water. As the air rushed in, the water was forced out so he found the air was compressed to eight times its original volume. He then placed a corn of gunpowder in a glass with just one tiny hole at the narrowest end, which was then placed under water. The powder is fired and this forced out 160 grains of water. Thirteen corns of gunpowder constitute a grain, so to multiply 160 by 13 gives 2080 and the rate of gunpowder's expansion.[135]

The work continued in this manner. Francis Hauksbee in 1704 presented his own gunpowder experiments in the *Phil Trans.*[136] His aim was to undertake the experiment 'well worthy of trial' to see if 'the Factitious Air of fir'd Gunpowder was endu'd with any Quality differing from Common Air.'[137] To conduct the experiment he put a 'candent iron' (an iron heated white hot) in the vacuum chamber with the

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131 From The Royal Society Archives. "Concerning the pump exhausted by means of gunpowder by Papin," Read to the Royal Society 26 October 1687, Ref CI.P/18i/62.

132 Hall, *Ballistics*, 64.

133 These theories of gunpowder detonation, based on the air and its products, are cogently explained in: Mauskopf, "Gunpowder and the Chemical Revolution."

134 Anthony van Leuwenhoek, "The Extract of a Letter from Mr. Anthony Van Leuwenhoek, S.R.S. to the R. Soc. Containing several observations on cinnabar and gunpowder," *Phil Trans* (1693), 754-60.

135 Leuwenhoek, "cinnabar and gunpowder," 759.

136 Fr. Hauksbee, "An Account of an Experiment Made Decemb the 26th, 1704. To Try the Quality of Air, Produc'd from Gunpowder, Fir'd in Vacuo Boyliano," *Phil Trans* 24 (1704-05), 1807-09.

137 Hauksbee, "Quality of Air," 1807.

mercury gage at 29 ½ inches. When the first grain of powder was dropped onto the iron, the explosion caused the mercury to drop one inch. This procedure was continued through 32 grains of powder, and the mercury fell to just under thirteen inches. After the explosions, the gage continued to rise again. Hauksbee concluded that the air produced from the gunpowder is 'actuated by heat and cold as common air.'[138] He reaches this conclusion by observing that when he puts his warm hands on the receiver the mercury descends, and rises when returning to the temperature of the air outside. In the experiment he showed that the explosions of consistent quantities of gunpowder 'should be greater when resisted by air, than *in vacuo*, where nothing seems to hinder the extension of their flame.'[139]

The gunpowder experiments of these inquirers, especially Papin and Hooke, show a deep understanding of the need to marry experiment and theorising. In contrast, the collective nature of the Royal Society hindered genuine Baconian investigations. The organisation as a collective may have been engaged primarily in low-level literate experience, but certain more tenacious fellows did not let the pretence of corporate unity prevent them from conducting *experimenta lucifera.* The gunpowder experiments of Papin are perhaps the closest thing we see to a genuine research project on gunpowder within the early Royal Society. They demonstrate focus, consistency, and a blend of both operation and speculation aimed at the understanding of gunpowder's causes.

External Factors and The Decline of Gunpowder in the Early Royal Society

Having looked at how the internal dynamics of the Society inhibited a more focussed and ultimately more Baconian programme of research, in this section we consider some of the external factors. Social and practical factors proved to be major obstacles in the sufficient carrying out of gunpowder research. Finally, we look at the Royal Society's more extensive projects with gunpowder in the late eighteenth and nineteenth centuries. The later fellows, as I will show, were interested in

[138] Hauksbee, "Quality of Air," 1809.

[139] Hauksbee, "Quality of Air," 1809.

gunpowder for largely the same reason as their predecessors. Yet they were highly critical of the early Society's efforts, which they saw as erroneous and ineffective.

Social and Political Factors

It is possible that the hesitance to really engage with gunpowder could have had socio-political motivations. Werrett demonstrates how pyrotechnics came to be associated with Catholicism and sedition in the aftermath of the gunpowder plot, and also the great fire of London in 1666.[140] He argues that the efforts of natural philosophers to experiment with gunpowder and fireworks were part of an effort to neutralise these concerns, claiming that the mystery of pyrotechnics could be reduced if only they were to be rendered as nothing more than the result of natural and explicable causes. As we know from Sprat's *HRS,* and as we saw in Chapter 4, the gentlemen of the early Royal Society were desperate to distance themselves from any contamination by religious and political sectarianism. They were a society, and societies in this period often had political and religious orientations at odds with traditional views. But if gunpowder could be turned to other uses, then its well-deserved negative connotations might be overcome. Nevertheless, any cause for suspicion could be addressed by demonstrating that they were not working on gunpowder for seditious ends but for human welfare.

It is also the case that the immediate need for improved and multiplied stores of gunpowder was perhaps not felt so strongly as it had been in the middle of the century. From the 1660s England was in a period of relative peace. The monarchy had been restored after a bloody civil war. The peace was interrupted later in the century, with the Glorious Revolution in 1688. By that time, the Royal Society's experimenting with gunpowder was mostly aimed at calculating its expansive energy imparted on ignition. There was less interest in, for example, saltpetre generation and the procurement of gunpowder. The Society in its founding years operated in a period of relative stability, in contrast to Samuel Hartlib and his correspondents who worked in the midst of a Civil War that saw the future of the English monarchy at stake. The latters' utilitarian efforts were driven by a very real need gunpowder in the midst of war.

[140] Werrett, *Fireworks,* 73-101.

That gunpowder would of course always retain its principle function as an undeniable power on the battlefield was beyond dispute. Raffaelo Vergani conducted a 'reappraisal' of perceptions regarding the uses of gunpowder in civil industries – particularly in quarrying and mining.[141] He emphasises the difference between these more productive uses of gunpowder and its more obvious destructive capacity. The destruction of mines and rocks was a productive industrial activity, and gunpowder helped to speed up this important work as it destroys rocks quicker than manpower alone. Considerations of gunpowder's evident expansive force raised the question what more could it be made to do? Part of the value to be gained from bringing gunpowder a laboratory setting is the opportunity to strip it of common assumptions and associations. Many of the experiments examined so far have shown gunpowder in a radically different setting than contemporaries were used to.

Moral concerns may also have dissuaded the Royal Society for engaging more effectively with gunpowder. The substance was destructive. It took lives and destroyed on a horrific and massive scale. Roy Wolper has argued that gunpowder had a difficult status when it came to early modern ideas of progress.[142] His comments on the paradoxical rhetoric associated with gunpowder are worth consideration. He argues that while gunpowder's obvious power signalled technological progress, its progressive status was rendered dubious by the fact that so many people came to harm by it.[143]

Wolper does not explore the capacity of gunpowder to generate knowledge, which I argue, was an effective way to combat its negative associations. As a novel venture, the Royal Society required public support for its Baconian goals. Expanding gunpowder's uses into non-military territories was one way to overcome its negative image. It could demonstrate its value to other scientific communities and the public by making marvellous new inventions, such as Petty's proposed flying machine, and by furthering knowledge. If successful it would have been able to show that its method could do what opposing methods could not. An old substance could do new

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141 Vergani, "Civil Uses of Gunpowder."

142 Wolper, "Gunpowder and Progress."

143 Wolper, "Gunpowder and Progress," 593-97. He does note that generating knowledge was used to justify gunpowder (along with its ability to defend good Christian lives), but interprets this as allowing scholars to blast their way into hitherto untraveled territories and learn new things there. He does acknowledge in a footnote that some scholars connected gunpowder to meteorology, but nothing beyond that.

things simply by altering how we study it. But we also have seen plenty of examples of military experiments with gunpowder. I have argued that this was mainly owing to the prevalence of certain individuals whose immediate interests overrode more corporate interests.

The Royal Society to some extent attempted to neutralise gunpowder by considering other ways to harness its power. Papin was especially interested in transforming the traditional uses of the substance, through systematic research and mechanical invention in the laboratory and beyond. He tells us that part of the motivation behind Huygens's gunpowder engine is the problem 'about making a better use of gunpowder than hitherto hath been done,'[144] and that 'it is certain that it is a thing of great consequence to be able to apply the force of fire.'[145] He further wrote, that 'turning to the use of Men the great strength of the gunpowder which had hitherto scarce been imployed but to their destruction, is such a noble and generous design.'[146]

These moral concerns about gunpowder were not new to the world of scientific organisations. Some decades earlier Cheney Culpepper wrote to Hartlib about a town that provided the King of Spain with gunpowder, telling how saltpetre was made 'in that little dominion.'[147]

> My opinion is that Matter, by which men are killed & fedde, is but one & the same, & differs onely in the minde & hande that uses it […] My desires are that (towards the last and best use of salpeter) you woulde (If it Lyes in your way) informe your selfe from Hamborough, whether there be any such artificiall way at Hamborough of making salpeter. What the materials, the manner of mixing them, & such other circumstances as can be knowne. For I am perswaded that God will goe beyond the [devil] in his owne Materials of Destruction, by Changinge the use of them into a blessinge, For that is moste agreeable to his power & [goodness], to rayse best out of worst by changing onely the use.[148]

[144] Royal Society Archives. Denis Papin "Use of gunpowder to raise weights," Ref : CI.P/18i/65.

[145] Royal Society Archives. Denis Papin "Proposals about the machine for raising water by the force of fire by Denis Papin," Ref: CI.P/18i/85.

[146] Royal Society Archives. Denis Papin, "Paper on a machine to raise weights by gunpowder," (Sent by Denis Papin to Edmund King 1688), Early Letters P1 1660-1725, Ref : EL/P1/ 1688.

[147] Copy Letter in Scribal Hand G, Cheney Culpeper to Hartlib, 18 Feb 1653, in *The Hartlib Papers Online,* Ref: 39/1/5A-B.

[148] Copy Letter in Scribal Hand G, Cheney Culpeper to Hartlib, 18 Feb 1653, in *The Hartlib Papers Online,* Ref: 39/1/5A-B.

Culpeper's concerns are economic and moral; both of which involve a reinterpretation of gunpowder procurement. It is true that saltpetre, by virtue of its inclusion in gunpowder, was destructive and capable of taking lives. Yet Culpeper encourages Hartlib to set about investigating this method of artificial saltpetre generation that has proven to be successful. To use such a method in England could bring economic prosperity, as well as the required stores of the material. We can also see in this passage the moral problems associated with gunpowder. Some perceived gunpowder as dangerous and unnatural, but it could be used for good if its energies put to a more productive cause; swords could be turned into ploughshares, as the biblical saying goes.[149] As explained by Stephen Clucas, Culpeper studied many issues, not always with great authority, yet 'his letters often provide a useful commentary on contemporary matters.'[150] This passage, like many of Culpeper's works, combines his chemical and political interests.[151] With that in mind, this passage may be even interpreted as a commentary on warfare, which in another letter to Hartlib concerned with gunpowder, he describes as 'unnatural'.[152] Gunpowder's frightening destructive power could not be avoided, but it could perhaps be balanced out by clever minds capable of altering its uses and perceptions of it.

Finally, to return to a point that has already been discussed above, gunpowder was common and lowly. It was difficult for gunpowder to shake off its obvious persona as dangerous, filthy and unsuited to gentlemanly pursuits. As much as gentlemen could be persuaded to tinker with microscopes and mechanical devices, gunpowder was beneath them. They were not going to put themselves in the role of common artisans. Gunpowder did not have the prestige or novelty status shared by phosphorus for example. It was not a new and exciting curio; it was an everyday

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[149] Culpepper does use this saying in reference to gunpowder and saltpetre, see: M. J. Braddick and M. Greengrass, "The Letters of Sir Cheney Culpeper (1641-57)," *Camden Fifth Series* (1996), 105-402, on 226-27.

[150] Stephen Clucas, "The Correspondence of a XVII-Century 'Chymicall Gentleman': Sir Cheney Culpeper and the Chemical Interests of the Hartlib Circle," *Ambix* 40 (1993), 147-70, on 147. It should also be noted that, as explained by Clucas, the strictly puritan Culpeper rejected empiricism, 153.

[151] Culpeper was involved in the Hartlibian puritan project for advancing the human condition, and he was also interested in the improvement of saltpetre stores. As such he was interested in Glauber's work, and he was involved in Worsley's project: Clucas, "Chymicall Gentleman," 150-56, 159-60. For more on the intertwining of his political, religious and chemical interests: Braddick and Greengrass, "The Letters of Sir Cheney Culpeper," 136-50.

[152] Braddick and Greengrass, "The Letters of Sir Cheney Culpeper," 226-27.

material used by gunners. Indeed gunnery was far from a highly respected profession as illiterate and uneducated commoners generally carried it out. Anybody could learn to load and fire a musket. Archers, on the other hand, took years of training to become genuinely skilled. It can hardly be denied that in spite of their personal use of weapons and their familiarity with firearms in hunting and battle, the gentlemanly fellows simply did not see tinkering with gunpowder as a worthy pursuit.

As an experimental project, gunpowder in the early modern period was problematic, it was dangerous, filthy and commonplace yet at the same time it was far too useful to ignore. One way to combat this was to find other ways to apply its powers. From the foregoing it seems undeniable that the failure to engage with gunpowder was at least partly owing to moral and social reservations. Others, such as Papin, rose to the challenge of transforming perceptions of the such a paradoxical material based through his alliance of practical endeavours with theoretical speculation he too was driven by a motivation that lay at the heart of the Baconian enterprise to harness the powers of nature for human utility and a deeper understanding of those hidden powers.

Practical Problems

Regardless of their diverse interests and intentions, the handling gunpowder posed several practical problems for seventeenth-century natural inquirers. Rumford, writing in the late-eighteenth century, considered that the dangerous volatility of gunpowder prevented its more adequate investigation. He offered an explanation as to why gunpowder had not been studied as often as it perhaps should have been:

> The explosion of gunpowder is certainly one of the most surprising phaenomena we are acquainted with, and I am persuaded it would much oftener have been the subject of the investigations of speculative philosophers, as well as of professional men, in this age of inquiry, were it not for the danger attending the experiments: but the force of gunpowder is so great, and its effects so sudden and so terrible, that, notwithstanding all the precautions possible, there is ever a considerable degree of danger attending the management of it, as I have more than once found to my cost.[153]

[153] Rumford, "Force of Fired Gunpowder," 222.

These concerns are clearly expressed in the records of early experimenters in the Society. When trying to make gunpowder raise a weight by harnessing its energy in a spring, 'the weight was thrown off, instead of being raised.'[154] When trying an experiment influenced by Papin to ignite gunpowder *in vacuo* and study the air, the powder melted into a 'lump' which ignited so violently that it 'burst his glass into a thousand pieces, and stuck great part thereof into the ceiling.'[155]

On more than one occasion gunpowder's violent explosive tendencies inhibited the fellows' endeavours.

> Sir Robert Moray remarked that in this experiment it was to be considered, how the impetus of the gunpowder might be so ordered as not to break the bodies tried, and that if that could not be done, then to make a compound which might move strongly enough, and yet slowly.[156]
>
> Dr Wren moved, that this experiment might be tried by laying within a pair of bellows, with a weight upon it, a serpentine line of powder, to make it fire with such a degree of velocity, that it should break nothing; adding that if the concussion be made too quick for the vibration of parts, the body tried must break.[157]

The problem was that gunpowder moved too swiftly and with too much force to apply it in this manner. To make gunpowder useful in industry, they had to find a way to control and slow down its motions. It is likely then that a contributing factor to gunpowder's lack of attention was the thing that made it interesting. It was too dangerous and untameable to really get to grips with it.

It is worth noting an isolated instance, although we must bear in mind that this was a one-off observation, whereby Boyle offered a potential reason for an experimental failure. He mentioned that the gunpowder might be damp owing to it being carried in the operator's pocket.[158] If true, this demonstrates a remarkable lack of knowledge of how to handle gunpowder. Those familiar with it would likely use a powder horn or other appropriate container to hold their supplies. Thus the non-military contingent possibly did not have the practical experience of working with

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154 Birch, *History,* II, 146.

155 Birch, *History,* IV, 470.

156 Birch, *History,* II, 146.

157 Birch, *History,* II, 147.

158 Birch, *History,* I, 452

this particular material, known to be volatile and dangerous, in order to develop it into sophisticated experiments of light. Gunpowder was a philosophically valuable material to bring into the seventeenth-century laboratory, but it was by no means an easy one to work with.

Into the eighteenth century

The work of Papin and his colleagues that connected gunpowder so intimately with the air represent a turning point in approaches to gunpowder in the Royal Society. From the mid-eighteenth to late-nineteenth centuries, several extensive publications on gunpowder chemistry are published in the *Phil Trans.* All of which draw upon the emerging understandings of the nature of the air. Whilst we definitely see more focussed projects on gunpowder come into play, however, that initial variety of the early Royal Society is lost. The point of gunpowder research returns to having a completely military focus.

Brett D. Steele describes the period 1742-53, the period between the publication of *New Principles of Gunnery* by Benjamin Robins and the translation and extension to that work written by Leonhard Euler, as the period wherein ballistics was 'revolutionised.'[159] Robins's work conjectured an explanation of gunpowder based on the theory that on ignition gunpowder was 'instantly transformed into an elastic fluid or compressible gas'.[160] Further, he invented the 'ballistic pendulum' to assess the velocity of projectiles.[161] Steele summarises that in just 'eleven years, Robins and Euler dramatically increased the predictive power of ballistics by constructing theoretical and empirical foundations.'[162]

Scholarly work on gunpowder continued in this manner. In 1779 Jon Ingen-Housz presented his work on gunpowder in the *Phil Trans.*[163] He drew heavily on contemporary chemistry of the air, particularly the phlogiston theory of Joseph

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159 Steele, "Muskets and Pendulums," 348.

160 Steele, "Muskets and Pendulums," 348.

161 Steele, "Muskets and Pendulums," 358-59.

162 Steele, "Muskets and Pendulums," 350.

163 Ingen-Housz, "Imflammable Air or Gass."

Priestley.[164] Ingen-Housz was unhappy with explanations of gunpowder's causes, like those produced by Robins, that draw upon the notion of a large amount of an 'elastic fluid' contained within the material. He laments:

> this explanation does not convey a clear idea of the manner in which the extrication is carried on; nor of the reason why one single spark of fire, thrown into an immense heap of gunpowder, should almost in an instant spread the conflagration throughout the whole mass. Neither does it explain clearly, why nitre and charcoal (which separately yield no flame at all, through ever so much heated) when combined and intimately mixed together, explode with as loud a report as a large ordnance piece, surpassing even in loudness thunderclaps; nor why this forcible explosion is accompanied by a most brilliant flame.[165]

He concludes that the 'generation of dephlogisticated and inflammable air by the inflammation of gunpowder is the reason why this ingredient is almost the only one known, which does not want a free access of common air to be consumed by fire; and therefore it may be said to feed, as it were, upon its own air.'[166]

In 1797 Count Rumford presented his views on gunpowder to the Society.[167] He argued that the methods of Robins were not capable of determining the 'initial force of gunpowder.'[168] Rumford complained that gunpowder deserved more, and better quality, attention than it hitherto had received, noting that the contemporary advances in chemistry had offered the conditions to radically transform knowledge of gunpowder and its components. Such research is important, he maintains, as 'the use of gunpowder is become so extensive, that very important mechanical improvements can hardly fail to result from any new discoveries relative to its force, and the law of its action.'[169] Even a century later, the Royal Society continued its earlier conviction that gunpowder's energies could be harnessed to great effect if only they were properly understood.

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164 Ingen-Housz, "Imflammable Air or Gass," 377-78. This theory posited that an oxygen-like substance called 'phlogiston' was given off by bodies during combustion.

165 Ingen-Housz, "Inflammable Air or Gass," 395.

166 Ingen-Housz, "Inflammable Air or Gass," 404.

167 Rumford, "the Force of Fired Gunpowder."

168 Rumford, "the Force of Fired Gunpowder," 223- 24.

169 Rumford, "the Force of Fired Gunpowder," 227.

In 1858 L. Thomas reviewed previous attempts to study gunpowder in the Royal Society, citing Leuwenhoeck, Hauksbee and Robins, among others. [170] He remarked critically that while ‘each of the eminent persons contributed largely towards the development’ of gunpowder, it was the result of their ‘limited knowledge of the initial force and action of fired gunpowder’ that ‘their theories remained imperfect.’[171] Even as we approach the nineteenth century, gunpowder remained contentious for the Society. The still valued substance was the subject of ‘The Bakerian Lecture’ given by H. Debus in 1882.[172] Indeed this occurred during the later stages of the transition from black powder to modern nitro-cellulose propellants. Debus in the lecture sought to outline a theory explaining the chemical reactions that occur both during and after the ignition of gunpowder. By this time, Debus is using the chemical terminology and equations that we would recognise today.

The Royal Society’s work on black powder culminated in 1875. Noble and Abel presented a mammoth two-part analysis of fired gunpowder in the *Phil Trans.*[173] They were working for a committee put together by the Secretary of State for War. The Secretary wanted to delineate ‘the most suitable description of powder for use in heavy ordnance, which is still continually increasing in size.’[174] Reflecting, they observed until just before their own time, ‘discordant opinions have been entertained as upon the phenomena and results which attend the combustion of gunpowder.’[175] They are critical of Robins and Rumford, whose results are radically varying, and note that even ‘modern interpretations’ are inconsistent.[176] This is why Noble and Abel think their own work could be useful, and should come after a description of what had gone before.

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170 The Royal Society Archives, “On the nature of the action of fired gunpowder by L. Thomas,” Nov 17, 1858. In “Archived Papers” Ref: AP. 41.8.

171 The Royal Society Archives, “On the nature of the action of fired gunpowder by L. Thomas,” Nov 17, 1858. In “Archived Papers,” Ref: AP. 41.8.

172 H. Debus, “The Bakerian Lecture: Chemical Theory of Gunpowder,” *Phil Trans* 173 (1882), 523-594.

173 Noble and Abel, “Researches on Explosives;” “Research on Explosives. No. II.”

174 Noble and Abel, “Researches on Explosives,” 49-50.

175 Noble and Abel, “Researches on Explosives,” 50.

176 Noble and Abel, “Researches on Explosives,” 50.

The experiments on eighteenth- and nineteenth-century gunpowder show some familiarity with their predecessors. They continued the shared programmatic view that gunpowder's effects were so profound and practically important that no effort should be spared in analysing its chemical nature and causes with a view to harnessing its power in all possible ways. Yet the later experimenters were oftentimes unrelentingly critical of the work of their predecessors. In fact they were often ignorant of the details of the earlier work and, moreover, had little interest in considering the historical context and its complex restraints. The earlier work on gunpowder did not fulfil the promise signified by the inclusion of Henshaw's Baconian history in Sprat's apologia for the nascent Society, and so it is correctly deemed to be insufficient. In contrast to the progressive rhetoric of later critics, this chapter has offered historical explanations for the failure to pursue what was evidently of paramount importance.

Conclusion

The goal of this chapter has not been to argue whiggishly that inquiry into gunpowder's properties and effects ought to have proceeded at a much quicker rate. Rather, given the auspicious treatment of gunpowder in the Society's propaganda that we saw in Chapter 4, I argue that for gunpowder to have been studied only in a piecemeal manner in the Society's actual experiments is surprising. Dear argues that 'the various "theoretical" positions held by [the Society's] members were far too diverse for a consensus to be possible except in a very general way.'[177] The example of gunpowder supports Dear's view. A genuinely Baconian study of gunpowder was hindered by a blend of factors pertaining to the eclectic dynamics of the Royal Society, in addition to the inherent challenges of gunpowder itself.

A material that was heralded as a key to understanding matter's occult powers received comparatively little attention from an institution that claimed to be devoted to enacting Bacon's *great instauration.* This is surprising for the historian of science. I have argued that the fellows were not inclined to invest in a more cohesive Baconian goal when it came to a dangerous and morally and politically suspect material. Further, I have attempted to shed some light in the complex blend of

[177] Dear, "Totius in Verba," 157.

internal and external factors that prohibited gunpowder from receiving the treatment that Count Rumford and his contemporaries thought that it merited.

The sporadic and piecemeal nature of the early Royal Society's gunpowder experiments would not seem so alarming if it had not been for gunpowder's inclusion in Sprat's public appeal. These self-proclaimed Baconians in possession of a Baconian history on gunpowder did not continue the programme that they had started. Gunpowder was presented as one of the important topics that the Royal Society's method would be capable of tackling and turning to the use of mankind. Whilst the gunpowder experiments inside the Society walls did pursue *experimenta fructifera* with the potential to advance the material's practical applications, the over reliance on the practice part of Bacon's project meant that these fruits never quite came to fruition.

Jardine's claims that some scholars preferred the more utilitarian side of Baconianism and engaged themselves in *experientia literata* are vindicated through this examination of gunpowder. The knowledge and experience from one experiment is extended to produce another. There was little in the way of trying to increase understanding of gunpowder so that it would generate fresh knowledge and novel inventions. The project was focussed mostly on utility. There is cohesion in the sense that philosophers were beginning to focus on the air and expansion of gunpowder in their search for understanding the material. But these philosophers were not working together. This was not a designed or unified project.

A final factor to consider was the changing focus of the Society's researches around the turn of the eighteenth century. It is also possible that other successes, such as Isaac Newton's more public interests, shifted attention away from the chemical and onto the more mathematical. Indeed, as Thomas Kuhn has pointed out, there was a 'tension' between the two styles of seventeenth-century science.[178] These constantly shifting foci were certainly an important factor preventing a more detailed analysis of gunpowder by the virtuosi. Perhaps this powerful and important material, subject to so many internal and external contingencies, not the least of which were the challenges in simply handling it, required more sustained attention preferably from the State. As it was, the very nature of the early Royal Society, a corporation

[178] Thomas Kuhn, *The Essential Tension: Selected Studies in Scientific Tradition and Change* (Chicago and London: University of Chicago Press, 1979). See Chapter 3: 'Mathematical versus Experimental Traditions in the Development of Physical Science,' 31-65.

comprising diverse and often incompatible interests that diverged even more as the century wore on, inhibited such a project from materialising in any governed and systematic way.

Conclusion

> If this wonderful and awful ingredient had not been discovered by accident, could the secret have escaped a long while the penetration of our modern philosophers […] without any regard to the known properties of gunpowder?[1]

I have argued that the putative Baconians of the seventeenth century transferred gunpowder from the battlefield to the laboratory. This relocation was both physical and mental. Not only did they have to practically work with gunpowder in the experimental space. They also had to reinterpret and re-envision the material. When made the subject of study by Bacon and his followers, gunpowder took on a new persona as a philosophical material; and this persona was multifaceted. Bacon, Boyle, the Hartlib Circle, and the early Royal Society all employed gunpowder in ways consistent with their own particular interpretations of Bacon's project. In the nascent seventeenth-century experimental philosophy in England, gunpowder simultaneously fulfilled programmatic, inquisitional, and symbolic roles.

I have demonstrated why there was both philosophical and practical interest in gunpowder. The natural philosophers were interested in what gunpowder could be made to do and what it could be made to tell us. Bacon and his colleagues saw gunpowder as an example of the huge forces currently lying dormant in nature. To study gunpowder, as Bacon and Boyle realised, would be to study the powers of matter. Understanding these powers would eventually lead to power over them; an ability to manipulate them for the benefit of man. Such fruits were the goal of the *great instauration*, but they could only be achieved via systematically acquired knowledge. Gunpowder was a locus of both theory and practice, and experimental procedures had begun to unveil its manifold potential. This is why there was a growth of interest in gunpowder outside its normal use.

It has been the goal of this thesis to clarify the role played by gunpowder in seventeenth-century experimental natural philosophy. The vast majority of gunpowder commentators, as shown in detail in the introduction, focus on the

1 Ingen-Housz, "Account of Inflammable Air and Gass," 406.

material as a social and political commodity. They examine its origins and procurement, its necessity to the state, and its application in the arena of war. In contrast, I have shown a hitherto unexplored side to gunpowder whereby it occupied an important but complex position at the vanguard of the emerging experimental philosophy of the seventeenth century.

Through the central focus of gunpowder I have covered several key themes. Central to our understanding of the philosophical applications of gunpowder is the blend of theory and practice that characterised Bacon's vision for natural philosophy. It was precisely this experimental mode of inquiry that brought together hand and mind in a fruitful union that enabled gunpowder to uptake this new range of philosophical and practical uses. Secondly, the range of case studies analysed here has gone some way to demonstrate the importance of the study of materials in understanding the emergence of early modern science. Having a material substance as a central focus does a great deal to elicit the varying roles that substances could play in early experimentalism. The importance of materials in scientific inquiry is not of course peculiar to the early modern period. All the more reason for unearthing their rise to prominence and correcting the one-sided view of natural philosophy as solely a matter of knowledge production. Furthermore, the use of reworking as a methodology enables us to greatly enhance our understandings of these materials and how they were transposed to the natural philosophical world. Thirdly, the focus on gunpowder has proven insightful in highlighting the gulf between Baconianism as promoted by Bacon and Baconianism as interpreted by his followers. That Bacon, Boyle, and Hooke aimed to generate knowledge of gunpowder before works, and that their colleagues in the Hartlib Circle and Royal Society jumped straight to gunpowder's utilitarian potential, evinces that differing styles of Baconianism were at play in seventeenth-century England.

I have argued that the first role played by gunpowder in the nascent seventeenth-century experimental philosophy was programmatic. We are studying gunpowder in relation to the Baconian philosophy and its all-important novel method of inquiry. It is important to keep in mind that historians are fully aware that Bacon's *instauration* demanded a departure from the philosophy that had gone before, which he and his followers criticised for being based in speculation with little payoff in terms of works. What is far less understood is that not everyone who acknowledge the great Verulam as a preceptor recognised that his departure demanded both contemplation and operation. This as we have seen is evident in the way that Bacon, Boyle, and the Royal Society all used gunpowder to demonstrate their own protocols of inquiry.

A central claim in this thesis is that the split between theory and practice in Bacon's programme is exemplified by gunpowder. Bacon's method had a marriage of theory and practice at its heart, and this marriage was clearly understood and embraced by Boyle and Hooke.[2] Others, as we have seen in the chapters dealing with the early Royal Society, paid no more than lip service to this ideal. They were less invested in the marriage of theory and practice, and more interested in the works and social acceptance that experiment and practice had the potential to generate. As put by Rees, 'after 1640 Bacon's writings were more than ripe for selective appropriation […] for they offered an ideology of remarkable consistency and force that could be adopted flexibly and piecemeal in the service of incompatible causes.'[3]

Bacon and Boyle engaged primarily in *experimenta lucifera.* Their aim was to use experiment to reveal knowledge of causes that could eventually be applied in the production of useful works. Boyle was Baconian in this sense, but we must not lose sight of his departure from his forebear. Firstly, as shown in Chapters 1 and 2, Boyle and Bacon profoundly differed in their approaches to matter. The importance of this disparity cannot be overstated. Matter is the stuff that makes up the world as we experience it. To even broach a comprehension of matter, however, it has to be worked with practically and manipulated. The work conducted in the laboratory by Boyle and Hooke would allow them to explicate the novel effects, using their preferred theories of matter, produced by their manipulations. Laboratory work is essential in Boyle's theorising because the laboratory is a distinct space whereby he can unite operation and contemplation; both of these must be used at all stages of the Baconian method.

Moreover, Boyle's programme was much more chemically inclined than was Bacon's. Chemistry was what made his interpretation of Bacon's *great instauration* novel. To classify Boyle as a meagre and full-on follower of Bacon's doctrine would

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2 Anstey, "Philosophy of Experiment." Anstey calls the philosophy of experiment as shared by Bacon, Boyle and Hooke the 'BBH' view of experiment. He looks at the similarities between the approaches of each philosopher, such as their distaste for overly speculative philosophies, and their focus on using experiment to produce knowledge.

3 Graham Rees, "Reflections on the Reputation of Francis Bacon's Philosophy," *Huntington Library Quarterly* 65 (2002), 379-94, on 380.

be a gross error. Nonetheless the fundamental ethos of Boyle's programme, using experiment to produce natural knowledge and then works, was undoubtedly Baconian. Gunpowder shows how both men interpreted matter and its potential powers, and how they wanted experiment to be carried out. Each understood clearly that only experiment had the power to elicit novel phenomena—those effects that nature left to itself would never produce. These phenomena could provide a realistic foundation for the eventual production of great works.

The Hartlib Circle and the early Royal Society sought utility in gunpowder. In their more practice-oriented programmes, they strayed from Bacon's original texts. They made the compiling of natural histories and the gathering of information the core of their main project. Whilst natural history was to form a key early stage in Bacon's method, their projects lacked the cohesion, theorising, and organisation that Bacon had envisaged. The virtuosi were too keen to engage in *experimenta fructifera* and start producing the works that Baconianism promised. By concentrating on fruits too early in the process, they could never have ascended the ladder of inquiry and reached what Weeks has called 'philosophical mechanics.'[4] In effect they remained at the level of literate experience, whose basis, as we have seen, rests in the extension of artisanal craft knowledge. The process of systematic induction, that is the drawing of high-level axioms that cut across a wide range of natural phenomena, was never within their reach. It was not only the early inquirers in the Hartlib circle who fell short of Bacon's strict protocols. Malherbe rightly claims that many 'members of the Royal Society claimed kinship with the author of the *Novum Organum,* but ignored Baconian induction as a scientific method.'[5]

Bacon and Boyle used gunpowder in highly significant areas of scientific inquiry and indeed in attempting to fulfil the very aspirations of the experimental method. They engaged with gunpowder and manipulated it at a high theoretical level with every intention of understanding its occult causes. The institutional Baconians, by contrast, had a corporate façade to maintain and wanted products to show for their efforts. They worked toward more economical ways of making gunpowder's components, and on devising clever ways to quantify and harness gunpowder's useful energy. They alluded to the fact that understanding the nature, rate, and speed

4 Weeks, "Mechanics," 134.

5 Malherbe, "Bacon's method of science," 75.

of its expansion on ignition would be the key to introducing a new range of practical mechanical applications for gunpowder.

Unfortunately, the theory part of Bacon's equation was outweighed by the practice, and these novel proposals were not given the tenacious treatment and repetition that they needed to be brought to fruition. This is most probably because failure was not treated as an important stage in Baconian inquiry. Concern with immediate fruits and economic factors in the face of public criticism overrode Bacon's emphasis on the contribution of failure to furthering inquiry. Boyle's works on the other hand report fastidiously his failures as a fact that he no doubt owed to his understanding of its importance in Baconian terms.

The second major role of gunpowder in seventeenth-century experimental philosophy was inquisitional. Bacon and Boyle reconfigured gunpowder as a tool of inquiry. They used their experiments and musings on gunpowder to speculate on nature and produce knowledge. To do this, they brought it into the experimental domain. As a philosophical material, gunpowder was stripped back. Its important uses in warfare were by no means forgotten, but these were conceived as just one way in which the substance could be appropriated.

Bacon and Boyle both used gunpowder in inquiry; inquiring into, for example, effluvia, natural magic, and combustion/ respiration. With particular fervour, they also employed gunpowder in exploring and explicating their theories of matter. As we saw in Chapter 1, Bacon understood gunpowder's forces as evidence of the collaborations of simple motions from opposite quaternions. For Bacon, gunpowder could assist in explicating the manifold and powerful potential of matter. It promised a command over nature's hidden powers. Boyle used gunpowder in this capacity because the combined effects of gunpowder's components were in great excess of what they could do separately. Thus gunpowder was used by Boyle, as we saw in Chapter 2, to explore and support his corpuscular theory, which was based on the premise of properties of bodies being produced by arrangements and interactions of corpuscles. Gunpowder gave Boyle the opportunity to investigate, in his laboratory, the occult but powerful properties of matter. Both Bacon and Boyle studied many phenomena and materials. However, owing to the unique power and ferocity of gunpowder, in addition to its massive power as an artificially mixed substance, it was especially important. Such power was normally only found in natural phenomena, for example, earthquakes and thunder and lightning. Yet these phenomena could not be physically transported into Boyle's laboratory for closer examination; gunpowder, on the other hand, could. Gunpowder's inherent properties made it the ideal inquisitional material. This is why the early moderns made the effort to elevate this quotidian, filthy and workaday material to the level of philosophy.

Even though few of the Royal Society's efforts were brought to any satisfying conclusion, their gunpowder experiments did steer towards important avenues of inquiry. The efforts to test gunpowder's expansion using the eprouvette, metal containers, and springs, would certainly have had important practical implications if successful. Lacking the tenacity demanded by Bacon, they nevertheless also asked probing questions about gunpowder's nature and forces. These questions were not pursued with sufficient commitment by the Society until the 1680s and 90s. Even then, this was only in a few isolated readings and papers in the *Phil Trans*. In spite of a lack of institutional support, Papin's efforts continued the work of Boyle on developing an aerial account that would explain the effects of gunpowder.

Gunpowder has been used as an example to show the complex and important roles played by materials in the history of science. Materials came into the laboratory with their own baggage and associations that made an impact on how they were approached. When materials were studied, they were studied for specific reasons, and they offered specific challenges and benefits to the scholars that employed them. Everything from the social status of materials to their inherent properties impacted on how they were utilised and interpreted in natural philosophy.

Materials remind us about the practice part of the theory-practice equation that characterised Baconianism. It is much easier to focus on the acquisition of knowledge but we must be aware how important experiment/practice was in producing this knowledge. Baconian knowledge and works absolutely had to be born of practical experience. This was the only way, according to Bacon, to gain genuine insight into nature's workings. However, experiment as a methodology was far from uncontested in the seventeenth-century, and we must keep this in mind. Materials, as opposed to ideas, had to be handled as well as interpreted. Their handling required particular tacit skills and a set of mental attitudes for engaging with them that was beyond the everyday experience of the virtuosi. If hands-on studying of materials was to be the basis for the new sciences, then skills and techniques hitherto belonging to despised crafts and trades would have to be elevated to experimental and philosophical status. Furthermore, focussing on substances such as gunpowder calls into question any clear boundaries between scholarly experiment, practice, and the everyday manipulation of materials. Gunpowder serves to remind the historian of science, who is more used to dealing with scholarly ideals than the handling of materials, of the procedures that were essential if an experimental philosophy was to become a cultural reality. It is a serious oversight to overlook the novel historical integration of ideas and practices that, if not always adhered to, at least provided an ideal for early modern natural philosophers.

The Baconian method demanded an on-going feedback between hand and mind, and this is why Weeks depicts the method as 'cybernetic inquiry.'[6] The practitioner goes from observation to experiment and back and forth between the two, as both the theories and the practices become more and more refined. Mistakes will accrue, and they are a crucial part of inquiry as they signal where the processes are to be redirected. The practical experiences and observations inform the speculative part of the procedure, and this is on-going until an appropriate conclusion is reached. I have argued that we need a greater appreciation of the wide-ranging process of experiment, and that reworking historic procedures helps us to access this. It was not as simple as gathering apparatus and doing an experiment. It required planning, skills, interaction, and reflection. In contrast to Schaffer and Shapin's now dominant view of early modern experiment,[7] I argue that experimentalism was about much more than the securing of a particular form of knowledge over competing systems. Actually working with materials raised questions for the experimentalists, and in carrying out material processes they were given answers. This is the knowledge that would lead to practical innovation.

I have also argued that reworking historic experiments highlights the complexity and challenges of experiment. The virtuosi had to attempt to combine the radically different worlds of scholarship and craft practice. Reworking gives us a better sense of what our authors were actually talking about. It is not until we rework an experiment that we can truly grasp and envision the complex procedures that our texts attempt to describe. These descriptions can often seem abstract, even with

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6 Weeks, "Mechanics," 179-80.

7 As presented in: Shapin and Schaffer, *Leviathan and the Air-Pump.*

materials as basic as gunpowder. There is much detail left out of the text, and it is the case that terminology and equipment has changed over the years.

To study materials gives insights into the environments of knowledge production. In contrast to the social constructivism of Shapin and Schaffer,[8] a Latour inspired approach provides more credence to the importance, and revelatory and inquisitional powers of, experiment.[9] It is true that a material item, the air-pump, is the central protagonist in *Leviathan and the Air-Pump* but the authors do not give a sense of what was involved in laboratory practice. Rather, their observations mostly surround perceptions of it. Their work, although excellent in other ways, overlooks complex aspects of laboratory practice and the accompanying hand-mind relationship that was so essential for the experimental philosophers.

Michael Ben-Chaim has examined the ideas of historians and philosophers of science concerning the relationship between Boyle's theorising and his experimentation.[10] He praises the more recent turn to experimental practice, but he adds 'despite these departures from the theory-centred perspective on Boyle's scientific work, the older view of experiment as a practice that belongs to the general area of epistemology and methodology of science has nevertheless been retained'.[11] Ben-Chaim finds fault with Shapin and Schaffer, Peter Dear, Alan Chalmers and Rose-Mary Sargent, on the grounds that whilst the more recent studies give a 'greater autonomy' to experiment, nevertheless they 'acknowledged that its ultimate value and purpose pertained to epistemic considerations of knowledge-claims'.[12] Arguing against the overriding epistemological focus, Ben-Chaim says that 'the principal intention of Boyle's experimental work was economic', and moreover, it drew theological sanction from God's dominion and goodness.[13] Whilst Ben-Chaim may be correct that Boyle's experimental work derived cultural sanction on theological grounds, that still leaves the issue of what exactly his lifetime of experiment aimed at. I have argued that Boyle aimed at the production of material

[8] Shapin and Schaffer, *Leviathan and the Air-Pump.*

[9] Latour, "Give me a Laboratory."

[10] Michael Ben-Chaim, "The Value of Facts in Boyle's Experimental Philosophy," *History of Science* 38 (2000), 57-77.

[11] Ben-Chaim, "The Value of Facts," 58-59.

[12] Ben-Chaim, "The Value of Facts," 58.

[13] Ben-Chaim, "The Value of Facts," 59.

effects and to that end he adhered to the Baconian prescription for a continual reciprocity between experiment and theorising. It is at this juncture that materials enhance historical understanding of the rise of experiment because without them there is no experimental practice.

Therefore, I maintain that we must emphasise the role of materials (and related material culture) in laboratory practice. Experimentally produced knowledge demanded much more than approval from peers. The physical and interpretive processes were crucial in the formation and explication of the knowledge sought through them. Reworking experiments allows us to have a look inside the laboratory, and to witness its associated experiences. I consider reworking to be a vital contribution to the history of science—not just a bit of fun.

Finally, gunpowder had an important symbolic role to play in seventeenth-century experimental philosophy. Gunpowder, for most of the philosophers discussed in this thesis, represented the potential of the experimental method, regardless of the particular approach taken by the particular scholars. For Sprat and Henshaw, and the Royal Society, gunpowder was employed strategically. They used it to symbolise the utility and relevance of their endeavours. The institution with royal patronage was not interested in studying trifling matters and petty curiosities. It aimed to tackle themes that were pressing on early modern Society. There were few better mediums to showcase its potential value than gunpowder. Everybody knew what it was and its importance to the early modern state.

Considering that procuring and making gunpowder was by no means cheap or easy, any improvements to the procedure was bound to receive further promotion for the Society. Including gunpowder in the *HRS* was a deliberate strategic ploy to attract support within and outwith the experimental community. This symbolic relevance filtered through to the internal workings of the early Royal Society. Most of its experiments with gunpowder aimed to quantify and harness its potentially useful energy. The goal was to uncover ways that existing uses of gunpowder could be improved; or to find ways of applying gunpowder's forces to civil and industrial uses.

One other very significant theme emerges from the focus on materials. Some of the most philosophically valuable materials are ubiquitous and indeed often derived from socially questionable sites: phosphorus and urine; saltpetre and mud/excrement. Indeed, the common occurrence of gunpowder proved to be a central point guiding the efforts of Bacon and Boyle. The fact that such a powerful material was found so widely but still had not been studied with any rigour was an utter oversight, according to Bacon who promoted the study of common everyday materials as a core feature of his programme of reform. The fact that gunpowder was an example of a great work, and one that was so well-known, provided an argument, or a reason, for pursuing the experimental method. The example of gunpowder could draw scholars to the experimental method because the material symbolised the sort of thing that could be invented via knowledge produced in the Baconian fashion. Gunpowder in Bacon's view was a marvel of nature. The fact that it was born of chance only underscored Bacon's view that an infinity of marvels of nature were not outside human grasp if natural inquiry were systematised and state-funded.

An exercise in demonstrating the contribution that materials and artefacts can make in historical analysis has, it is to be hoped, raised questions and suggestions that it cannot deal with here. More time should be given over to the important themes that I have not had the space to develop within the dissertation. For example, it is a great advantage to the historian to get their hands dirty in reworking experiments. Handling materials and artefacts has the capacity to link the historian in a more direct manner than texts, even texts that describe in detail, as Boyle's do, the procedures of early modern laboratory practice. The values of the reworking methodology were related in Chapter 3 and do not need repeated here. However, one point already mentioned above arising from the reworking experience is deserving of a more comprehensive analysis: the instructive value of failure. My reworked experiments were often accompanied by severe challenges and failures. Yet these failures had an important purpose of informing future efforts. Failure was certainly common in the early modern laboratory. Count Rumford said that:

> [he] shall not here give a detail of the numerous difficulties and disappointments [that he] met with in the course of these dangerous pursuits; it will be sufficient […] to give a cursory view of the train of unsuccessful experiments by which [he] was at length led to the discovery of the truly astonishing force of gunpowder.[14]

Bacon placed negative instances at the centre of his procedures. Failure contributes to inquiry by alerting the investigator of a wrong turn and potential dead end.

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[14] Rumford, "the Force of fired Gunpowder," 224.

Materials are not as accommodating as ideas, and practical engagement reinforces that lesson through hard-earned experience. I propose that an examination of experimental failure in early modern science would make a valuable contribution to the history of science.

My incorporation of hands-on as an equal partner in natural inquiry is deserving of more attention from historians of science. Given that there are few historical studies that take into account what was intended by the term 'experimental philosophy' and whether or not it satisfied Bacon's stipulations, my own work is a much needed contribution. Among early modern historians there is still a tendency to prioritise or overemphasise the knowledge partner of the Baconian equation. I show how an everyday substance, albeit a potent one, found its place in the experimental philosophy. The various treatments of gunpowder shown here demonstrate just how messy and complex the history of experimental philosophy can be. We need to get to grips with the complexity of early modern experimental philosophy, and the way to do this is, I argue, to give more due to the difficult nature of practice.

Finally, I suggest that a study on the concept of expansion in early modern science would be a valuable contribution to the discipline. Such a study would focus not only on early modern ideas concerning the expansion of the air. Gunpowder, as we have seen, cut across various bodies capable of expansion and contraction and it incorporated them all in the process of ignition. To explore interpretations of expansion and contraction in natural bodies could shed further light on early modern theories of matter and experimental practice.

The designation of gunpowder as 'imitable thunder' by Bacon is appropriate.[15] Regardless of whether the *desiderata* of the individuals and groups studied was knowledge or works, they were all moved by gunpowder's power. Only now, by virtue of the emergence of experiment as a method, this power need not be confined to the battlefield. To draw on the words of John Ingen-housz one last time, gunpowder's force was 'almost irresistible'.[16] It was irresistible in the sense that few bodies would be able to withstand the power that it unleashes on ignition. Yet there is a double meaning at work. Gunpowder was also irresistible to scholars of nature.

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[15] Bacon, *De Augmentis, SEH*, IV, 311

[16] Ingen-Housz, "Account of Inflammable Air and Gass," 379.

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