‘Though their Causes be not yet discover’d’:
Occult Principles in the Making of Newton’s Natural Philosophy

Xiaona Wang

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Abstract

This thesis aims to provide a fuller understanding of a highly important but still controversial aspect of Isaac Newton's natural philosophy: the role of occult, or at least non-mechanical, principles in his natural philosophy. The most obvious of these was his belief that gravity was an attractive force which operated across empty space, and so was an occult *actio in distans*. But there are other aspects of Newton's work which would have been regarded by Cartesian contemporaries as occult; such as his belief that light can be an active component within bodies, that light and other matter can be converted into one another, and that bodies are not inert and passive but manifest various principles of activity. R. S. Westfall, suggested in the 1970s that Newton's unprecedented success as a natural philosopher was due to the fact that he combined two seemingly antithetical traditions of natural knowledge, the mechanical tradition, and what he called the Hermetic tradition. This thesis replaces Westfall's outdated notion of a "Hermetic" tradition with broader occult or natural magical traditions and shows how they formed the context within which Newton's own work was formed. The thesis is not primarily a study of Newton's work but a study of the work of earlier English thinkers who can be seen to have established the occult traditions which were subsequently taken up by Newton. Each chapter, therefore, focuses on a different aspect of occult ways of thinking in natural philosophy during the early modern period, and finally shows, in the conclusion to each chapter, how these ideas appeared in Newton's work, and, as Westfall suggested, contributed to his unprecedented success. Over six chapters the thesis considers theories that the world system is a network of radiating forces analogous to light rays, that gravity is an attractive force analogous to magnetism and operates at a distance, that matter has the power to attract and repel other matter, or has the power to incessantly emit active material effluvia, or the power to vibrate. It also shows how beliefs about the mathematical principles of natural philosophy, and the usefulness of the

experimental method made possible, and supported, these theories about occult principles.

The focus is on English thinkers and developments in English natural philosophy. This is not just an arbitrary choice but reflects sympathetic attitudes to occult ways of thinking in English thought which are shown to derive from the first natural philosophers in England to acquire international reputations since the Middle Ages, John Dee, Francis Bacon, and William Gilbert. Writing before the mechanical philosophy was conceived, these three thinkers all embraced occult ideas and left them as a legacy for subsequent English thinkers, up to and including Newton. The thesis shows that the combination of occult and mechanical traditions discerned in Newton's work by Westfall was in fact highly typical of English thinkers who combined occult ideas deriving from Dee, Bacon, and Gilbert, with the emerging mechanical philosophy. This marked trend in English natural philosophy reached its culminating point in the work of Newton, but Newton's achievement was only possible because of what had gone before. The thesis shows, therefore, that Newton's achievement crucially depended upon this English background.

Lay summary

This thesis presents a historical survey of some important aspects of the scientific work which was being produced in England in the seventeenth century, and upon which Isaac Newton (1642–1727) can be shown to have drawn in his own work. Isaac Newton is known to have developed a new physics, in his *Principia mathematica* (1687) and his *Opticks* (1704 and 1717) which was not compatible with the dominant scientific theory of his day—the so-called mechanical philosophy, developed by René Descartes (1596–1650) and others. Newton's theory of gravity (developed in his *Principia*), for example, seemed to his contemporaries to assume that bodies could act upon one another across empty space, without touching one another, or without any material connection between them. This so-called action-at-a-distance was held to be impossible in the mechanical philosophy. Similarly, in the *Opticks* he developed the idea that bodies interacted with one another by means of their attractive and repulsive forces—again an idea which was dismissed by mechanical philosophers as non-mechanical and even occult. It is often assumed that these ideas were completely original to Newton, and their appearance in his work is simply attributed to his towering genius. The only attempts by historians to explain his rejection of strictly mechanistic approaches to physics have focused on his work on alchemy—which seems to be an obvious source for his occult ways of thinking. This thesis, however, looks in detail at the development of similar "occult" and non-mechanical ways of thinking by earlier English thinkers; from the earliest English "scientists": John Dee (1527–1608), William Gilbert (1544–1603), and Francis Bacon (1561–1626), to members of the Royal Society of London, the first scientific society (founded in 1660), including Robert Boyle (1627–1691), Robert Hooke (1635–1703), and others. This thesis shows, therefore, that the occult ways of thinking that can be seen to have shaped Newton's new physics were already current in English thought (and were by no means confined to

alchemy), and already provided a powerful and fruitful alternative to the mechanical philosophy which was dominant in Continental Europe. The power and fruitfulness of these English ideas is shown by the very fact that these ideas can all be seen, as this thesis shows, to have culminated in the highly successful work of Isaac Newton.

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Declaration

I, Xiaona Wang, declare that I composed this thesis, that all the work is my own and that the work has not been submitted for any other degree or professional qualification. Parts of Chapter 3, Sections 4, 5, 6, of this thesis have been previously published in my article "Francis Bacon and Magnetical Cosmology", *Isis* 107 (2016): 707–21.

_____ XIAONA WANG ______

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Introduction

Research Aims

The aim of this thesis is to provide a fuller understanding of a highly important but still controversial aspect of Isaac Newton's natural philosophy: the role of occult, or at least non-mechanical, principles in his natural philosophy. My starting point is based on the claim of the leading Newton scholar, R. S. Westfall, that Newton's unprecedented success as an internationally influential natural philosopher was due to the fact that he combined two seemingly antithetical traditions of natural knowledge, the mechanical tradition, and what he called the Hermetic tradition. As Westfall put it: "by wedding the two traditions, the hermetic and the mechanical, to each other", Newton's ideas were the real origin of modern science.[1]

It is my contention, however, that Newton was by no means the first to bring together these antithetical traditions. There was already a strong tendency towards combining the mechanical philosophy with more occult approaches among the leading English natural philosophers. If Westfall was correct, and Newton's ideas were the origin of modern science by combining occult and mechanical ways of thinking, he did so not by taking a radical move that nobody had thought of before, but by taking further a general trend that was already present in English natural philosophy.

This immediately raises the question as to *why* English natural philosophers should have been so different from their Continental counterparts, and preferred not to embrace the strict version of the mechanical philosophy as proposed most influentially by René Descartes. Consequently, the specific historical context should be shown as to how and why English natural philosophers continued to accept occult

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[1] Richard S. Westfall, "Newton and the Hermetic Tradition," in *Science, Medicine and Society in the Renaissance*, ed. Allen G. Debus, vol. 2 (London, 1972), ii: 195. I will come back later to the problem of terminology, including the use of "Hermetic".

ways of thinking after the introduction of the mechanical philosophy, and produced what has been recognized in the historiography as a version of mechanical philosophy which was radically different from the stricter mechanical philosophies developed by Descartes and Thomas Hobbes.

In fact, there is a need to broaden our understanding of what constituted the mechanical philosophy. Descartes's version of the mechanical philosophy was essentially a kinematic system, allowing no forces unless they are forces of impact, or collision. Newton introduced forces of attraction and repulsion into his physics and yet still referred to them as "mechanical principles".[2] Can both of these thinkers be regarded as mechanical philosophers? There have been attempts in the literature to suggest that mainstream English natural philosophy should be designated as "experimental philosophy", leaving "mechanical philosophy" to refer to Cartesians and others who developed a physics which depended only upon inertial motions, and allowed no principles of activity.[3] But I want to suggest that the "mechanical philosophy" is not simply a historians' term. It was an actors' category, and Boyle and Newton, and other English thinkers, clearly saw themselves as mechanical philosophers. This thesis thus shows how and why the mechanical philosophy became broader in its scope than Descartes had originally intended.

The main focus of the thesis is not simply on the work of Isaac Newton himself. The thesis takes up the suggestion of another leading Newton scholar, I. Bernard Cohen, that what is needed is "a better understanding of Newton's predecessors, and the background, sources, and development of his ideas."[4] Although Cohen suggested

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2 Isaac Newton, *The Principia: Mathematical Principles of Natural Philosophy*, trans. I. Bernard Cohen, and Anne Whitman (Berkeley, 1999), Preface to the Reader, 382.

3 See, for example, Peter R. Anstey, "Experimental versus Speculative Natural Philosophy," in *The Science of Nature in the Seventeenth Century*, ed. Peter R. Anstey and John A. Schuster (Dordrecht, 2005), 215–42.

4 I. Bernard Cohen, "The *Principia*, Universal Gravitation, and the 'Newtonian Style', in Relation to the Newtonian Revolution in Science," in *Contemporary Newtonian Research*, ed. Zev Bechler

this in 1982, and since then much work has been done on the background and sources of Newton's ideas in many of the areas to which he contributed, I believe there has been no systematic study of the various occult or non-mechanical principles that played a prominent role in Newton's natural philosophy.

The most obvious of such occult principles in Newton's physics are actions at a distance—in which it is assumed that bodies can act upon one another *without* making contact.[5] But there are other occult features of Newton's physics, such as his belief that light can be an active component within bodies, that light and other matter can be converted into one another, his belief that matter can be active, and that there are active principles of various kinds at work in the world. None of these aspects of Newton's natural philosophy conform to the principles of mechanical philosophy, as it was first developed by Descartes. Indeed, Descartes would have dismissed all of them as "occult", and therefore unacceptable according to his new mechanistic way of understanding the world.

Furthermore, as will be shown in this thesis, none of these occult ideas were uniquely and originally developed by Newton. On the contrary, as we shall see, they were all already current in seventeenth-century English natural philosophy. What follows, therefore, is an attempt to understand the background, sources, and development of Newton's ideas, and does not focus chiefly on Newton himself but on the earlier natural philosophers who can be shown to have developed the background and context from which Newton's own work subsequently emerged. Additionally, we will focus on those aspects of the background to Newton's thought which help to

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(Dordrecht, 1982), 27.

[5] I am assuming throughout that Newton did believe in actions at a distance, although I am aware of the claims by a number of leading Newton scholars, including Alexandre Koyré and I. B. Cohen, as well as a number of more recent philosophers, that Newton did not believe in action at a distance. On Newton as a believer in action at a distance see John Henry, "Gravity and *De gravitatione*: The Development of Newton's Ideas on Action at a Distance", *Studies in History and Philosophy of Science*, 42 (2011): 11–27.

make sense of the various occult, or at least non-mechanical, aspects of his natural philosophy. The thesis as a whole, therefore, offers an important new account of the development of early modern English natural philosophy, and shows how these provide important insights into the development of Newton's natural philosophy. While writing this dissertation I was guided by the assumption that was nicely stated by Peter Dear, namely, that the significance of Newton's contribution to early modern natural philosophy "makes sense only when seen in the light of the story that leads up to it."[6]

Why Focus on English Thought?

Before going any further, one aspect of this thesis should perhaps be justified. It might be objected that I should not have restricted my focus to English thinkers in the background to Newton's work, because, after all, natural philosophy was an international discipline, pursued all over Europe and published in the shared learned language of Latin. Newton was thoroughly aware of developments in mathematics, in natural philosophy, and no doubt in alchemy and his other interests, that were taking place across Europe. Nevertheless, apart from the need to restrict the scope of the thesis on purely practical grounds, it is easy to justify a focus on developments in England. Significant developments in English natural philosophy would have become known rapidly, and their differences from continental developments may well have been seen as marking them out as more compatible with English religion, politics, and other aspects of English culture.[7]

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[6] Peter Dear, *Discipline and Experience: The Mathematical Way in the Scientific Revolution* (Chicago, 1995), 248.

[7] I do not pursue such national differences in this thesis, but for interesting treatments of these differences, see, for example, Carolyn Iltis, "The Leibnizian-Newtonian Debates: Natural Philosophy and Social Psychology," *The British Journal for the History of Science* 6 (1973): 343–77; Steven Shapin, "Of Gods and Kings: Natural Philosophy and Politics in the Leibniz-Clarke Disputes," *Isis* 72 (1981): 187–215; Gideon Freudenthal, *Atom and Individual in the Age of Newton: On the Genesis of the Mechanistic World View* (Dordrecht, 1986).

Furthermore, Newton would have been all too aware as he set out on his career as a natural philosopher that English science was making highly significant contributions to the development of the natural sciences, and had recently produced a number of thinkers with international reputations, Francis Bacon, William Gilbert, William Harvey, Robert Boyle and Robert Hooke. Additionally, he would have been aware that the Royal Society was making its presence felt throughout the European community of natural philosophers, and that it was proudly claiming to produce a unique, and uniquely reliable, kind of natural knowledge.[8] It makes sense, therefore, to focus on the English scene in order to achieve "a better understanding of Newton's predecessors, and the background, sources, and development of his ideas", as called for by I. B. Cohen, even if it can only provide a partial picture.

However, there is another crucially important reason why a focus on the English background to Newton's work is justified. Essentially, this stems from the important influence of Francis Bacon. Bacon is well known to have shaped English natural philosophy in a way that he did not on the European continent.[9] In particular, Bacon's emphasis upon the experimental method made it possible to accept the reality of occult influences, provided they could be established, preferably repeatedly, by experiment.[10] Indeed, it was implicit in the meaning of an "occult quality" that it was a quality that could only be discovered or revealed by experiential means. It is surely no coincidence that Keith Hutchison and Ron Millen, in their seminal articles on changing attitudes to occult qualities in the Scientific Revolution, both emphasise the importance of the experimental method in the story, and both are led to discussing English developments, where the experimental philosophy was most

[8] For example, Michael Hunter, *Establishing the New Science: The Experience of the Early Royal Society* (Woodbridge, 1989).
[9] Charles Webster, *The Great Instauration: Science, Medicine, and Reform, 1626-1660* (London, 1975).
[10] Paolo Rossi, *Francis Bacon: From Magic to Science* (London, 1968).

dominant.[11] It will be seen in Chapter 2 and beyond that Bacon's impact on English thought led to a much more positive attitude to occult principles among English thinkers compared to continental European thinkers. Where Descartes and his followers wanted to dismiss the very idea of occult qualities and to explain everything in terms of their strictly mechanical principles[12], Baconians were happy to accept that occult qualities such as magnetism could be shown to exist and their precise behaviour codified by experimental investigation. When Newton added at the end of the second edition of the *Principia* in 1713 a comment that "In this experimental philosophy, propositions are deduced from the phenomena and are made general by induction", he was clearly writing as a Baconian. But he was also writing to justify the fact that he had not yet "been able to deduce from the phenomena the reason for these [previously summarised] properties of gravity".[13] As is well known, Newton had been accused by both Christian Huygens and G. W. Leibniz of allowing occult philosophies back into natural philosophy after Descartes had so ingeniously excluded them. Newton's defence was to claim that the "law of gravity" had been discovered by this Baconian method, and it was sufficient that he had established "that gravity really exists and acts according to the laws that we have set forth…"[14] It is possible that Leibniz failed to see the point (Huygens had died in 1695), because Newton's response was thoroughly Baconian and characteristically English. Certainly, writing to Samuel Clarke just before his death in 1716, Leibniz continued to insist that Newton "must suppose [gravity] to be effected by miracles or

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[11] Keith Hutchison, "What Happened to Occult Qualities in the Scientific Revolution?," *Isis* 73 (1982): 233–253; Ron Millen, "The Manifestation of Occult Qualities in the Scientific Revolution," in *Religion, Science and Worldview*, ed. Margaret J. Osler, and Paul Lawrence Farber (Cambridge, 1985), 185–216.
[12] For example, explaining magnetism in terms of the rapid motions of invisibly-small screw-threaded particles.
[13] Newton, *The Principia*, 943.
[14] Ibid. On Huygens's and Leibniz's response to the *Principia*, see Alexandre Koyré, *Newtonian Studies* (London, 1965), 115–39.

else have recourse to absurdities, that is, to the occult qualities of the schools; which some men begin to revive under the specious name of forces."[15]

Focusing on English natural philosophy therefore is justified not just on practical grounds, but also on historical and philosophical grounds. Indeed, it is my contention that the success of Newton's natural philosophy, which Westfall attributed to his "wedding… to each other" the "Hermetic" and the mechanical traditions, was a direct result of his being an English natural philosopher. As we shall see, Newton's philosophy developed quite naturally into a combination of the mechanical philosophy with an experimentally justified acceptance of occult principles, simply as a result of combining a deep-seated Baconian way of thinking with a more mechanistic approach. It is possible to see why and how these two seemingly antithetical ways of thinking could come together in a highly productive way in an English thinker such as Newton. By contrast, it seems hard to imagine any thinker raised on the Continent, who would be able to productively combine the precepts of Baconianism (with its in-built experimental defence of occult principles) with those of Cartesianism: on the Continent, Baconianism was not sufficiently well understood, and Cartesianism was too dominant. Interestingly, Westfall makes no mention of Bacon or Baconianism in his article on "Newton and the Hermetic Tradition", and nor does he offer any explanation as to how it was that Newton, and nobody else, combined Hermeticism and the mechanical philosophy. My thesis offers an advance on this: Newton was not so much influenced by Hermeticism as by Baconianism and the occult and magical ways of thought that were perfectly compatible with Baconianism, and he could draw freely upon the earlier work of English thinkers such as Walter Charleton, Robert Boyle, Robert Hooke, and other fellows of the Royal Society, who had already combined Baconianism with a modified, less strict,

[15] See H. G. Alexander, ed., *The Leibniz-Clarke Correspondence* (Manchester, 1956), 92.

version of the mechanical philosophy. With regard to this combination of distinct traditions, Newton was not unique, and was not doing something that nobody had done before. Newton's natural philosophy, with its combination of occult principles and mechanical philosophy was developed within a tradition of English science which already combined these two distinct approaches.

The importance of Bacon and his subsequent influence on English thought for this thesis brings attention to another feature of the story that is being told here. The thesis necessarily covers developments before the mechanical philosophy was first devised, and before its principles came to be properly understood. Indeed, it was during this earlier pre-Cartesian period that English natural philosophy was led to adopt favourable attitudes to occult principles. We can see this positive attitude to occult operations in nature in the work of the first three English natural philosophers to acquire international reputations since the Middle Ages: John Dee, Francis Bacon, and William Gilbert.[16] Given that these were the first early modern English thinkers, their work provided a natural *terminus a quo* for the thesis. Furthermore, all three of them can be seen to have turned to the occult as a way of reforming natural philosophy. The first three chapters of the thesis, therefore, show how occult traditions took hold in England as a result of the work of these three thinkers. The following three chapters show that these ways of thinking that were sympathetic to the occult were not *displaced* by the advent of the mechanical philosophy but were *amalgamated with it*. Again, it was chiefly the philosophical method developed by Francis Bacon that made this possible. Here it might be said that this thesis incidentally makes an additional significant contribution to another on-going historiographical debate. I do not directly assess throughout this dissertation the contested role of magic and the occult in the origins of modern science, but it should

[16] In the Middle Ages, England produced Roger Bacon and William of Ockham, although both of them made their names in the University of Paris, and the less well-known group of "Calculators" at Merton College, Oxford. Since then, England had been a philosophical backwater.

be clear that this thesis implicitly offers support for long-standing claims that magical ways of thinking did indeed play a role in the formation of modern science. Although resistance to the idea that magical traditions might have played a part in the development of modern science is finally diminishing, it has not entirely gone away.[17] By showing that occult ways of thinking, which were developed before the mechanical philosophy was introduced, continued to play a role in English natural philosophy, including even in the work of the great Isaac Newton, I am implicitly arguing for the role of magic in the establishment of modern science.

Defining "Occult"

Following on from this, it is important to note that throughout this thesis the term "occult" is used in a historically sensitive way. The word "occult" as it is used here should not be considered to have any connotations that the word has acquired since the nineteenth century as a result of the writings and popular influence of self-styled occultists, such as Eliphas Lévi, Helena Blavatsky, and Aleister Crowley.[18] Essentially, I use it the way a late seventeenth-century Cartesian might have used it. That is to say, I designate as occult any feature of contemporary natural philosophy which would not have been accepted by Descartes as deriving from the strict mechanistic principles which he set forth in his *Principia philosophiae*.[19] The features we will be discussing are those which are not explained in mechanistic terms, but seem to assume unexplained, or occult, principles at work in the natural world. I

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[17] For example, even A. Rupert Hall, shortly before his death, came to accept that Newton was interested in alchemy. A. Rupert Hall, *Isaac Newton: Adventurer in Thought* (Cambridge, 1996), 199–200. For an indication of how vigorous the opposition to claims about magical input used to be, see Walter Pagel, "The Vindication of "Rubbish," (1945), reprinted in Pagel, *Religion and Neoplatonism in Renaissance Medicine*, ed. Marianne Winder (London, 1985), 1-14.

[18] On the importance of this clear historical distinction, see William R. Newman and Lawrence M. Principe, "Alchemy vs. Chemistry: The Etymological Origins of a Historiographic Mistake," *Early Science and Medicine* 3 (1998): 32–65.

[19] René Descartes, *Principia Philosophiae* (Amsterdam, 1644). For detailed accounts of Descartes's mechanical philosophy, see Stephen Gaukroger, *Descartes' System of Natural Philosophy* (Cambridge, 2002); John Schuster, *Descartes-Agonistes: Physico-Mathematics, Method & Corpuscular-Mechanism 1618-33* (Dordrecht, 2013).

say “*seem* to assume” because it is in some cases possible that the occult notions used by some of Newton’s immediate predecessors were adopted carelessly, or without critical thought, not by deliberately *assuming* that a particular natural phenomenon required an essentially occult account. In some cases, they may even have been contradictory to other (mechanistic) accounts provided by the same thinker. We will see in Chapter 4, for example, that Henry Power presented himself as a follower of Descartes, and sometimes provided accounts of physical phenomena which conformed to Cartesian principles, but elsewhere slipped into talking about bodies as having an unexplained power of continually emitting effluvia, or streams of moving particles.[20] Similarly, Boyle sometimes wrote as a mechanical philosopher, and at others as a critic of the mechanical philosophy, using Baconian experiments to reveal that some phenomena could not be understood in mechanist terms. Unlike Power, Boyle always seems to have been aware of the line he was taking, and at times freely described himself as writing a “Philosophy of Occult Qualities”, or discussing “the Doctrine of occult Qualities.”[21]

An alternative way to designate these occult features of Newton’s philosophy, and the philosophy of his immediate predecessors, which I sometimes use, is *non-mechanical*. Again, I mean “mechanical” in the strict sense, as manifested in the work of Descartes, and also in the work of Thomas Hobbes. So, when I suggest a particular claim or way of arguing is “non-mechanical”, I mean it would not have been regarded by Descartes as confirming his insistence that there are “no forces so secret, no marvels of sympathy or antipathy so astounding, and finally no effects in all of nature which are properly attributed to purely physical causes… the reasons for which cannot be deduced” from his mechanical principles of “figure, magnitude,

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[20] See Chapter 4, section 4.

[21] Robert Boyle, *The Works of Robert Boyle*, ed. Edward B. Davis and Michael Hunter (London, 1999), vii: 229; and vi: 177.

situation and motion of particles of matter".[22] And such a claim would be seen by Hobbes as just another example of "empty words":

> For as for those that say any thing may be moved or produced by *it Self,* by *Species,* by *its own Power,* by *Substantial Forms,* by *Incorporeal Substances,* by *Instinct,* by *Anteperistasis,* by *Antipathy, Sympathy, Occult Quality,* and other empty words of Schoolmen, their saying so is to no purpose.[23]

It is important to note, however, that for both Descartes and Hobbes, the motions attributed by them to their particles were what we would now call inertial motions. It was crucial to the mechanical systems of natural philosophy of both Descartes and Hobbes that matter is completely inert and passive. Accordingly, bodies cannot be said to have any powers, or to be self-active in any way. Bodies can only act on other bodies by means of their motions (by impact), and bodies can only move when set in motion by collision with another body or bodies which are already moving (having themselves been put in motion by an earlier collision with other bodies, and so on). The only exception to this is that, in the beginning, matter had to be set moving at the Creation by God. By contrast, the figures discussed in this dissertation will all be shown to have accepted that bodies could have inherent principles of activity, powers, or some other occult or non-mechanical properties. As Alan Gabbey has pointed out, power in bodies "meant something wholly unmechanical before Leibniz hijacked it."[24]

The early modern English thinkers considered here drew heavily upon non-mechanical principles which Hobbes would have dismissed as "empty words", and which Descartes would have dismissed as supposedly secret forces or marvels of nature which he could explain mechanically. It is legitimate, therefore, to refer to

[22] Descartes, *Principia Philosophiae*, Part IV, § 187. I have used Descartes, *Principles of Philosophy*, trans. V. R. Miller and R. P. Miller (Dordrecht, 1983), 275.
[23] Thomas Hobbes, *Elements of Philosophy* (London, 1656), 394.
[24] Alan Gabbey, "Between *Ars* and *Philosophia Naturalis*: Reflections on the Historiography of Early Modern Mechanics," in *Renaissance and Revolution: Humanists, Scholars, Craftsmen and Natural Philosophers in Early Modern Europe*, ed. J. V. Field and F. A. J. L. James (Cambridge, 1993), 133–45, 135. On power as an "unmechanical" concept, see, for example, Walter Ott, *Causation and Laws of Nature in Early Modern Philosophy* (Oxford, 2009), chap. 16.

these principles, properties, or qualities as "occult", as the term was understood in the seventeenth-century, meaning hidden, unexplained, and capable of being known only through experience.[25]

Recent Reassessments of the Mechanical Philosophy

This discussion of occult qualities leads us to an on-going historiographical debate about the nature of the mechanical philosophy, to which the thesis contributes. The correct way to understand what was meant by the "mechanical philosophy", clearly requires serious consideration, especially in the light of what has just been said about the use of the term "occult".

One of the first scholars to point to the need to regard the mechanical philosophy as including principles of activity was the leading Newton scholar, R. S. Westfall. He was clearly inspired to make this move chiefly because he was aware that Newton did not conform to the strict versions of the mechanical philosophy as they were developed by Descartes and Hobbes. Writing at a time when Frances Yates had excited scholars with her talk of a "Hermetic Tradition" in Renaissance and early modern scholarly culture, Westfall saw Newton as a participant in the Hermetic tradition, in which "nature was seen as active", and bodies, far from being passive and inert, "have their own sources of activity, active principles, whereby they set themselves in operation and perform their specific acts."[26] Westfall pointed out that the so-called Hermetic tradition, and the mechanical philosophy were seen as

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[25] See Lawrence M. Principe and William R. Newman, "Some Problems with the Historiography of Alchemy," in *Secrets of Nature: Astrology and Alchemy in Early Modern Europe*, ed. William R. Newman and Anthony Grafton (Cambridge, MA, 2001), 385–431.

[26] Westfall, "Newton and the Hermetic Tradition," 184. The so-called Yates Thesis, about the influence of Hermetic ideas on Renaissance culture, emerged after the publication of Frances A. Yates, *Giordano Bruno & Hermetic Tradition* (Chicago, 1964). See Marjorie G. Jones, *Frances Yates and the Hermetic Tradition* (Lake Worth, FL, 2008). The designation of this cluster of ideas and attitudes as "Hermetic" has now fallen out of fashion, but it is used here to reflect Westfall's usage. The tendency now would be simply to call it an occult or magical tradition. See, for example, Robert S. Westman and J. E. McGuire, *Hermeticism and the Scientific Revolution* (Los Angeles, 1977); Brian Vickers, "Frances Yates and the Writing of History," *The Journal of Modern History* 51 (1979): 287–316.

"mutual antitheses", and that scholars had tended to assume that the history of seventeenth-century science saw "the replacement of the Hermetic conception of nature by the mechanical" Westfall, conscious of Newton's anomalous position in this account, suggested a new approach: "I wish to propose that the logical antithesis as it appears to us, of the two conceptions of nature was not an operative historical antithesis." He went on to claim that natural philosophy was pervaded by "descendants from the Hermetic tradition" which were merely "disguised by mechanistic veneers". [27] Westfall's conclusion to this paper seemed to suggest that it was Newton who single-handedly brought together these two very different approaches. "The champions of mechanical orthodoxy failed to realize what benefits the Hermetic idea could bestow on the mechanical philosophy", Westfall wrote, but Newton, "by wedding the two traditions, the hermetic and the mechanical, to each other," provided the real origins of modern science.[28]

Since then, a number of scholars have argued that it was not just Newton who brought these two traditions together, but it was the work of a significant number of earlier thinkers. John Henry has pointed to a rich tradition in English natural philosophy which combined theories of occult qualities and active principles with broadly mechanistic approaches as a way of trying to overcome perceived flaws in the system of Descartes.[29] Similarly, Allen G. Debus, Antonio Clericuzio, Lawrence Principe, William Newman and others have shown how alchemical, or chymical, ideas were introduced into the matter theory of the mechanical philosophy, and thereby changed its character by acknowledging inherent chemical powers in matter.[30] Keith Hutchison and Ron Millen wrote important papers showing that the

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[27] Westfall, "Newton and the Hermetic Tradition," 185.
[28] Ibid., 195.
[29] John Henry, "Occult Qualities and the Experimental Philosophy: Active Principles in Pre-Newtonian Matter Theory", *History of Science* 24 (1986): 335–81; idem, "The Fragmentation of Renaissance Occultism and the Decline of Magic," *History of Science* 46 (2008): 1–48.
[30] For example, Allen G. Debus, *Man and Nature in the Renaissance* (Cambridge, 1978); Antonio

standard view that the mechanical philosophy completely removed occult qualities from natural philosophy was mistaken. Hutchison pointed out that the new philosophers of the seventeenth century all agreed that there were qualities beyond the four so-called *manifest* qualities acknowledged by the scholastics (hot, cold, wet, and dry), and "innovators openly argued that the ability to accommodate occult qualities was one of the signs of the superiority of their new science."[31] Millen noted that "the persistence of occult modes of action in the writings of prominent virtuosi is viewed [in the prevailing historiography] as an anomaly", and went on to show that this was the result of seeing the mechanical philosophy purely in the strict terms set out by Descartes.[32] Alan Chalmers has noted that Boyle's philosophy failed to live up to the demands of the mechanical philosophy (as proposed by Descartes), and introduced incomplete explanations. For example, claiming that the ability of a bladder to restore itself to its original shape and size after being squeezed "happens from the spring of those Aerial Particles… though he that says this, be not perhaps able to declare, whence proceeds the Motion of Restitution."[33]

Similarly, Daniel Garber has recently shown that Robert Boyle, one of the first to explicitly use the phrase "mechanical philosophy", did not confine the phrase to strict mechanical philosophers, such as Descartes and Hobbes, but applied it to his own work even though he believed that matter "must have Motion in some or all its

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Clericuzio, "A Redefinition of Boyle's Chemistry and Corpuscular Philosophy," *Annals of science* 47 (1990): 561–89; Lawrence M. Principe, *The Aspiring Adept: Robert Boyle and His Alchemical Quest* (Princeton, 2000); William R. Newman, *Atoms and Alchemy: Chymistry and the Experimental Origins of the Scientific Revolution* (Chicago, 2006). For similar works, see, for example, Joel Shackelford, "Seeds with a Mechanical Purpose: Severinus' *Semina* and Seventeenth-Century Matter Theory," in *Reading the Book of Nature: The Other Side of the Scientific Revolution*, ed. Allen G. Debus and Michael T. Walton (Kirksville, MO, 1998), 15–45; Bruce T. Moran, *Distilling Knowledge: Alchemy, Chemistry, and the Scientific Revolution* (Cambridge, MA, 2006); Hiro Hirai, *Medical Humanism and Natural Philosophy: Renaissance Debates on Matter, Life and the Soul* (Leiden, 2011).

31 Hutchison, "Occult Qualities", 242.

32 Millen, "Manifestation", 185.

33 Boyle, *Certain Physiological Essays* (1661), in *Works*, i: 22. See Alan Chalmers, "The Lack of Excellency of Boyle's Mechanical Philosophy," *Studies in History and Philosophy of Science* 24 (1993): 541–64.

designable Parts", and so was innately active.[34] Garber sees this wider view of what constituted the mechanical philosophy as the result of what he calls Boyle's "irenic program of the mechanical philosophy", in which Boyle wanted to reconcile the opposing views of the Cartesians and the atomists, represented chiefly by Pierre Gassendi.[35] In his *Certain Physiological Essays* of 1661 Boyle wrote that although the Cartesians and the Atomists

> disagree about the Notion of Body in general, and consequently about the Possibility of a true Vacuum, as also about the Origine of Motion, the indefinite Divisibleness of Matter, and some other points of less Importance than these: But in regard that some of them seem to be rather Metaphysical than Physiological Notions, … and especially for this Reason, That both parties agree in deducing all the Phænomena of Nature from Matter and local Motion; I esteem'd … they might be thought to agree in the main, and their Hypotheses might by a Person of a reconciling Disposition be look'd on as, upon the matter, one Philosophy.[36]

It is significant that Boyle included "the Origine of Motion" as one of the important differences between Descartes and Gassendi. While Descartes held matter to be inert, Gassendi, following Epicurus, believed that atoms contained their own innate principle of movement. Gassendi wrote, for example, that gravity is "nothing but the natural and internal faculty or force by which an atom moves itself through itself, and can move."[37] But for Descartes gravity was not a real property of bodies, but was merely the result of bodies being pushed to earth by the incessant motion of particles generated by his system of vortexes. Descartes was right to insist that his philosophy differed from ancient atomism as much as it did from scholasticism.[38] As we shall see later, Boyle subscribed to the Gassendist view that bodies had their own principles of motion, and if he was reluctant to affirm this in 1661, later in his career, he became increasingly opposed to the strict forms of the mechanical philosophy proposed by Cartesians and by Hobbes. Garber is correct, therefore, to recognise a

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[34] Boyle, *The Origin of Forms and Qualities* (1666), in *Works*, v: 306.
[35] Daniel Garber, "Remarks on the Pre-History of the Mechanical Philosophy," in *The Mechanization of Natural Philosophy*, ed. Sophie Roux and Daniel Garber (Dordrecht, 2013), 8.
[36] Boyle, *Works*, ii, 87.
[37] Pierre Gassendi, *Opera omnia* (Lyon, 1658), i: 273, quoted from Garber, "Remarks," 17.
[38] Descartes, *Principia Philosophiae*, 1:Part IV, § 202, 284.

difference between Boyle's version of the mechanical philosophy and what had gone before. As Garber wrote:

> Though many have read Boyle as another figure in a long, continuing, and well established tradition of mechanical philosophers, the *Origin of Forms and Qualities* was in fact a kind of *manifesto*, the declaration of a *new* program, and not a simple description of a going program. It was, in essence, the construction of something new out of pre-existing elements.

Where Westfall had seen Newton as single-handedly changing the mechanical philosophy to make it include occult principles, for Garber it was Boyle who "articulated a new paradigm", and "founded a club in which other, later thinkers could and did claim membership."[39]

Certainly, the historiography has tended to present Boyle and Newton as the major figures in changing the mechanical philosophy and making it more accepting of features which would not have been regarded as mechanical by Descartes or Hobbes, but, as I show in this thesis, the movement was much wider, at least in England, and should not be seen as the work of one dominating thinker. This is confirmed also by Dmitri Levitin, who sees this as the result of a much wider group of English natural philosophers.[40] So, Garber, Clericuzio, and others are wrong to see Boyle as being the first to articulate a new programme in which the mechanical philosophy was combined fruitfully with more non-mechanical worldviews; and Westfall was wrong to see Newton as the first to bring the mechanical philosophy, and what he called "Hermeticism" together.

In fact, it is my contention in this thesis that although Westfall was correct to see the combination of mechanical and more occult ways of thinking in Newton's work as a major reason for its success, he failed to notice that Newton was simply taking an approach that had already become fairly commonplace among English natural

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[39] Garber, "Remarks", 22.

[40] Dmitri Levitin, *Ancient Wisdom in the Age of the New Science: Histories of Philosophy in England, c. 1640–1700* (Cambridge, 2015), 329–446.

philosophers. By pursuing the main aim of my thesis, therefore, I have on the one hand reaffirmed the earlier work of scholars who have pointed to the incorporation of occult principles into the mechanical philosophy, and on the other hand I have shown how this can be seen to have shaped the work of Isaac Newton. With regard to this historiographical debate, I have provided more detailed and extensive surveys of the ways in which occult ways of thinking flourished throughout the early modern period. I have thereby confirmed the earlier work in this area, but have also added to it, and made it more unassailable. Furthermore, I have shown how Newton's own work can be seen as following similar paths to those taken by his immediate predecessors and by his contemporaries engaged in natural philosophy. As Dear has said, Newton's work "makes sense only when seen in the light of the story that leads up to it". It is only by considering the background to Newton's thought that we can understand why he was able to write in the preface to the *Principia* of "natural powers" and of forces such as gravity, and other attractive and repulsive forces, and yet could still write: "If only we could derive the other phenomena of nature from *mechanical* principles by the same kind of reasoning!"[41] It is clear from the context that for Newton, powers and attractive and repulsive forces were mechanical principles, and he expected his readers to accept this too. Newton was not working in an intellectual and cultural vacuum, but was participating in a lively and innovative field, with a number of great thinkers, all seeking to understand the natural world at a time when it was all too apparent that scholastic natural philosophy was misconceived, and that the various replacement philosophies offered so far by so-called *novatores* (including pre-mechanical reformers of natural philosophy such as Girolamo Cardano, Paracelsus, Bernardino Telesio, Tomasso Campanella, Sebastian Basso, J. C. Magnenus, J. B. van Helmont, and others) were equally

[41] Newton, *The Principia*, 382.

unsatisfactory.[42] It was clear, however, that Newton believed the version of the mechanical philosophy developed by Boyle, Hooke, and other predecessors, that is to say the version of the mechanical philosophy which incorporated various unexplained occult principles, offered the best chance of success.

It might be supposed, however, that there is a contradiction between my claim that I have used the word “occult” the way a mechanical philosopher such as Descartes might have used the term, and yet now I am agreeing that the mechanical philosophy should be recognised as incorporating occult principles. There is no contradiction if we look at it with correct historical awareness. Descartes was strict in his adherence to purely kinematic principles and his rejection of anything that had the slightest suggestion of the occult or inexplicable about it. The same could be said of Hobbes, and, of course, of the followers of both these strict mechanists. I have used *their* definition of what was occult, therefore, to be able to make it clear that Petty, Charleton, Boyle, and others up to and including Newton, were in fact introducing occult qualities into what they still persisted in calling the mechanical philosophy. Newton even admitted as much in the 1717 edition of the *Opticks* when he spoke of gravity, fermentation, and the cohesion of bodies as “manifest Qualities, and their Causes only are occult.”[43] It was always the *causes* of occult qualities that were the issue, if their effects could not be allocated a cause then they were occult.

What is Missing in this Thesis

Before going any further, and summarising the contents of the chapters of this thesis, I must first offer some explanation for various omissions from this thesis. There are a

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[42] Drawing upon the lists of prominent *novatores* compiled by various leading seventeenth-century natural philosophers, Garber indicates the range of different new philosophies on offer. See, Garber, “Remarks”, 20–22. See also, Brian P. Copenhaver and Charles B. Schmitt, *Renaissance Philosophy* (Oxford, 1992).

[43] Isaac Newton, *Opticks; Or, A Treatise of the Reflections, Refractions, Inflections & Colours of Light*, Based on the 4th Ed. London, 1730 (New York, 1979), 401.

number of prominent aspects of the recent historiography of Newton that I do not discuss, even though it might have been expected that they are relevant to my purposes.

Most obvious, perhaps, is the fact that I pay little more than passing attention to Newton’s well known and undeniable interest in alchemy. Given my focus on occult aspects of Newton’s natural philosophy, it surely seems that alchemy would play a significant role in my story. Strange as this may seem, for the most part I did not need to call on Newton’s alchemy, much less the background to it as developed in earlier writers, such as George Starkey or Robert Boyle, in order to account for the appearance of any of the occult ideas in Newton’s work that are covered in this thesis. Although both Westfall and Betty Jo Dobbs claimed that Newton’s alchemy played a significant role in his concept of forces capable of acting at a distance, there seems to be little real evidence for these claims. As William R. Newman, one of the leading scholars on Newton’s alchemy, has recently pointed out:

> there is no direct evidence for the claim that Newton’s alchemical research contributed to his view of gravitation as an immaterial force in any of the documents submitted by Dobbs or Westfall for scrutiny. In fact, on the very few occasions where Newto[44]n does describe the causes of gravity in an explicitly alchemical context, he explains the falling of bodies by *mechanical means*, not as a result of force at a distance.[45]

Newman’s comment about a *mechanical* cause of gravity in Newton’s alchemical work is a reference to the work known as “Of Natures obvious laws & processes in vegetation”. Here, Newton suggests that a material aether may push bodies down to earth because of a “crouding for room” in the atmosphere.[46] As Newman points out,

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[44] For example, Richard S. Westfall, *Force in Newton’s Physics: The Science of Dynamics in the Seventeenth Century* (London, 1971), 369; Westfall, “Newton and the Hermetic Tradition,” 193–94; Betty Jo Teeter Dobbs, *The Foundations of Newton’s Alchemy: Or, “The Hunting of the Greene Lyon”.* (Cambridge, 1975), 211–12.

[45] William R. Newman, “A Preliminary Reassessment of Newton’s Alchemy,” in *The Cambridge Companion to Newton*, ed. George E. Smith and Rob Iliffe, 2nd ed. (Cambridge, 2016), 456, see also 476-77.

[46] Isaac Newton, “Of Natures obvious laws & processes in vegetation”, Smithsonian Institution, Dibner Ms. 1031B. This is now available at the *Chymistry of Isaac Newton* website (www.chymistry.org). “Of Natures obvious laws” can be found at

there is a similar mechanical explanation of gravity in the "Hypothesis explaining the Properties of Light" which Newton wrote shortly after this alchemical work, in 1675. Here, gravity is "explained" as the result of the condensing of an aetherial spirit "of an unctuous or gummy, tenacious, and springy nature". Newton says that the condensing of this spirit may "cause it from above to descend with great celerity", and since it is gummy and tenacious it will carry bodies downwards with it. It is not at all clear, however, why condensation of this spirit should cause it to descend. It looks very much as though Newton is simply begging the question—assuming that the aether descends, so that he can use it to explain the descent of all other bodies.[47] It seems, therefore, that Newman is perfectly correct in saying that Newton's early alchemical work led him to try to provide a mechanical account of gravity. But, as is well known, and as we will see later in this dissertation, Newton soon abandoned attempts to explain gravity in mechanistic terms and accepted the idea, suggested by Robert Hooke, that gravity was an action at a distance.[48] Accordingly, in spite of the claims of Westfall and Dobbs, I did not need to introduce Newton's alchemy into my account of how he adopted actions at a distance, immaterial forces, active matter, and other occult phenomena.[49]

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http://webapp1.dlib.indiana.edu/newton/mss/dipl/ALCH00081/

[47] Isaac Newton, "An Hypothesis explaining the Properties of Light, discoursed of in my several papers", was read at a meeting of the Royal Society in 1675. It is now published in Sir Isaac Newton, *Isaac Newton's Papers & Letters on Natural Philosophy and Related Documents*, ed. I. Bernard Cohen (Cambridge, MA, 1978), 181. See also, Newman, "Preliminary Reassessment", 456–58.

[48] See, Richard S. Westfall, *Never at Rest: A Biography of Isaac Newton* (Cambridge, 1980), 388; and Chapter 3 below.

[49] It should be noted that Newman's major study on Newton's alchemy has just appeared, William R. Newman, *Newton the Alchemist: Science, Enigma, and the Quest for Nature's "Secret Fire"* (Princeton, 2019). I was unable to consult this before submitting my thesis, and it is possible that this may reveal that alchemy did play a role in Newton's adoption of various occult principles in his mature philosophy. But judging from his "Preliminary Reassessment", and other recent works (for example, Newman, "The Unknown Newton: The Problem of Alchemy," *The New Atlantis*, Winter, 2015: 65–75), this seems unlikely. The "Preliminary Reassessment" does show a very clear link between his chymical work and his theory of colour, but it does not involve occult concepts and is perfectly compatible with the mechanical philosophy, even of a strict Cartesian kind. See Newman, "Preliminary Reassessment", 463–68.

Those who are at all familiar with recent Newtonian scholarship will also wonder why there is no mention in this thesis of Newton's, or his English predecessors', religious views, or indeed, their political views. Recent historiography has made it abundantly clear that "science" and "religion" were intimately connected throughout this period, and that, as politics was also intimately connected with religion, "science" must also have been connected to political interests.[50] Furthermore, with regard to Newton, his natural philosophy and his religion have been seen as especially interconnected, and it is undeniable that he was, at least at some points in his career, actively engaged in politics, either as a member of parliament, or as Warden and then Master of the Mint.[51]

There is no need to introduce Newton's religious beliefs, much less his political interests, into this attempt to understand what led Newton to adopt occult and non-mechanical principles into his natural philosophy. It is possible that there are religious or socio-political dimensions to the natural philosophical assumptions, arguments, and conclusions that are discussed in this thesis, and these may be a productive path to follow in future research, but they were not necessary to be able to draw the inferences or to reach the conclusions, about Newton's background, sources, and the development of his ideas presented here. The aim was to find antecedents to

[50] I put "science" in quotation marks because it is of course anachronistic at this time, and I put "religion" in inverted commas because according to Peter Harrison, it too should be considered as anachronistic. See Peter Harrison, *The Territories of Science and Religion* (Chicago, 2015); Peter Harrison, *"Religion" and the Religions in the English Enlightenment* (Cambridge, 1990). For leading historiographical examples of the connection between science and politics during our period see, for example, Joseph Ben-David, *The Scientist's Role in Society; a Comparative Study* (Englewood Cliffs, NJ, 1971); Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump : Hobbes, Boyle, and the Experimental Life* (Oxford, 1985); Otto. Mayr, *Authority, Liberty, & Automatic Machinery in Early Modern Europe* (Baltimore, MD, 1986).

[51] On the links between science and religion in the work of Newton, see, for example, Frank E. Manuel, *The Religion of Isaac Newton* (Oxford, 1974); Betty Jo Teeter Dobbs, *The Janus Faces of Genius: The Role of Alchemy in Newton's Thought* (Cambridge, 1991); James E. Force and Richard H. Popkin, eds., *Newton and Religion: Context, Nature, and Influence* (Dordrecht, 1999); James E. Force and Sarah Hutton, eds., *Newton and Newtonianism: New Studies* (Dordrecht, 2004). But for a cautionary view, which we are about to discuss, see, Rob Iliffe, *Priest of Nature: The Religious Worlds of Isaac Newton* (Oxford, 2017), 14. On Newton's direct involvement with politics, see Westfall, *Never at Rest*; John Craig, *Newton at the Mint* (Cambridge, 1946); Iliffe, *Priest of Nature*, especially 157–88, and 315–53.

Newton's way of thinking in natural philosophy, in particular in the natural philosophy of his English predecessors. This may be a source of disappointment to some readers, who have been convinced by the claims of Westfall, Dobbs, James Force, and others that Newton's natural philosophy and his theology must have been intimately and inseparably combined, because they both emerge from the same great mind. But, as Rob Iliffe has pointed out, recent scholarly analysis of Newton's manuscripts "has provided no support for the notion that there is some simple conceptual or methodological coherence to his work." Indeed, Iliffe has reminded Newton scholars that Newton, like his contemporaries, was trained "to think, write, and argue in modes that were appropriate to distinct disciplines." Moreover, Newton himself "stipulated that that separate forms of enquiry, argument, and demonstration were appropriate for specific subjects."[52] Certainly, this fits with my own attempts to understand, in what follows, why Newton believed that light could act as an efficient cause, and was interchangeable with matter, and accepted the possibility of attractive and repulsive forces capable of acting at a distance, or that some matter might be incessantly vibrating. It was possible to relate all of these to natural philosophical ideas that were already current among English natural philosophers, and there was no need to resort to Newton's or anyone else's religious or political beliefs to understand why they were thinking this way. This is not to say that Newton and his predecessors did not make links in their own minds between natural phenomena and their religious beliefs, but it was not necessary to uncover those links here to be able to describe the development of Newton's natural philosophy.

[52] Iliffe, *Priest of Nature,* 14–15; Rob Iliffe, "Abstract Considerations: Disciplines and the Incoherence of Newton's Natural Philosophy," *Studies in History and Philosophy of Science* 35 (2004): 427–54. Newman, "Preliminary Reassessment", 458–63, as well as denying that alchemy inspired Newton's belief in action at a distance, also denies the claims of Dobbs that Newton's alchemy was really intended to promote his theology.

Summary of the Chapters

I have already mentioned the importance of Francis Bacon in persuading his followers that occult principles could be acceptable in natural philosophy provided their operations could be demonstrated experimentally. As we shall see, this was one of the major reasons for the promotion of the experimental method by Bacon, and one of the chief reasons for its success in subsequent English natural philosophy. Accordingly, chapter 2 is focused on these aspects of the experimental method, Bacon's role in promoting this method, and its significance in the background to Newton's thought. But Newton is perhaps better known today as what we would call a "mathematical physicist"; that is to say, one who used mathematics as a way of confirming, and making more certain, the speculative theories of the natural philosopher. It seemed important, therefore, to spend time discussing the background to this aspect of Newton's methodology, as well as the background to his experimentalism.

The first chapter, therefore, focuses on the mathematization of natural philosophy. This can be seen to have been a major concern of the Elizabethan magus, John Dee. Dee is shown to have been the first English thinker to promote the growing belief, developed earlier by Continental thinkers, that mathematics can make a real and valuable contribution to natural philosophy thereby countering scholastic claims that mathematics cannot explain causes and so should be excluded from natural philosophy. As well as discussing the methodological aspects of Dee's thought, the chapter on Dee also shows how he used geometrical optics and the magical tradition known as "light metaphysics" to demonstrate the relevance of mathematics to natural philosophy. Finally, it is shown that both aspects of Dee's work, his mathematization of natural philosophy, and his use of light as an active principle in nature can be seen to have prefigured aspects of Newton's thought.

The second chapter is on Francis Bacon and the experimental justification of occult principles, which shows the inextricable connection between Bacon's new methodology of the sciences, including his emphasis upon inductive logic, and experimental practice, and his theory of matter. It is shown that for Bacon matter was inherently active, being infused with occult principles of activity. Bacon's theory of matter and the methodological justification of this theory are shown to be taken from the natural magic tradition and to have been hugely influential in English natural philosophy, including on Newton's thought. These two chapters constitute the first of three parts of the thesis. This first part is designated as being concerned with "Method".

The second part, "Magnetism", is also divided into two chapters: "The Tradition of Magnetical Cosmology and the Universal Principle of Gravitation"; and "From Magnetic Cosmology to Active Matter". The first, on Gilbert and the tradition he founded—magnetical cosmology or magnetical philosophy—shows how English natural philosophers came to accept theories of action at a distance. This chapter also shows the previously unnoticed role of Bacon in the development of magnetical cosmology. The chapter shows how analogies between magnetic attraction and gravitational attraction led to Robert Hooke's theory of gravity as an attractive force capable of acting at a distance, and ultimately to Newton's universal principle of gravitation.

Continuing to follow the fortunes of magnetical philosophy, the next chapter shows how theories of magnetism gave rise on the one hand to William Petty's foreshadowing of Newton's later belief that all phenomena could be explained by attractive and repulsive forces acting between particles of matter. And on the other hand to effluvial theories, in which not only magnets, but all bodies came to be seen to be acting on other bodies by emitting incessant streams of particles.

The third and final part of the thesis focuses on "Matter", and is again presented in two chapters: "From Active Matter to Active Aethers: Boyle, Hooke, and Newton"; and "Rarefactions & Condensations and the Origins of Newtonian Repulsive Force". The first follows on from the previous chapter, about effluvia as a sign of the inherent activity of matter, and reveals other theories of unexplained in-built activity in matter, including the idea that matter can be incessantly vibrating, even when it appears to be at rest. The importance of vibrating matter in English natural philosophy from Bacon to Hooke is revealed, and shown to culminate in Newton's speculations on a material vibrating aether in the so-called "Aether Queries" which he added to his *Opticks* in 1717. The final chapter demonstrates the problematic nature of the related phenomena of rarefaction and condensation, and shows how attempts to explain these phenomena were exacerbated by the extreme rarefaction that could be achieved by using the newly invented air-pump. It is shown that speculation on the nature of such extreme rarefactions finally culminated in Newton's belief that there must be repulsive forces operating at a distance between particles.

The thesis is brought to an end with a Conclusion, in which it is reiterated that the emphasis upon the mechanical philosophy as characteristic of seventeenth-century thought is misleading if the mechanical philosophy is presented as dependent on the view that matter is completely passive and inert, and that all physical phenomena can be explained merely in terms of the inertial motions of such passive matter. In fact, traditions of thought which are more usually associated with the Renaissance revival of natural magic can still be seen to be flourishing in the early modern period, especially in England, and were even incorporated into the mechanical philosophy, and can be seen as one of the major reasons for the success of such a towering figure in the history of modern science as Isaac Newton, whose natural philosophy can be seen as the perfect blend of mechanism with magic.

Part I: Method

The new philosophies developed during the so-called Scientific Revolution proposed and promoted a number of new ideas about the nature of the world system and its constituent parts, from planets to particles, and how they interact with one another. But many of these new ideas would have been impossible to uphold, and to confirm as legitimate aspects of natural philosophy, if it were not for newly developed theories about the correct methods for establishing the truth of these newly proposed natural phenomena. In the first part of this dissertation, therefore, we will look at the new methods which were taken up by Isaac Newton and used by him to justify his own version of the new philosophy. Newton's mathematical approach to natural philosophy is seen as the culmination of a movement which began in the sixteenth century, in which mathematics was seen as an important means of establishing the nature of the physical world. This movement was set against the Aristotelian view, promoted by the scholastic philosophers who dominated the universities, that the aim of natural philosophy was to discover the physical causes of natural phenomena, and that mathematics, because of its abstract nature, could not contribute to efforts to establish causes. This was an international movement and Newton might have become aware of it through the work of leading European contributors, most notably Johannes Kepler and Galileo Galilei. In the first of the two following chapters, however, we will show that significant contributions to this new way of thinking about the role of mathematics in natural philosophy had already been introduced into English thought by one of the first English philosophers to develop an international reputation since the Middle Ages, John Dee.

Newton was also a committed experimental philosopher, however, and always claimed that his theories about the nature of the world were derived "from phenomena", that is to say, from observing what actually occurred in the natural world. One of the major promoters of the experimental method in natural philosophy, and undoubtedly a major influence on the reform of natural philosophy, was the English philosopher Francis Bacon. In the second chapter of this part, therefore, we will look at this new Baconian methodology, and consider its importance in setting the scene for Newton, and making his own work possible, and perhaps even shaping it.

It is more likely that Newton was directly influenced by reading Francis Bacon than he was by any knowledge he might have had of John Dee's work. But the aim is not to establish direct influence, merely to show that when Newton began to make his own major contributions to what has been called "the mathematization of the world picture", and to the experimental method, he was not initiating anything new, but was building upon already established, and flourishing, movements in early modern English thought.

Chapter 1: From Geometrical Optics to Light Metaphysics: John Dee and the Mathematical Principles of Natural Philosophy

Introduction

The title of Isaac Newton's *Mathematical Principles of Natural Philosophy* (*Philosophiae naturalis principia mathematica*) is now recognized as a bold claim, asserting to contemporary readers that there are indeed mathematical principles involved in natural philosophy. Although this seems unobjectionable to modern readers, when the *Principia* appeared in 1687, the dominant view was still the traditional scholastic, or Aristotelian, insistence that mathematics was not capable of making a significant contribution to natural philosophy, and therefore that mathematics should be kept separate from natural philosophy.[1] To talk of the "mathematical principles of natural philosophy", therefore, was at this time, as Peter Dear has pointed out, a category mistake.[2] The *Principia* is often seen as finally establishing the relevance of mathematics to natural philosophy after more than a century of debate, but even Newton's great work did not change attitudes overnight. A brilliant mathematician like G. W. Leibniz wrote in 1696 of the "novelty" of "a curious mixture of philosophical and mathematical thought" in his own work.[3]

We need not go into the details of this historical debate here, but it has been seen as a response by mathematical practitioners across a range of mathematical sciences – architecture, astronomy, ballistics, cartography, navigation, and others – to the standard scholastic view that natural philosophy was concerned with explaining

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[1] For example, Robert S. Westman, "The Astronomer's Role in the Sixteenth Century: A Preliminary Study," *History of Science* 18 (1980): 105–47; Dear, *Discipline*; Nicholas Jardine, "Epistemology of the Sciences," in *The Cambridge History of Renaissance Philosophy*, ed. Charles B. Schmitt, Quentin Skinner, and Eckhard Kessler (Cambridge, 1988), 685–711; Niccolò Guicciardini, *Isaac Newton on Mathematical Certainty and Method* (Cambridge, MA, 2009).

[2] Dear, *Discipline*, 179.

[3] Leibniz to Basnage de Bauval, January 1696. Leibniz was describing the hybrid nature of his correspondence with Antoine Arnauld, which he was intending to publish. I have taken this from David Rabouin, Norma B. Goethe, and Philip Beeley, "The Interrelations Between Mathematics and Philosophy in Leibniz's Thought," in *G.W. Leibniz, Interrelations between Mathematics and Philosophy*, ed. Rabouin, Goethe, and Beeley (Dordrecht, 2015), 3.

phenomena in terms of causes, and that mathematics could say nothing about physical causes and so must be excluded from natural philosophy. According to scholastic natural philosophers, their aim was to provide a "demonstratio propter quid" for any given natural phenomenon, that is to say, a "demonstration according to which", or "on account of which" (and referring to causes), but the best that mathematics could provide was what they called "demonstratio quia", or "a demonstration that", that is to say simply a demonstration of the fact, but not why or how this fact occurred.[4]

Scholarly literature on the attempts of mathematicians to extend the scope of mathematics into natural philosophy has added a new dimension to earlier literature, by Alexandre Koyré and others, about the so-called "mathematization of the world picture."[5] It was usually assumed that the intellectual status of mathematics was increased by the efforts of individual geniuses, such as Kepler and Galileo, and ultimately Newton, who were seen as natural philosophers who also happened to be gifted mathematicians. Recent scholarship, however, has shown that the movement was much more widespread, and was brought about not by natural philosophers introducing mathematics into their work, but by mathematicians increasingly demonstrating the practical and intellectual value of mathematics.[6]

This was a Europe-wide movement and much of the literature has focused on Continental developments. It is highly possible, therefore, that as Newton grew to maturity as a mathematician, he picked up the new attitude to mathematics from his knowledge of Continental mathematicians. But, it is equally possible, as this chapter

[4] For fuller discussion, see Jardine, "Epistemology of the Sciences."
[5] Alexandre Koyré, *Galileo Studies* (Hassocks, Sussex, 1978). See also, for example, E. A. Burtt, *The Metaphysical Foundations of Modern Physical Science.* (London, 1932); E. J. Dijksterhuis, *The Mechanization of the World Picture*, trans. C. Dikshoorn (Oxford, 1961).
[6] For example, Paul Lawrence Rose, *The Italian Renaissance of Mathematics: Studies on Humanists and Mathematicians from Petrarch to Galileo* (Geneva, 1975); Mario Biagioli, "The Social Status of Italian Mathematicians, 1450–1600," *History of Science* 27 (1989): 41–95.

aims to show, that Newton might have picked up the idea that mathematics could make valuable contributions to natural philosophy from English mathematical writers. Although England does not figure prominently in general histories of mathematics, until Newton appears on the scene, there was one significant mathematician working in England and who did make an important contribution to the changing intellectual status of mathematics.[7] This was John Dee (1527-1608), who is much more well-known as the Renaissance magus and hermetic philosopher who believed he could talk to angels with the help of his "scryer", Edward Kelley.[8]

In what follows, we shall show that Dee should be considered as one of the earliest mathematical practitioners who tried, through the example of his own work, to break down the disciplinary barrier between mathematics and natural philosophy. We shall also see that Dee's work, made an impression on some English natural philosophers, and his new approach made it possible, indeed likely, that any mathematically gifted youth, educated in England, might well have been expected to reject the traditional scholastic separation of mathematics from natural philosophy, and to develop attitudes that were much closer to those first promoted in England by John Dee. Furthermore, we shall show that Dee's work in mathematics was connected to his magical beliefs and that the natural philosophy that was so closely linked to his

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[7] A search in the *Oxford Dictionary of National Biography* for mathematicians active between the years 1400 and 1600, turns up only five names. One of these is a patron of mathematics and one is Scottish. That leaves three mathematical practitioners working in England, none of whom are active before John Dee. There is a case to be made for the claim that Dee was the first significant mathematician to appear in early modern England. See E. G. R. Taylor, *The Mathematical Practitioners of Tudor & Stuart England* (Cambridge, 1954). Taylor discusses numerous practitioners of much lower achievements, but in which Dee figures largely as the leading teacher of mathematics. For confirmation of the marginal, and minimal, nature of mathematical practice in England before Dee, see Stephen Johnston, "The Identity of the Mathematical Practitioner in 16th-Century England", in *Der "Mathematicus": Zur Entwicklung Und Bedeutung Einer Neuen Berufsgruppe in Der Zeit Gerhard Mercators*, ed. Irmgarde Hantsche (Bochum, 1996), 93–120.

[8] Peter J. French, *John Dee: The World of an Elizabethan Magus* (London, 1972); Nicholas H. Clulee, *John Dee's Natural Philosophy: Between Science and Religion* (London, 1988); Deborah E. Harkness, *John Dee's Conversations with Angels: Cabala, Alchemy, and the End of Nature* (Cambridge, 1999); Steven Vanden Broecke, *The Limits of Influence: Pico, Louvain, and the Crisis of Renaissance Astrology* (Leiden, 2003).

mathematical approach was essentially occult, and that even these occult aspects of his work can be seen to have their echoes in the later work of Isaac Newton.

John Dee and the Mathematization of Natural Philosophy

Although he was appointed as reader in Greek at Trinity College, Cambridge, in 1546, Dee almost immediately left to study at the University of Louvain in the Southern Netherlands. It is usually supposed that he left England because of the poor state of mathematical knowledge at that time.[9] Certainly, while he was in Louvain he made contact, and in some cases close associations, with a number of leading mathematical practitioners, including Gemma Frisius, Gerardus Mercator, Gaspar à Mirica, Antonio Gogava, and Pedro Nunes.[10] Dee returned to England in 1551 and continued promoting mathematical studies, mostly by teaching. In 1558 he published his first significant work, the *Propaedeumata aphoristica*, which presented his views on "Certain Outstanding Virtues of Nature".[11]

It is clear from this work that Dee was fully committed to the belief that mathematics could make an important contribution to natural philosophy, not merely by providing *demonstrationes quia*, but also by providing *demonstrationes propter quid*. But it is now known that Dee developed these ideas earlier, in response to an attack on the work of the leading mathematician of the day (and a personal friend of Dee's), Pedro Nunes, by Diogo de Sá in his *De navigatione*.[12] Dee's copy of De Sá's book, which he acquired in 1552, is heavily annotated by Dee, and the notes clearly reveal his belief not only in what a recent commentator has called "the mathematical principles of nautical science", but also in "the power of mathematics to construct valid

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[9] Clulee, *John Dee's Natural Philosophy*, 23–8.

[10] Ibid.; Broecke, *Limits*; Bruno Almeida, "On the Origins of Dee's Mathematical Programme: The John Dee–Pedro Nunes Connection," *Studies in History and Philosophy of Science* 43 (2012): 460–69.

[11] John Dee, *Propaedeumata Aphoristica… de Praestantioribus Quibusdam Naturae Virtutibus* (London, 1558). This is translated in John Dee, *John Dee on Astronomy: "Propaedeumata Aphoristica" (1558 and 1568)*, ed. Wayne Shumaker (Berkeley, 1978). Cited hereafter as Dee, *Propaedeumata*.

[12] Diogo de Sá, *De Navigatione Libri Tres: Quibus Mathematicae Disciplinae Explicantur* (Paris, 1549).

knowledge."[13] De Sá takes the traditional view that mathematical knowledge is limited and superficial when judged from a philosophical point of view, and is vigorous in his opposition to what has been called Nunes's "program for the mathematization of the real world."[14] It seems clear from Dee's annotations to De Sá's criticisms of Nunes that Dee was already committed to the view that mathematics could make a much more valuable contribution to natural philosophy than scholastics allowed. The importance of this for Dee was made public in his *Propaedeumata*.

Dee announces his intention in the dedication to the famous cartographer, Gerard Mercator, with whom he worked at Louvain. Addressing the mathematician and instrument-maker Mercator as "renowned mathematician and philosopher", Dee writes of them philosophizing together. Dee's book "on the power of the heavenly bodies" not only proceeds demonstratively, Dee claims, but also establishes "the main principles of the science." It is therefore rightly called by Mercator, Dee's "great demonstrative work".[15] Nicholas Clulee sums it up well when he says that Dee's approach in the *Propaedeumata* is to use the principles of geometrical optics to establish the way all forces are propagated in nature (all forces are assumed to be propagated in the same way that rays of light are), and this then enables Dee to develop "a mathematical theory of astral influences that he believed met Aristotle's criteria for a demonstrative science." It met Aristotle's criteria precisely because the rays of force which Dee saw as conforming to the principles of geometrical optics were the fundamental causal mechanisms operating throughout the whole cosmos.[16]

13 Almeida, "Mathematical Programme", 463, 465.
14 Ibid., 462.
15 Dee, *Propaedeumata*, 111, 113.
16 Clulee, *John Dee's Natural Philosophy*, 162, 233. See also Broecke, *Limits*, 208.

Dee continued to point to the importance of mathematics in the "Mathematicall Praeface" that he added to Henry Billingsley's translation of Euclid's *Elements* (1570). This was supposedly addressed to "unlatined people and not Universitie Scholars", and because these readers might not have been aware of disciplinary disputes about the relationship between mathematics and natural philosophy, Dee made his own beliefs about the mathematical principles of natural philosophy clear throughout.[17] As Clulee writes, "Within the limits of this imposed role [as the writer of a preface] Dee seems to have taken what liberties he could to incorporate ideas on mathematical and natural philosophy…"[18] Even in Dee's opening paragraph we read that both Platonic idealists and more down to earth Aristotelians will benefit from what Dee has to tell them about mathematics: "the *Pythagoricall*, and *Platonicall* perfect scholer, and the constant profound Philosopher, with more ease and spede, may (like the Bee,) gather, hereby, both wax and hony."[19] Dee goes on to claim that mathematical entities exist in between supernatural beings and natural things: "not so absolute and excellent, as thinges supernatural: Nor yet so base and grosse, as things naturall".[20] And shortly after he draws support from "the great & godly philosopher" Boethius, and "the noble Earle of Mirandula", Giovanni Pico. Boethius is quoted as saying that "All thinges (which from the very first originall being of thinges, haue bene framed and made) do appeare to be Formed by the reason of Numbers. For this was the principall example or patterne in the minde of the Creator." Similarly, Pico is quoted as saying "By Numbers, a way is had, to the searchyng out, and vnderstandyng of euery thyng, hable to be knowen."[21] According to Dee, the

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17 Euclid of Megara, *The Elements of Geometrie*, trans. Henry Billingsley (London, 1570). See also John Dee, *The Mathematicall Praeface to the Elements of Geometry of Euclid of Megara (1570)*, ed. Allen G. Debus (New York, 1975). Quotation from sig. *Aiiiv*.

18 Clulee, *John Dee's Natural Philosophy*, 147.

19 Dee, *The Mathematicall Praeface*, sig. *iiir*.

20 Ibid.

21 Ibid., sig. *ir-v*. Dee is quoting from Boethius, *De institutione arithmetica,* I, 2; and from the eleventh of the "Conclusions Mathematicall" from Giovanni Pico della Mirandola, *Conclusiones nongentae in omni genere scientiarum* (Rome, 1486). For modern editions, see Boethius, *Boethian Number Theory: A Translation of the* De Institutione Arithmetica, trans. Michael Masi (Amsterdam,

"profound and diuine Science" of mathematics will take the "zelous Philosopher" beyond mere contemplation to certainty and truth.[22]

Dee's "Mathematicall Praeface" presents the study of mathematics as far more important than was ever allowed in the scholastic tradition. As Peter French rightly observed, Dee's preface was "a revolutionary manifesto calling for the recognition of mathematics as a key to all knowledge and advocating broad application of mathematical principles".[23] His belief that mathematics should be an indispensable aspect of natural philosophy could hardly be missed. As he wrote at one point:

> O comfortable allurement, O rauishing perswasion, to deale with a Science, whose Subiect, is so Auncient, so pure, so excellent, so surmounting all creatures, so vsed of the Almighty and incomprehensible wisdome of the Creator, in the distinct creation of all creatures: in all their distinct partes, properties, natures, and vertues.[24]

Furthermore, as Nicholas Clulee has pointed out, Dee's belief that mathematics could reveal truths about the natural world derived, at least in part, from his commitment to natural magic. Within the magical tradition mathematics was seen as one of the most powerful ways of providing knowledge which enabled control over, and manipulation of, nature.[25] This could be seen, for example, in the various stories about automata which were common in the magical tradition, from Archytas's flying dove, made of wood, to Regiomontanus's iron fly, and the mechanical scarab beetle that Dee himself made for a spectacular stage production of a play by Aristophanes.[26] Indeed, Dee's reputation as a "conjuror" was largely based on his invention of this mechanical beetle. Automata, and other mechanical marvels, were regarded as magical productions because they were seen as artificial and unnatural, and therefore should not be included in *natural* philosophy. For those who knew how these things

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1983); Giovanni Pico della Mirandola, *Syncretism in the West: Pico's 900 Theses (1486) : The Evolution of Traditional, Religious, and Philosophical Systems*, trans. S. A. Farmer (Tempe, AZ, 1998).

22 Dee, *Mathematicall Praeface*, sig. *iv.*

23 French, *John Dee*, 167.

24 Dee, *Mathematicall Praeface*, sig. *ir.* See also, Clulee. *John Dee's Natural Philosophy*, 149–70.

25 Clulee, *John Dee's Natural Philosophy*, 157–59.

26 Ibid., 161, see also 166-76.

were made, however, they were aspects of natural magic, because they worked as a result of natural phenomena—in the same way that a clock worked because it was driven by the gradual descent of a weight, but the descent of that weight was due to its gravity and was entirely natural.[27]

Dee's belief in the links between mathematics and magic reflect those of the German occultist, Heinrich Cornelius Agrippa. The first chapter of Book II, of Agrippa's *Three Books of Occult Philosophy* is entitled "Of the necessity of Mathematicall Learning", and opens:

> The Doctrines of Mathematicks are so necessary to, and have such an affinity with Magick, that they that do profess it without them, are quite out of the way, and labour in vain, and shall in no wise obtain their desired effect.[28]

Dee's list of the books he had acquired between 1557 and 1559, shows that he acquired Agrippa's *De occulta philosophia* at the same time that he acquired Pico's *900 Conclusions* and Marsilio Ficino's influential magical treatise *De triplici vita*, and it was obviously a source from which he drew heavily.[29] This is important for our purposes because Agrippa not only insisted upon the link between mathematics and magic, but he also insisted that natural philosophy was an essential part of magic. "There is no work that is done by meer Magick", Agrippa wrote, because magic also incorporates the learning of what he calls the three faculties: natural philosophy, mathematics, and theology.

> Whosoever is desirous therefore to study in this Faculty [magic], if he be not skilled in naturall Philosophy, wherein are discovered the qualities of things, and in which are found the occult qualities of every Being, and if he be not skillful in the Mathematicks, and in the Aspects, and Figures of the Stars, upon which

[27] Ibid., 161. See Dee's account of "Thaumaturgike" in the "Mathematicall Praeface", sig. *A.j.r-v.* On the links between magic and technology, see, for example, Lynn Thorndike, *A History of Magic and Experimental Science*, 8 vols. (New York, 1923); J. Peter Zetterberg, "The Mistaking of 'the Mathematicks' for Magic in Tudor and Stuart England," *The Sixteenth Century Journal* 11 (1980): 83–97; William Eamon, "Technology as Magic in the Late Middle Ages and the Renaissance," *Janus* 70 (1983): 171–212; John Henry, "Magic and Science in the Sixteenth and Seventeenth Centuries," in *Companion to the History of Modern Science*, ed. R. C. Olby *et al*. (London, 1990), 583–96.

[28] Heinrich Cornelius Agrippa von Nettesheim, *Three Books of Occult Philosophy*, trans. John French (London, 1651), Book II, Chapter 1, 167.

[29] Clulee, *John Dee's Natural Philosophy*, 135; Frances Yates, *The Occult Philosophy in the Elizabethan Age* (2003), 49–61; 79–95; Yates, *Giordano Bruno*, 149–50; 187–89.

> depends the sublime virtue, and property of every thing, and if he be not learned in Theologie, wherein are manifested those immaterial substances, which dispence, and minister all things, he cannot be possibly able to understand the rationality of Magick.[30]

Dee shows the same tendency to disregard the disciplinary distinctions between philosophy, mathematics, theology, and of course magic.[31]

This can be seen in the numerous places throughout the "Praeface" where Dee claims that mathematics not only reveals the arrangement and structure of things, but thereby indicates the *causal* relations between things—in making claims like this, Dee is rejecting the scholastic separation of mathematics from philosophy on the grounds that mathematics cannot lead us to causes. Consider, for example, his account of "Perspective", where he writes:

> Againe, of thinges being in like swiftnes of mouing, to thinke the nerer, to moue faster: and the farder, much slower. Nay, of two thinges, wherof the one (incomparably) doth moue swifter then the other, to deme the slower to moue very swift, & the other to stand: what an error is this, of our eye? Of the Raynbow, both of his Colours, of the order of the colours, of the bignes of it, the place and heith of it, (&c) to know the causes demonstratiue, is it not pleasant, is it not necessary? of two or three Sonnes appearing: of Blasing Sterres: and such like thinges: by naturall causes, brought to passe, (and yet neuertheles, of farder matter, Significatiue) is it not commodious for man to know the very true cause, & occasion Naturall?[32]

The science of perspective does not just provide a demonstration of what can be seen (*demonstratio quia*), but explains why these things are seen the way they are (*demonstratio propter quid*). Similarly, it can explain why a peacock's tail and a dove's neck look the way they do, and why an oar in water seems to be broken:

> by demonstration Opticall, the order and cause therof, is certified: euen so, as the effect is consequent. Yea, thus much more, dare I take vpon me, toward the satisfying of the noble courrage, that longeth ardently for the wisedome of Causes Naturall.[33]

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30 Agrippa, *Three Books of Occult Philosophy*, Book I, Chapter 2, 5.

31 I do not discuss the theological dimension to his work here, but see Clulee, *John Dee's Natural Philosophy*.

32 Dee, *Mathematicall Praeface*, sig. *b.j.r.*

33 *Ibid*., sig. *b.j.v.*

Similarly, in the description of "Astrologie" Dee insists that it is based on "Not onely (by *Apotelesmes* [the influence of the stars]) τὸ ὁτὶ. but by Naturall and Mathematicall demonstration τὸ διότι."[34] These Greek expressions, meaning "the fact that" and "the reason that", respectively, are the Greek equivalents of *demonstratio quia* and *demonstratio propter quid*. Accordingly, Dee is claiming that the particular influences of the stars are not just stated as facts in astrology, but are explained by means of natural and mathematical demonstrations.

It seems clear, therefore, that Dee was the first promoter in England, and in English, of the increasingly acceptable view that mathematics could, and did, provide knowledge of causes, and *demonstrationes propter quid*, and should be seen, therefore, as making a valuable contribution to natural philosophy. Frances Yates seems to have been perfectly correct to suggest that Dee's magical perspective stimulated his attempts to establish the relevance of mathematics to natural philosophy.[35] If Newton's *Principia* can be seen as the culmination of this mathematizing of natural philosophy in England, then Dee's *Propaedeumata aphoristica* and "Mathematical Praeface" can be seen as its beginnings.

So far, we have been discussing Dee's new approach to natural philosophy in general terms. There is more to be learned, however, from looking in detail at the way Dee developed his own mathematical natural philosophy. As we shall see, it developed out of his attempts to establish astrological influence upon a more certain foundation.

Geometrical Optics and Dee's Mathematical Treatment of Celestial Influence

Dee believed that mathematics could reveal the way the occult virtues of things operated, and thereby could contribute to natural philosophical understanding. This belief seems to have originated in work that he did at Louvain to base astrology on a

[34] *Ibid*., sig. *b.iiiv*. See Clulee, *John Dee's Natural Philosophy*, 61–64.
[35] Yates, *Giordano Bruno*, 148–50; Broecke, *Limits*, 212.

more secure foundation, in response to the damaging criticism of astrology by Giovanni Pico, in his *Disputationes adversus astrologiam divinatricem* (*Disputations against Divinatory Astrology*).[36] Dee was one of those thinkers, therefore, with "contemporary concerns about astral powers", as Robert S. Westman put it, as a result of Pico's attack on astrology and the new Copernican theory which was, at least in part, a response to Pico.[37] Although Dee never fully accepted Copernican theory, it is evident that the new theory led him to believe that it should be possible to calculate the different strengths of the astral powers on earth, and thereby improve understanding of astrological causes and effects.

The important point about the Copernican theory from Dee's point of view was that it enabled astronomers to establish the distances of the Sun, moon, and planets from the earth. Assuming that celestial influence was propagated in the same way that light was emitted from the celestial bodies, the more distant a body was from the earth, the weaker would be its power. The Copernican theory enabled calculations to determine the distances of heavenly bodies from the earth, and therefore the relative strengths of their influences on the earth. Just as the celestial bodies emitted rays of light, so they emitted rays of whatever other influences they were supposed to have, according to astrological traditions. Given that a light source is less intense the further away it is from an observer, so a planet's influence on the earth would be less intense the further away it is. Similarly, a larger light source would have a greater effect than a smaller, although it too would diminish with distance. Dee also noted that the angle of incidence of the rays from a celestial body on the surface of the

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[36] Giovanni Pico della Mirandola, *Disputationes Adversus Astrologiam Divinatricem* (Bologna, 1496). For a major study of the impact of this work, see Robert S. Westman, *The Copernican Question: Prognostication, Skepticism, and Celestial Order* (Berkeley, 2011).
[37] Westman, *Copernican Question*, 3.

earth would also affect the power of those rays. Geometrical optics, therefore, provided the mathematical techniques for determining astrological influence.[38]

It might seem that this is an obvious way to think about celestial influence, but it would have been unthinkable before the appearance of Copernican theory. In the geocentric system of Claudius Ptolemy it was impossible to determine even the order of the planets, much less their distances from the supposedly central earth. The order of the heavenly bodies in the Ptolemaic system was established only by convention, because geometrically, they could be in any order. For the outer planets, the time for a complete orbit of the sky was taken to indicate their order (Saturn, taking 30 years to circle the earth, was assumed to be the furthest away; Jupiter at 12 years was next, and Mars at two years was next). The order of the sun, Mercury and Venus, however, was more controversial. Some astronomers held Mercury and Venus to be above the sun, between the sun and Mars, while others held them to be below the sun, between the sun and the moon, which was the closest to the earth. But, it was acknowledged that even Saturn could be below the sun, and the appearances and the mathematics would be the same.[39]

Astrologers before Copernicus, therefore, did not think of connecting the powers of celestial influence with planetary distances. We need not pursue the details here, but astrological influence in the Ptolemaic tradition was considered to vary in accordance with so-called "aspects", that is to say the angular formations the heavenly bodies made to one another against the backdrop of the fixed stars. Planets in conjunction – appearing close together in the sky – had a strong effect on each other and might reinforce one another or cancel one another out with regard to the earth. Planets in opposition – opposite to each other across the sky – had opposing

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[38] Broecke, *Limits*, 174–81. I have draw heavily on Broecke for this part of my discussion. See also Westman, *Copernican Question*, 183–5.
[39] Westman, *Copernican Question*, 48–61.

effects on the earth. Planets separated by 90°, by 60°, or by 30° were held to have correspondingly different effects on one another and on the earth. The nature of causation, according to Aristotle's model of four causes (material, formal, efficient, and final) was held to be formal causation. It was known that planets in conjunction might be separated from one another by vast differences, even though they appeared to be close together against the fixed stars. So, their effect on earth was not due to combined *efficient* causation (like shining two bright torches at the earth instead of one), but was due to the pattern they made in the sky – hence it was *formal* causation. Even after Copernicus, Johannes Kepler, a fully committed Copernican, continued to believe that astrology depended upon formal causation. He likened the earth to an ignorant peasant. Just as a peasant who has no understanding of music and the mathematical patterns that underlie it will spontaneously respond with pleasure to a beautiful harmony, and recoil from dissonance, so the earth (and its inhabitants) responds to the geometrical patterns in the sky.[40] This is formal causation.

Significantly, in his attack on astrology, Pico insisted that there were only two kinds of celestial influence – light and heat, or more specifically *calor caelestis* (celestial heat), the kind of life-giving heat that could be perceived to emanate from the sun, and promoted all life on earth.[41] Pico was now disregarding the usual emphasis upon formal causation and implying that if the heavenly bodies were to have any effect it must be through efficient causation – by the effect of light or heat. Consequently, Pico could now bring in geometrical assumptions, and argue that the further away a planet was from the earth, the weaker would be its light and heat. Accordingly, all the heavenly bodies are too far away, or too small, to have any effect at all, except for the sun and moon (and indeed the sun and moon were so powerful in their efficient causation, due to their size and proximity, that they would overwhelm

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[40] J. Bruce Brackenridge and Mary Ann Rossi, "Johannes Kepler's *On the More Certain Fundamentals of Astrology* Prague 1601," *Proceedings of the American Philosophical Society* 123 (1979): 98.
[41] Broecke, *The Limits*, 66–71. See also Westman, *Copernican Question*, 320–1.

whatever tiny efficient causes the planets might have).[42] As Steven Vanden Broecke has pointed out, "This critique eliminated the complexity of astrological practice by reducing it to two bodies (Sun and Moon) only."[43] But it seems that it also inspired astrologers at Louvain and in Wittemberg to counter-attack by accepting the *efficient* causation of astrological influence, and using the newly possible (Copernican) ability to calculate planetary distances to try to develop the details.[44] John Dee was at the forefront of these efforts during his time in Louvain, and his *Propaedeumata aphoristica* is his own attempt to develop a new astrology in which the efficient causes of the heavenly bodies can be accurately assessed by using geometry to take into account the size and distances of the heavenly bodies and the angle of incidence their rays make with the earth.[45]

In Aphorism 31, for example, he advises his readers that "The true distances of the fixed stars and of each of the planets from the center of the earth at any given time should be determined by the astrologer".[46] While in the following aphorism he turned his attention to the angle of incidence of heavenly rays:

> It is of the first importance to know what star, either fixed or wandering, hangs perpendicularly over what spots on the earth at a given time, and how great an angle of direct incidence it makes with all the other places over whose horizons the same star hovers at the same moment of time.

In Aphorism 33 he explains that a ray of influence from a star to an external point is reinforced by a surrounding cone of influence; "The axis of the cone is the ray, the vertex is the external point"; while the base of the cone "is that luminous portion of the convex surface of the same star" which faces the external point. Here he is

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42 Dee dismisses Pico's suggestion that the sun would overwhelm any effects the planets might have in Aphorism 90 of Dee, *Propaedeumata*, 177. But see also, Aphorism 95 (179), where he acknowledges "As the sun surpasses other celestial bodies in size, so it is – one might say – a perpetual and immense source of heavenly light and the chief producer of sensible and vital heat for us."

43 Broecke, *Limits*, 71–2.

44 Ibid., 164–70. See also Westman, *The Copernican Question*, 178–83.

45 See also John L. Heilbron, "Introductory Essay," in Dee, *Propaedeumata*, 51–73.

46 Dee, *Propaedeumata*, 137. Dee clearly believes that it ought to be possible to determine planetary distances, as shown by Copernicus, even though he himself does not accept the truth of Copernican theory. See Broecke, *Limits*, 179–80.

dealing with surface effects – rays emanating from the surface of a star or planet – but he tells his readers that "we shall speak in another place of rays coming from the depths of stellar bodies". Meanwhile, he points out that "All stars larger than the earth imprint their rays upon it more strongly in the degree in which they are nearer to it; and they also illuminate a larger portion of the earth by their sensible and direct rays than when they are separated from it by a greater interval."[47]

It is clear that Dee was using the principles of geometry, and of geometrical optics, to develop a new account of astrological influence. And this was clearly intended to refute Pico's claims that only the sun and moon can exert a sensible effect on the earth, and that the only means by which they can affect the earth is through light and celestial heat. On this last point, Dee implied throughout that there are other kinds of influence. In Aphorism 25, for example, he tells us that "the rays of all stars are double: some are sensible or luminous, others are of more secret influence".[48] Later (Aphorism 45), he says that the geometry of influence he is developing "skilled persons perceive to be of great importance in optics, in astrology, and in magic."[49] Similarly, writing later in the "Mathematicall Praeface", Dee showed that he did not confine geometrical "perspective" merely to light:

> Perspectiue, is an Art Mathematicall, which demonstrateth the maner, and properties, of all Radiations Direct, Broken, and Reflected. This Description, or Notation, is brief: but it reacheth so farre, as the world is wyde. It concerneth all Creatures, all Actions, and passions, by Emanation of beames perfourmed. Beames, or naturall lines, (here) I meane, not of light onely, or of colour (though they, to eye, giue shew, witnes, and profe, wherby to ground the Arte vpon) but also of other Formes, both Substantiall, and Accidentall, the certaine and determined actiue Radiall emanations.[50]

In the "Mathematicall Praeface", Dee referred back to his *Propaedeumata* with some pride, presenting himself as the first to have properly developed this new mathematical method of treating natural philosophy: "And in my *Propædeumes*

47 Dee, *Propaedeumata*, 137–39.
48 Ibid., 133.
49 Ibid., 145.
50 Dee, *Mathematicall Praeface*, sig. b.j.*r*.

(besides other matter there disclosed) I have Mathematically furnished up the whole Method: To this our age, not so carefully handled by any, that ever I saw, or heard of."[51] It is clear, therefore, that it was a major aim of Dee to show the relevance of mathematics to natural philosophy, and that this methodological ambition was first fully developed in his *Propaedeumata*.

It only remains, therefore, for us to go beyond Dee's methodology and to look at the actual details of his natural philosophy. We need to understand just how the models provided by geometrical optics actually applied to, and explained the behavior of, the phenomena of the real world (at least, the real world as it was envisaged by Dee). Dee's new mathematical method applied to natural philosophy precisely because he developed what Nicholas Clulee has called an "astrological physics".[52] For Dee astrology was "an Arte Mathematicall, which reasonably demonstrateth the operations and effects, of the natural beames, of light, and secret influence: of the Sterres and Planets: in every element and elementall body..."[53] Accordingly, if physics was astrological, it must also be mathematical.

The Light Metaphysics Tradition and Dee's Astrological Physics

Dee's physics was astrological in the sense that astrology was held to provide the model for all causation and all changes in the world. Light was held to be the fundamental causal principle in the natural world, and to provide the model for all other efficient causes supposed to be operating in nature. All change was brought about by the action of light, or by rays of some other influence emanating from an active source (and which also operated in accordance with the principles of geometrical optics). And as we have just seen, Dee was not content to describe the

51 *Ibid.*, sig. b.iii*v*–b.iiij*r*.
52 Clulee, *John Dee's Natural Philosophy*, 42–52. Similarly, Broecke refers to Dee's "mathematical astrological physics", Broecke, *Limits*, 211.
53 Dee, *Mathematicall Praeface*, sig. b.iii*r*.

nature of celestial and other influences merely in qualitative terms. He tried also to calculate the strength of these rays, and the behaviour of the species, in geometrical terms. In so doing he promoted the new claims of mathematicians that mathematics, contrary to what the scholastics claimed, really was able to provide causal explanations in natural philosophy. The geometry of rays provided the key to understanding all natural phenomena; all influences, forces, and powers were propagated in accordance with the principles of geometrical optics.[54] What Dee's *Propaedeumata* offered was a natural philosophy based on radiated influences, and these influences were held to be the principal causal actions operating throughout the cosmos.[55] The "outstanding virtues of nature", mentioned on the title page, were radiated from all things. As Dee wrote in Aphorism 4:

> Whatever exists by action emits spherically upon the various parts of the universe rays which, in their own manner, fill the whole universe. Wherefore every place in the universe contains rays of all the things that have active existence.[56]

Furthermore, the importance of light in the universe can be seen from the fact that it was "the first of *Gods Creatures*."[57]

As a new kind of natural philosophy this is really remarkable, and marks a very radical departure from anything found among the scholastics. If we see Dee's *Propaedeumata* within the context of Renaissance magical cosmologies, however, it clearly draws upon earlier systems of thought, including those of Marsilio Ficino and earlier neo-Platonists, Cornelius Agrippa and other magical theorists, and alchemy as well as astrology.[58] Arguably the biggest influence on Dee, however, was the

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54 Clulee, *John Dee's Natural Philosophy*, 54, 162.

55 Ibid., 169, 233. See also Broecke, *Limits*, 170–71, 210–12.

56 Dee, *Propaedeumata*, 123.

57 Dee, *Mathematicall Praeface*, sig. b.j.*r*.

58 On Dee as a Renaissance neo-Platonist, see I. R. F. Calder, "John Dee Studied as an English Neoplatonist" (Ph.D., Warburg Institute, 1952); Yates, *The Occult Philosophy*. On the influence of Agrippa and other magical thinkers, see Clulee, *John Dee's Natural Philosophy*; Harkness, *John Dee's Conversations*. On Dee as an alchemist see Jennifer M. Rampling, "John Dee and the Alchemists: Practising and Promoting English Alchemy in the Holy Roman Empire," *Studies in History and Philosophy of Science* 43 (2012): 498–508. On Dee as an astrologer, see Broecke, *Limits*; Westman,

medieval English thinker, Roger Bacon and the tradition of which he was a part, known to historians as "light metaphysics".[59]

The so-called "light metaphysics" tradition is usually seen as deriving from the emanationism of the neo-Platonist philosopher Plotinus, and developed by Proclus, Pseudo-Dionysius, and others, in which the world system was seen as consisting of a series of emanations from God, beginning with the most spiritual (light), and ending with the densest matter. The ancient neo-Platonic emanationists considered light to be the efficient cause by which God brought about the Creation. Their speculations were not restricted to visible light, because they also believed that light could act as a hidden cause of phenomena, and even a hidden source of force as though light could push things as it disseminated from a source. Accordingly, the tradition provided an alternative way of understanding physical causation, and this alternative kind of explanation was prominent in the magical tradition. This can be seen most clearly in the medieval Latin work known as *De radiis stellarum* (*On the rays of the stars*), or even as *De theorica artium magicarum* (*On the theory of the magical arts*), which was attributed to the Arabic philosopher, al-Kindi (although no Arabic version of the work exists).[60] As al-Kindi writes at one point: "it is obvious that each thing in this world, whether substance or accident, produces rays in its own way like the stars". And "Assuming this to be true we say that everything which actually exists in the world of elements sends out rays in all directions. These [rays] fill the entire world of

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Copernican Question.

59 For Bacon's influence on Dee, see Clulee, *John Dee's Natural Philosophy*, 52–73. On Bacon and the tradition of light metaphysics, see David C. Lindberg, *Theories of Vision from Al-Kindi to Kepler* (Chicago, 1976); Roger Bacon, *Roger Bacon's Philosophy of Nature: A Critical Edition, with English Translation, Introduction, and Notes, of* De Multiplicatione Specierum *and* De Speculis Comburentibus, ed. and trans. David C. Lindberg (Oxford, 1983). Although usually called "light metaphysics", this is something of a misnomer, since the tradition is concerned with physics, not metaphysics. But see James McEvoy, *Robert Grosseteste* (Oxford, 2000), 90–5, where he argues that there were metaphysical aspects of the tradition.

60 On this work, and its authorship, see Peter Adamson, *Al-Kindī* (Oxford, 2007), 188–206; Al-Kindī, *The Philosophical Works of Al-Kindī*, ed. Peter Adamson and Peter E. Pormann, trans. Peter Adamson and Peter E. Pormann (Oxford, 2012), 218–19.

elements in their own way."[61] Dee's Aphorism 4, which we quoted above, seems to be a repetition of this belief.

The tradition was introduced into English thought in the thirteenth century by Robert Grosseteste, Bishop of Lincoln, who translated the works of Pseudo-Dionysius from Greek into Latin, and circulated them with his own commentary.[62] Grosseteste clearly believed that light did much more than illuminate the world; he also held it to be a universal principle of activity and a major cause of change in the universe. As he wrote:

> The first corporeal form, which some call corporeity I consider to be light. For light by itself diffuses itself in every part, in such a way that a point of light, a sphere of light of any size (as big as you like) is generated…

He goes on to say that matter and form are diffused throughout the universe in the same way, but it is the spontaneous diffusion of light which drives this: "I have proposed that it is light which possesses of its very nature the function of multiplying itself and diffusing itself instantaneously in all directions."[63] In another work, Grosseteste writes:

> Truly, when light generates itself following one path and dragging matter with itself, it creates local motion. Indeed, when light, which is inside matter, is sent out and what is outside sent in, it creates change. And it is clear, that the motion of bodies is [the result of] a multiplicative power of light.[64]

Commenting on this, James McEvoy has suggested that this tradition is based on "the idea that the physical universe is made up of light, so that all its features, including space, time, non-living and living things, spheres, and stars are different forms taken by a single fundamental energy."[65]

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61 Al-Kindī, *Philosophical Works*, 226.

62 Jean Leclercq, "Influence and Non Influence of Dionysius in the Western Middle Ages," in *PseudoDionysius, The Complete Works*, trans. Colm Luibheid (Mahwah, NJ, 1987), 25–33; McEvoy, *Robert Grosseteste*, 87–95.

63 Robert Grosseteste, *On Light*, trans. C. C. Reidl (Milwaukee, 1942), 10.

64 This is from Grosseteste's *De motu corporali et luce*, 51-2. "Cum vero lux secundum unam viam se generat secum trahens materiam, fit motus localis. Cum vero lux, quae est intra materiam, mittatur foras et quod foris est, immittit intus, fit alteratio. Et in hoc patet, quod motio corporalis est vis multiplicativa lucis." See also, A.C Crombie, *Robert Grosseteste and the Origins of Experimental Science, 1100-1700*, 107.

65 McEvoy, *Robert Grosseteste*, 87–8.

These ideas, and other aspects of the tradition, were taken up by Roger Bacon, who was a great admirer of Robert Grosseteste. Bacon was so committed to light metaphysics that, as David Lindberg suggested, he incorporated it into his entire system of physics: "Bacon never developed a full metaphysics of light; rather, he took the *physics* of light as expressed by al-Kindi and Grosseteste – the claim that radiation is the universal instrument of natural causation – and developed it into a systematic doctrine."[66] In his important work *On the Multiplication of Species* (*De multiplicatione specierum*), Bacon extended the meaning of "species" beyond its original meaning of "likeness" or "image", so that, as Lindberg has suggested, "It became the force or power by which any object acts on its surroundings, a synonym for al-Kindi's universal force." As Bacon wrote, the "species"

> is the first effect of an agent; in this regard, all the other effects are produced. Thus those wise and foolish men differ from their knowledge concerning species. Nevertheless they agree in this, that the agent sends species into the matter on which it acts, so that, through that which was first produced, it can bring out of the potentiality of the matter the complete effect the agent intended.[67]

Dee was a great admirer of Bacon, and it could be said that the system of natural philosophy presented in the *Propaedeumata* owes more to Bacon than to any other earlier thinker, although there are clear similarities also with al-Kindi, and Grossesteste.[68] Bacon and Dee even shared the same lexicon of terms. Dee used the terms "rays", "species", even "virtues" in almost interchangeable ways. In Aphorism 4 all things are said to emit rays, but in Aphorism 5 all things emit species:

> Both substance and accident emit their own species from themselves, but every substance far more excellently than an accident. Also, among substances, what is

[66] David C. Lindberg, "The Genesis of Kepler's Theory of Light: Light Metaphysics from Plotinus to Kepler," *Osiris* 2 (1986): 19.

[67] Bacon, *De multiplicatione specierum*, 1.1. 42–69, 75–80; "scilicet quod species est primus effectus agentis. Per hanc enim omnes aestimant effectus caeteros produci, unde sapientes et insipientes circa multa in specierum cognitione differunt. Communicant tamen in hoc, quod agens influit speciem et materiam patientis, quatenus per eam primo factam possit educere de potentia materiae effectum completum quern intendit".

[68] Dee seems to have been introduced to the work of Roger Bacon while he was in Louvain, and subsequently collected a number of Bacon manuscripts. See Clulee, *John Dee's Natural Philosophy*, 12–3, 28.

> incorporeal and spiritual, or becomes spiritual, far surpasses in this function, what is corporeal and composed of unstable elements.[69]

At the same time, in Aphorism 27 we read that celestial rays have the power of penetrating everything in the universe, and that this proves the stars "have a great readiness to influence everything", or to impart their "virtue" to everything.[70]

Dee also accepted the standard view of the light metaphysics tradition that light was not always visible, but sometimes operated in an occult way. Moreover, the occult influences were more pervasive. In Aphorism 25, for example, we read:

> The rays of all stars are double, some sensible or luminous, others of more secret influence. The latter penetrate in an instant of time everything that is contained in the universe; the former can be prevented by some means from penetrating so far.[71]

Similarly, Dee also accepted the standard view that light was the most active thing in the universe after the first mover (God): "As it is the prerogative of the first motion that without it all other motions should become quiescent, so it is the faculty of the first and chief sensory form, namely, light, that without it all other forms could do nothing".[72]

The opening aphorisms of the *Propaedeumata* make it clear that all change, including the motions of things, are the result of the rays which all things emit. So, in Aphorism 6 we are told: "Just as one thing differs from another, so their rays differ in their power of affecting and in the causing of their effects so long as they act wholly upon the same object." And in Aphorism 14, we read:

> Not merely spiritual species, but also other natural ones, flow from things both through light and without light, not to sight only but sometimes to other senses; and they come together especially in our imaginal spirit, as if in a mirror, show themselves to us, and enact wonders in us."[73]

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69 Dee, *Propaedeumata*, 123–25.
70 Ibid., 135.
71 Ibid., 133.
72 Ibid., 131.
73 Ibid., 125, 127–29.

But, as we said earlier, Dee was not content to describe the nature of celestial and other influences merely in qualitative terms, but wanted to provide mathematical reasons for the operations and strength of celestial influences. A nice example of this can be seen where Dee argued that a knowledge of catoptrics, the geometrical optics of plane and curved mirrors, could enable us to make the operation of occult virtues manifest: "If you were skilled in 'catoptrics', you would be able, by art, to imprint the rays of any star much more strongly upon any matter subjected to it than nature itself does."[74] Here Dee suggested that the use of curved mirrors might intensify the effects of occult celestial influences, just as they can be used to intensify the sun's heat. Accordingly, we could manipulate the rays making them either stronger or weaker, and thus could manipulate the influence of those rays upon the terrestrial realm. As Dee added in a corollary to this aphorism:

> By this means obscure, weak, and, as it were, hidden virtues of things, when strengthened by the catoptric art, may become quite manifest to our senses. The industrious investigator of secrets has great help offered to him from this source in testing the peculiar powers not merely of stars but also of other things which they work upon through their sensible rays.[75]

Significantly, Dee also suggests in this aphorism that he is merely reviving the natural magic of "the ancient wise men", but he also links it to the manipulations of nature performed by alchemists, or philosophers of so-called "inferior astronomy": "This, indeed, was by far the largest part of the natural magic [*naturalis Magiae*] of the ancient wise men. And this secret is not of much less dignity than the very august astronomy of the philosophers, called inferior…"[76]

Dee's mathematical astrological physics depended upon the same combination of geometrical optics with occult ideas about celestial rays that can be found in al-Kindi's *De theorica artium magicarum*, Grossesteste's *De luce*, and especially in Roger Bacon's *De multiplicatione specierum* and his *De speculis comburentibus* (*On*

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[74] Ibid., 149.
[75] Ibid.
[76] Ibid.

burning mirrors). But unlike these earlier writers, Dee was writing at a time when mathematics was being increasingly recognized as a potentially valuable contributor to natural philosophy, contrary to what scholastics had always taught. Although the *Propaedeumata aphoristica* might seem very strange to our eyes, for Dee's contemporaries, particularly those who shared Dee's belief that natural magic and alchemy may be more potentially fruitful than scholastic natural philosophy, it may well have seemed to offer a natural philosophy that was supported by, and perhaps even proved true by, the certainties of mathematics. Even if many of his contemporary readers were less favourable towards the occult, and remained unconvinced by Dee's specific claims, they might still have been inspired by the attempt to combine natural philosophy with mathematics. Just as Francis Bacon can be seen as promoting experimental investigations as a useful addition to natural philosophy (as we shall see in the next chapter), so John Dee can be seen as the first English thinker to promote the mathematization of natural philosophy to contemporary natural philosophers.

David Lindberg summed up the natural philosophy which was part of the light metaphysics tradition, and which he claimed Grosseteste and Bacon had learned from al-Kindi, as based on the assumption "that every creature in the universe is a source of radiation and the universe a vast network of forces."[77] In turn, Dee learned this natural philosophy of efficient forces from Roger Bacon. Given that these forces were envisaged as rays, and operated analogously to light, and to astrological influence, Dee, like Bacon, could apply geometrical analysis to establish the strength of these forces, and their sources. Accordingly, as Steven Vanden Broecke has pointed out, "Dee found it self-evident to associate his astrological pursuits with natural philosophy", and his natural philosophy was inherently a "mathematical

[77] Lindberg, "Genesis", 13.

astrological physics".[78] It was also, therefore, one of the first examples of a natural philosophy which actually depended upon mathematical principles.

After Dee: The Mathematization of Natural Philosophy from Digges to Barrow

Dee's role in the mathematization of natural philosophy has hardly been noticed in the historiography, but there can be no doubt that he was one of the first internationally known thinkers who was recognized as both a mathematician and a philosopher.[79] In England, Dee can be seen as the first in the new movement to establish the relevance of mathematics to natural philosophy, and to show its importance in understanding the causes of things.

This is not the place to trace Dee's subsequent impact on later readers, but in what follows we shall indicate that the movement to which Dee contributed did not die with him, but was carried on by later philosophers who could combine the skills of the mathematician with the skills of the natural philosopher. My aim is not to attempt a complete history of all the relevant thinkers and practitioners, but merely to consider a few landmark figures, to show that there was a continuous tradition of mathematizing natural philosophers, from Dee's time, right through to Newton's *Principia*.

We can begin with one of Dee's followers, and one of the first Copernicans in England, Thomas Digges. The son of Leonard Digges, who had published a few practical mathematical treatises, Thomas referred to Dee as his "second parent" in mathematics; and Dee returned the compliment by calling Digges his "heir."[80] Digges made his acceptance of Copernicanism clear in "A Perfit Description of the

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[78] Broecke, *Limits*, 210-1.

[79] Although the importance of Dee's mathematics to his wider ambitions has been noticed by Clulee, Heilbron, Broecke, and more recently Westman, in the works already heavily cited above, only Westman is aware of the new movement to introduce mathematics into natural philosophy, and recognizes Dee's place in that movement.

[80] Johnston, "Identity"; Westman, *Copernican Question*, 269.

Caelestiall Orbes", which he added to his edition of his father's *Generall Prognostication* in 1576, along with an English translation of four chapters from Copernicus's *De revolutionibus*.[81] Digges's Copernicanism already strongly suggests that he believed mathematics can reveal truths about the nature of the world, but we can see this confirmed in the preface to his "Perfit Description".[82]

Although he did not go into details Digges suggested that the sun drives the planets, including the earth, around itself because it "giveth laws of motion to the rest"; this is a philosophical claim. A few lines later Copernicus was presented as a philosopher who proves the truth of his claims by mathematics: "reason and deepe discourse of wit having opened these things to Copernicus, and the same being with demonstrations Mathematicall, most apparently to the world delivered."[83] Over the page he dismissed those who regard Copernican theory as merely an exercise in hypothetical mathematics:

> Copernicus ment not as some have fondly excused him, to deliver these grounds of the earth's mobility, onely as Mathematicall principles fayned, and not as Philosophicall truly averred: I have also from him delivered both the Philosophical reasons by Aristotle and others, produced to maintaine the Earths stabilitie, and also their solutions and insufficiencie…[84]

Digges did not completely forget the mathematical side of the matter. A little later he asked his readers:

> If therefore the Earth be situate immoveable in the Center of the world, why finde we not Theoricks upon that ground to produce effects as true and certain as those of Copernicus? Why cast wee not away those *Circles Aequantes*, and motions irregular?

[81] Leonard Digges, *A Prognostication Everlasting of Right Good Effecte… Lately Corrected and Augmented by Thomas Digges His Sonne* (London, 1592).The 1592 edition includes Thomas Digges, "A Perfit Description of the Caelestiall Orbes…" Hereafter cited as Digges, "Perfit Description".
[82] Copernicus himself took this line, of course. See Westman, "Astronomer's Role."
[83] Digges, "Perfit Description", sig. M*r*.
[84] *Ibid.*, sig. M*v*. Digges discusses Aristotle's arguments against a moving earth sigs N2*r*–N3*r*, and "The solution of these Reasons with their insufficiencie", sigs N3*r*–O*r*.

He went on to suggest that if it proves impossible to provide mathematical theories which explain the earth's stability, then we should allow ourselves to be ruled instead by the "Rule of Reason".[85]

The influence of Dee can perhaps also be seen in a remarkable outline of a new system of philosophy written around 1635. Entitled "A Short Tract on First Principles", this used to be considered to be an early work of Thomas Hobbes, but it now seems more likely to have been written by his friend, Robert Payne, who was chaplain and secretary to William Cavendish, Earl of Newcastle.[86] If Payne was not influenced by Dee, he was certainly directly inspired by Roger Bacon's *De multiplicatione specierum*, and like Dee developed what he found in Bacon into a natural philosophy which could be supported by the principles of geometrical optics.[87] "Every Agent that worketh on a distant Patient", Payne declares, must touch the patient, either by an intervening medium or "by somewhat issueing from it self". Although he accepts that an intervening medium may transmit a movement from one body to another, Payne evidently believes that efficient causation is more likely by "somewhat issueing", and Payne calls these emitted things "Species". We are also told that "Agents send out their species continually."[88]

It is very clear that species are held to behave in the same way as light, which is composed of "species visible", but they are not always visible, or sensible to humans

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85 Digges, "Perfit Description", sig. M*v*.

86 The "Short Tract on First Principles", British Library, Harley Ms. 6796, ff. 297–308; first published in Thomas Hobbes, *The Elements of Law Natural and Politic*, ed. Ferdinand Tönnies (London, 1889), 193–210; hereafter cited as Payne, "Short Tract". The "Short Tract" has recently been attributed to Robert Payne (though the attribution remains controversial). See Timothy Raylor, "Hobbes, Payne, and *A Short Tract on First Principles*," *The Historical Journal* 44 (2001): 29–58; Noel Malcolm, "Robert Payne, the Hobbes Manuscripts, and the 'Short Tract,'" in *Aspects of Hobbes* (Oxford, 2002), 80–145.

87 On Payne's knowledge of the work of Roger Bacon, see Mordechai Feingold, "A Friend of Hobbes and an Early Translator of Galileo: Robert Payne of Oxford," in *The Light of Nature: Essays in the History and Philosophy of Science Presented to A.C. Crombie*, ed. J. D. North and J. J. Roche (Dordrecht, 1985), 265–80.

88 Payne, "Short Tract", 197, 199.

in any way, as in the case of magnetism and "influence from the Moone on humide bodies".[89] As for Bacon and Dee, Payne's species seem to be immaterial substances, with specific properties. They are virtues, powers, or forces, emanating from material agents, but not themselves material, but they do have their own separate existence, and are held to move away from the emanating body to the so-called "patient" body.[90] Accepting the standard view that light was active, self-motive, and had a spontaneous ability to diffuse itself throughout space, Payne insisted that a species of light, or another species, had "active power inherent in it self" and "inherent power to move".[91]

The "Short Tract", written about 1635, has been seen as an early attempt to develop a mechanical philosophy, but it is important to note that Payne accepted some obviously occult beliefs:

> There is between Species Conveniency and Disconveniency, by which the agents whence they issue, attrude and repell one the other.
>
> This is manifest by Experience in things that attract or repell one the other by Sympathy and Antipathy. For seeing they touch not one another, and motion of the Attraction or Repulsion is not wrought by alteration of the Medium (by the 2 Concl. Sect. 2) it must be by Species; and seeing all Agents and Patients do not so move one the other, it follows that those which do so worke, must worke by somewhat proper to their Species, which is what we call Conveniency or Disconveniency and the Greekes, Sympathy and Antipathy.[92]

Not only did Payne accept that species could be inherently active, he also accepted, as we see here, that they could attract or repel one another at a distance. Payne's "Conveniency or Disconveniency" foreshadowed ideas that would be repeated decades later by Robert Hooke, who wrote of the "Congruity and Incongruity" of

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89 *Ibid.*, 199.

90 Earlier interpretations of the "Short Tract" tried to establish that the species were material streams of particles. This seems to have been an attempt to make it look more like an early mechanistic work by Hobbes (to whom it was then attributed). On the atomistic aspects of the "Short Tract", see Frithiof Brandt, *Thomas Hobbes' Mechanical Conception of Nature* (Copenhagen, 1928), 73–7. But see also, Malcolm, "Robert Payne," especially 125–27.

91 Payne, "Short Tract", 193, and 197. See also 195, where Payne writes of an "Agent that moveth by Active power originally in itself".

92 Ibid., 203. The "2 Concl. Sect 2" reads: "Agents at distance worke not all on the Patient by successive action on the parts of the Medium":198. Clearly, Payne is trying to forestall suggestions that action at a distance is always done by successive transmission through a material medium.

particles, and by Isaac Newton, who wrote of sociable and unsociable atoms.[93] I do not claim that Payne's "Short Tract" was known to, or a direct influence upon, Hooke and Newton. But, as Noel Malcolm has said, the "Short Tract" "is certainly an impressive piece of work, produced by a person who had thought long and hard about some of the most difficult problems in contemporary science and philosophy."[94] It is not so surprising, therefore, that Payne arrived at tentative solutions to those problems that prefigured the tentative solutions offered by Hooke and Newton.

The "Short Tract" is brief and consists of sets of numbered "Principles" followed by numbered "Conclusions" which follow from those principles. It is presented as natural philosophy, rather than geometry, but it is clear that some of the Conclusions are based on geometrical reasoning. In section 2, for example, Conclusion 4 reads: "Species, the farther they go from the body whence they issue, the weaker they are". It is evident that the species do not get weaker as a result of physical exhaustion, however, but merely as a consequence of the geometry of emanating particles:

> Suppose the Agent A send out species to DE, I say the species in DE are weaker than the species in BC. For seing there are no more species in DE than in BC, and in DE they are more diffused, and in BC more united; it followes that the species in DE are weaker than those in BC. By the same reason the species in FG are weaker than the species in DE, and so forewards, the farther they goe, still the weaker.

And Payne provides a geometrical diagram to illustrate what he means:[95]

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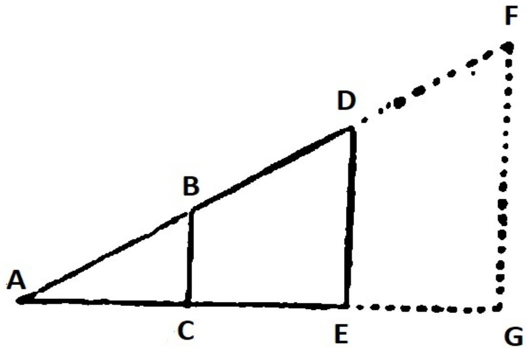
93 See Robert Hooke, *Micrographia: Or Some Physiological Descriptions of Minute Bodies Made by Magnifying Glasses: With Observations and Inquiries Thereupon* (London, 1665), 15, 16, 21, 31, 32; Isaac Newton, "An Hypothesis Explaining the Properties of Light, Discoursed of in My Several Papers," in *Isaac Newton's Papers & Letters on Natural Philosophy and Related Documents*, ed. I. Bernard Cohen (Cambridge, MA, 1978), 179. On Hooke, see John Henry, "Robert Hooke, the Incongruous Mechanist," in *Robert Hooke: New Studies*, ed. Michael Hunter and Simon Schaffer (Woodbridge, 1989), 149–80. On Newton's sociable and unsociable matter see Newman, *Newton the Alchemist*, 474–77. See also Chapter 5 below.

94 Malcolm, "Robert Payne," 126–27.

95 Payne, "Short Tract", 199.



The underlying geometry of Payne's species is the geometry of light rays, and although Payne does not explicitly discuss the importance of mathematics for a proper understanding of natural philosophy, it is clear that the system of philosophy outlined in the "Short Tract" is based on mathematical principles.

Although most people today would regard mathematics and magic as completely separate and non-overlapping approaches to understanding the world, we have seen throughout this chapter that this was by no means the case in the Renaissance and early modern periods. For many at this time the *mathematicus* and the *magus* were more often than not united. Certainly Roger Bacon was seen as both, as was John Dee in his turn.[96] By 1648, however, attitudes were beginning to change. It is significant that although John Wilkins called his survey of the practical usefulness of mathematics, *Mathematical Magick*, he felt the need to apologize for the title in his preface.[97]

> This whole Discourse I call Mathematical Magick; because the art of such Mechanicall inventions as are here chiefly insisted upon, hath been formerly so stiled; and in allusion to vulgar opinion, which doth commonly attribute all such

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[96] See Clulee, *John Dee's Natural Philosophy*, 64–6. On Bacon as a magician, see A. G. Molland, "Roger Bacon as Magician," *Traditio* 30 (1974): 445–60. For general works, see, for example, Zetterberg, "The Mistaking of 'the Mathematicks' for Magic in Tudor and Stuart England"; Henry, "Magic and Science."

[97] John Wilkins, *Mathematical Magick: Or, the Wonders That May Be Performed by Mechanical Geometry* (London, 1648). I have used the edition of *Mathematical Magic* in John Wilkins, *The Mathematical and Philosophical Works… in Two Volumes* (London, 1802). Hereafter cited as Wilkins, *Mathematical Magic*, with the page number from the second volume. On Wilkins, see Barbara J. Shapiro, *John Wilkins, 1614-1672: An Intellectual Biography* (Berkeley, CA, 1969); William Poole, ed., *John Wilkins (1614-1672): New Essays* (Leiden, 2017).

> strange operations unto the power of magic; for which reason the Ancients did name this art … *Mirandorum Effectrix*."[98]

But Wilkins's "To the Reader" also promotes mathematics as a worthy part of philosophy. He even writes of developing a new method in which mathematics and philosophy are inseparable:

> It hath been my usual custom in the course of my other studies, to propose divers mathematical or philosophical enquiries… and as I could gather satisfaction, to compose them into some form and method.

And a little later he praises mathematics as presenting "such notions as carry with them their own evidence and demonstration", before going on to talk of the pragmatic benefits to a gentleman's estates.[99]

He also calls upon ancient authority – naming the two parts of his book after Archimedes and Daedalus, "both these being two of the first authors, that did reduce mathematical principles unto mechanical experiments."[100] He even tries to persuade his readers that it was Aristotle, rather than Plato, who promoted the usefulness of geometry to philosophy (thereby trying to turn on its head the standard scholastic view that geometry was largely irrelevant to philosophy). Plato was one of those responsible for forbidding the practical use of the mathematical sciences, and reducing them to "vulgar experiment". This in turn led to a belief that these studies were nothing "but empty and useless speculations."[101] Aristotle, by contrast,

> Being so far from esteeming geometry dishonoured by the application of it to mechanical practices, that he rather thought it to be thereby adorned, as with curious variety, and to be exalted unto its natural end.[102]

Wilkins was referring here to Aristotle's *Mechanical Questions*, which is now known to be written by a member of the Peripatetic school rather than by Aristotle himself, but at this time the work was believed to be a newly recovered work by Aristotle,

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[98] John Wilkins, *Mathematical Magic*, 90.
[99] Ibid., 89.
[100] Ibid., 90.
[101] Ibid., 93.
[102] Ibid., 94. On the continuing importance of ancient authority for natural philosophers in seventeenth-century England, see Levitin, *Ancient Wisdom*.

first translated into Latin in 1517.[103] This pseudo-Aristotelian work has been described by Helen Hattab as based on "a form of explanation that combined geometrical principles with considerations regarding the physical causes of motion", and was itself an important work in contemporary attempts to raise the intellectual status of mathematics. It is surely significant, therefore, that Wilkins should draw on it to defend what he was doing in *Mathematical Magick*.[104] Wilkins declared that the art of mechanics sprang from "honourable parentage, being produced by geometry on the one side, and natural philosophy on the other."[105]

There is no hint of a magical aspect of mathematics in the work of Isaac Barrow, but he can be seen to be taking it for granted that mathematics is an important addition to, and part of, natural philosophy. Indeed, he has been seen as promoting a "strong program of mathematization of natural philosophy" and "categorically assert[ing] the scientific character of mathematical demonstration."[106] In his inaugural lecture as the first Lucasian Professor of Mathematics at Cambridge (the University's first chair in mathematics), Barrow even seems to treat mathematics and philosophy interchangeably. Describing how he moved from "the Drudgery of Grammar to the more desireable exercise of Mathematics", he explained "For though I was never wholly averse to Philology, yet not to dissemble, I was always more deeply in Love with Philosophy".[107] Clearly, Barrow is seeking to justify the establishment of this

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[103] Paul Lawrence Rose and Stillman Drake, "The Pseudo-Aristotelian *Questions of Mechanics* in Renaissance Culture," *Studies in the Renaissance* 18 (1971): 65–104.

[104] Helen Hattab, "From Mechanics to Mechanism," in *The Science of Nature in the Seventeenth Century: Patterns of Change in Early Modern Natural Philosophy*, ed. Peter R. Anstey and John A. Schuster (Dordrecht, 2005), 100.

[105] Wilkins, *Mathematical Magic*, 96.

[106] Antoni Malet, "Isaac Barrow on the Mathematization of Nature: Theologcal Voluntarism and the Rise of Geometrical Optics", *Journal of the History of Ideas* 58 (1997): 265, 274, 277. On Barrow, see Mordechai Feingold, *Before Newton: The Life and Times of Isaac Barrow* (Cambridge, 1990). Peter Dear points out that "Barrow… knew a lot about contemporary methodological and epistemological issues concerning the status and nature of mathematical knowledge". See, Dear, *Discipline*, 222–3.

[107] Isaac Barrow, *The Usefulness of Mathematical Learning Explained and Demonstrated*, trans. John Kirkby (London, 1734), "Prefatory Oration" [Barrow's inaugural lecture for the Lucasian Chair], xxii. This is a translation of Barrow's *Lectiones Mathematicae* (1683).

new chair of mathematics, but even so, he has no trouble listing all the practical and intellectual benefits that come from knowledge of mathematics. It is because of mathematics that we can "discover Things hidden, search Nature out of her Concealments, and unfold her dark Mysteries."[108] A little later, he added:

> The Steps are guided by no Lamp more clearly through the dark Mazes of Nature, by no Thread more surely through the intricate Turnings of the Labyrinths of Philosophy; nor lastly is the Bottom of Truth founded more happily by any other Line.[109]

Like Wilkins, Barrow also provides an account of the history of philosophy in which (contrary to scholastic assumptions) mathematics always played an important role, not just for Plato, but for Aristotle as well. The works of these "greatest philosophers", Barrow writes,

> are every where interspersed and bespangled with Mathematical Reasonings and Examples, as with so many Stars; and consequently any one not in some Degree conversant in these Studies will in vain expect to understand, or unlock their hidden Meanings, without the help of a Mathematical Key.[110]

Significantly, Barrow's major achievement in the history of science was in geometrical optics, and in particular in developing a geometrical account of image formation.[111] We need not consider the details here, but it is important to note that Barrow concentrated on mathematical accounts of the behaviour of light because he declared himself to be sceptical of physical accounts:

> These are what meditation has suggested to me about the part of Optics which is chiefly Mathematical. About the remaining parts (which are physical, and in so far as they pretty frequently necessarily have to offer for sale plausible conjectures rather than certain principles) almost nothing reliable occurs to anyone.[112]

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108 Ibid., xxix–xxx.
109 Ibid., xxxi.
110 Ibid., xxvi–xxvii.
111 See, Alan E. Shapiro, "The *Optical Lectures* and the Foundations of the Theory of Optical Imagery", in Feingold (ed.), *Before Newton*, 105–78.
112 Isaac Barrow, *Lectiones Opticae et Geometricae* (London, 1674), Lecture XVII, § XIII: 125. "Haec sunt, quae circa partem Opticae praecipue Mathematicam dicenda mihi suggessit meditation. Circa reliquas (quae physicae sunt, adeoque saepiuscule pro certis principiis plausibiles conjecturas venditare necessum habent) nihil fere quicquam admodum versimile succurrit…"

Barrow was sceptical about efficient causation in general: "For there can be no such connection of an external… efficient cause with its effect (at least none such can be understood by us)…"[113]

Nevertheless, he does offer a speculative theory of light in which material particles of light play the role of an efficient cause, capable of pushing other matter:

> I assume every luminous body, as such, to be a certain mass of corpuscles of a smallness and fineness almost beyond what can be thought; however, each of them, when struck by a very violent motion, extend outwards in a straight line (according to that law of nature sufficiently received and investigated)… Meanwhile… they must continue their course in a straight line, setting in motion and pushing before themselves the matter… which does not resist so strongly, putting it to flight.[114]

In spite of the fact that Barrow suggests here that light particles have to be struck out of luminous bodies "by a very violent motion", elsewhere he seems to regard light particles as self-moving: "And so continuously, and together, an indefinitely extended series of such corpuscles moves and endeavours forwards."[115] Indeed, one of the six hypotheses which Barrow assumes to explain the behaviour of light is that "From every point of a luminous (or illuminated) body is sent a ray of light in a straight line to any point in the medium (when no obstacle intervenes)."[116]

Alan Shapiro sees Barrow's theory of light as an eclectic theory which draws heavily upon Descartes. But, as he himself admits, "Barrow's theory differs fundamentally from Descartes's."[117] For Descartes, light is a pulse through the plenum, but nothing actually changes its place. Barrow's rays of light, however, are composed of particles

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[113] Barrow, *The Usefulness*, 88.

[114] Barrow, *Lectiones Opticae*, Lecture I, § VII: 5. "Pono corpus omne lucidum, ut tale, congeriem esse quandam corpusculorum ultra pene quam cogitari potest minutorum & exilium; horum antem unumquodque vehementissimo motu percitum, aliquot (secundum legem istam naturae satis receptam & exploratam) recta tendere; tum medium circumstare, fluidum quoque (cuius nempe partes nullo colligatae nexu quaquaversum libere feruntur)… Interim vero… via cursum suum recta continuare, materiam… deprehensam haud ita fortiter obsistentem in fugam agentia, & ante se protrudentia."

[115] Barrow, *Lectiones Opticae*, Lecture I, § VII: 6. "Et ita continuo, sic ut simul et semel indefinite protensa talium corpusculorum series promoveatur, et antrorsum connitatur."

[116] Barrow, *Lectiones Opticae*, Lecture I, § IX, Hypothesis 2: 7. "Ab omni corporis lucidi (vel illustrati) puncto ad quodvis medii (non obstaculis intercisi) punctum lucis aliquis radius dirigitur."

[117] Shapiro, "The *Optical Lectures*", 114-5.

which are really moving from the source outwards. Barrow's theory seems to owe as much to earlier assumptions about species, but he has clearly made them more corpuscularian, and materialistic. For Barrow a ray of light is a physical entity, as Shapiro suggests, "a long, thin, right cylinder or prism, which is the path traced out by the shape of the emitted… light particles."[118] Shapiro sees this concept as deriving from Thomas Hobbes, who promoted the idea in his *Tractatus Opticus* of 1644, and criticises Barrow for not acknowledging Hobbes: "it is difficult to justify Barrow's failure to attribute the concept of physical ray to Hobbes."[119] But Hobbes, like Descartes, assumed a light ray merely represented a pulse moving through a plenist medium, and so Barrow's theory of a ray as a body of moving particles was very different from that of Hobbes, and was in fact closer to the kind of rays described by Dee, and later by Payne. We should remember that Hobbes and Payne were close friends, and rivals in developing new approaches to natural philosophy.[120] We do not have to suppose that Barrow must have been aware of the earlier work of Dee or Payne; but it is highly possible that Barrow was unconsciously conforming to a way of thinking which was common in England among those working on optics.

In spite of his scepticism about physical causes, in his *Lectiones Mathematicae* (*Mathematical Lectures*), published in 1683, Barrow's sixth lecture was aimed at showing that mathematics could provide causal explanations. "We have treated in Part concerning the Evidence and certainty of the Mathematics in the last Lecture; it now remains that we speak of their Dignity, and shew more distinctly that they are really Scientific and Causal, and after what Manner."[121] For Barrow, mathematics was simply a different form of logic, and therefore "Mathematical Ratiocinations are the most perfect Demonstrations":

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[118] Ibid., 115.
[119] Ibid., 118.
[120] Malcolm, "Robert Payne".
[121] Barrow, *Usefulness*, Lecture VI: "Of the Causality of Mathematical Demonstration," 83.

> it seems to me that every certain and evident Discursus, flowing according to the irrefragable Rules of Logic, from Principles universally and perpetually true, and consequently wherein a necessary Connection of the Terms is found, is most properly, scientifically and perfectly a demonstration: And that all other Causality, which is here applicable, besides this Connection already explained, is mere Fiction, supported by no Argument, nor confirmed by any Example.[122]

As Peter Dear has pointed out, Barrow insisted throughout his lectures that physics and mathematics are strictly inseparable, and that the same attitude was held by Newton: "Barrow's position resembles closely Isaac Newton's idea of 'mathematical principles of natural philosophy' – a terrible category mistake by earlier standards."[123] To present mathematics as an important component of natural philosophy was certainly a category mistake for earlier, and perhaps for some later, scholastic thinkers, but by the time Newton came to write the *Principia* it was a much more familiar position. So much so, that even in the opening sentence of his Preface, Newton could refer to both ancients and moderns (Descartes and his followers) as supporting the combination of mathematics and philosophy:

> Since the Ancients (according to Pappus) considered mechanics to be of the greatest importance in the investigation of nature and science and since the moderns… have undertaken to reduce the phenomena of nature to mathematical laws, it has seemed best in this treatise to concentrate on mathematics as it relates to natural philosophy.[124]

Indeed, Newton was obviously aware that this new way of combining mathematics and philosophy was seen by his contemporaries as an exciting development. Writing to Halley as he was completing the *Principia*, Newton made it clear that he thought *De motu corporum* (*On the motion of bodies*) would be a better title. But, Halley had paid for the printing of the book, and was hoping to recover his money through sales, and so Newton wrote: "but upon second thoughts I retain the former title. Twill help the sale of the book which I ought not to diminish now tis yours."[125] A book on the

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[122] Ibid., 99. See also 44, where he says "mathematics… is co-extended and made equal with physics itself."

[123] Dear, *Discipline*, 178–9. See also, Malet, "Isaac Barrow", 265–87.

[124] Newton, *Principia*, 381.

[125] Issac Newton to Edmond Halley, June 1686, in H. W. Turnbull, *et al.*, ed., *The Correspondence of Isaac Newton* (Cambridge, 1960), ii: 437.

mathematical principles of natural philosophy, Newton believed, would attract buyers.

Dee and Newton, The Mathematization of Natural Philosophy, and Light as an Active Principle

It is well known that the full title of Newton's *Principia* announced that it was a book about the "mathematical principles of natural philosophy", and in so doing it implicitly rejected the scholastic exclusion of mathematics from natural philosophy. It is important to note, however, that Newton was already committed to this new attitude to mathematics and its relevance to philosophy long before he wrote the *Principia*. In his unpublished manuscript, known to scholars as "De Gravitatione", Newton wrote of "two methods", the mathematical and the philosophical, and yet clearly saw them as intimately related.[126] Demonstration of the science of weights "strictly and geometrically", he wrote, "may be judged to be somewhat akin to natural philosophy":

> in so far as it may be applied to making clear many of the phenomena of natural philosophy… and in order, moreover, that its [i. e. natural philosophy's] usefulness may be particularly apparent and the certainty of its principles perhaps confirmed.[127]

Furthermore, as early as 1672, or perhaps even earlier, Newton had already been aware of the inseparable connections between mathematics and physics while dealing with the problem of colour. In response to Hooke's opposition to his science of colour, in a letter to Henry Oldenburg, Newton wrote:

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[126] Edited and translated in Newton, *Unpublished Scientific Papers*, 89–156. The dating of this work is contested. The editors of *Unpublished Scientific Papers*, A. R. and Marie Boas Hall, date it between 1664 and 1668, and say that it is difficult to believe it was written later than 1672 (90). B. J. T. Dobbs, however, suggested in her *Janus Faces of Genius*, that it was written as part of the drafts for the *Principia*, in 1685. I have accepted the early dating of the Halls here.

[127] Newton, *Unpublished Scientific Papers*, 121.

> I said indeed that the Science of Colours was Mathematicall & as certain as any other part of Optiques; but who knows not that Optiques & many other Mathematicall Sciences depend as well on Physicall Principles as on Mathematicall Demonstrations: And the absolute certainty of a Science cannot exceed the certainty of its Principles.[128]

So if the mathematical demonstration was valid, so was Newton's science of colour. He adopted the same thinking in his optical lectures at Cambridge University. When dealing with colour theories Newton felt fully justified to say that, inspired by his speculation on colour, he

> …attempt[s] to extend the bounds of mathematics somewhat, just as astronomy, geography, navigation, optics, and mechanics are truly considered mathematical sciences even if they deal with physical things: the heavens, earth, seas, light, and local motion. Thus although colors may belong to physics, the science of them must nevertheless be considered mathematical, insofar as they are treated by mathematical reasoning.[129]

A whole treatise on colours (and light), *Opticks*, was published several years later first in 1704, and then the second English edition in 1717. I shall return to his theory of light later, but the way he treated colours follows completely the same attempt to combine mathematics and natural philosophy as we saw in "De Gravitatione". His conclusion about colours in the 1704 edition was striking, in that "the Science of Colours becomes a Speculation as truly Mathematical as any other part of Opticks".[130] Geometrical optics had always been conceded by scholastics to be a so-called "mixed mathematical science", which mixed the principles of mathematics (geometry) with principles of physics (the behavior of light rays), but in extending mathematics to the explanation of colours, which was not previously regarded as part of geometrical optics, Newton was once again linking geometry to natural philosophy. Colour theory was previously seen as part of natural philosophy, not part

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[128] Newton, *The Correspondence*, 96.
[129] Newton, *The Optical Papers*, 439.
[130] Newton, *Opticks*, 244.

of the mixed mathematical science of geometrical optics, but Newton showed that mathematics helped us to understand the nature of colours.[131]

When Newton came to write the *Principia* he acknowledged in the Preface that "the moderns… have undertaken to reduce the phenomena of nature to mathematical laws", and accordingly, "it has seemed best in this treatise to concentrate on mathematics as it relates to natural philosophy."[132] Although Newton is almost certainly referring to the Cartesians here, the attempt to introduce mathematical analysis into natural philosophy pre-dated the appearance of Descartes,[133] and, as we have seen, had its own promoters in English natural philosophy, beginning with John Dee. For most of his contemporaries, however, the claim that there were mathematical principles of natural philosophy still seemed, as Peter Dear has pointed out, to be a "category mistake".[134] It is perhaps for this reason that Newton included a defence of his use of mathematics in the General Scholium which he added at the end of the second edition of the *Principia* in 1713. Without fully going into details, Newton insisted in the General Scholium that "Gravity toward the sun is compounded of the gravities of toward the individual particles of the sun, and at increasing distances from the sun decreases exactly as the squares of the distances as far out as the orbit of Saturn…"[135]

Similarly, in the *Optice* of 1706, and the second English edition of the *Opticks* in 1717, Newton insisted to his readers that mathematics and natural philosophy should be seen as relying on the same methods: "[a]s in Mathematicks, so in Natural

131 Shapiro, *Fits, Passions, and Paroxysms*, 12–48.
132 Newton, *Principia*, 381.
133 Dear, *Discipline*.
134 Dear, *Discipline*, 179.
135 Newton, *Principia*, 943.

Philosophy, the Investigation of difficult Things by the Method of Analysis, ought ever to precede the Method of Composition."[136]

Given the unprecedented success and fame of Newton's *Principia*, however, it was that, as scholars have all agreed, which inaugurated a new era, in which mathematics came to be increasingly recognised as an indispensable part of the physical sciences.[137] Furthermore, it has also been noticed that Newton's so called "mathematization of natural philosophy" in the *Principia*, was essentially geometrical. As Guicciardini pointed out, although the mathematical structure of the *Principia* is complex, incorporating algebra and calculus, it is above all, and most obviously to casual readers, a work which relies on geometry as a way of showing the relevance of mathematics to natural philosophy. This aspect of Newton's method persisted in *Opticks* as well, and it clearly echoes Dee's (and Barrow's) geometrical physics, as detailed above.

In his study of John Dee's natural philosophy, Nicholas Clulee wrote that "it would be vain to argue that Dee's work on astrology represents any contribution to the progressive development of science."[138] But Clulee wrote before the new historiography of the introduction of mathematics into natural philosophy, and failed to see the full historical significance of Dee's *Propaedeumata aphoristica*, and his "Mathematicall Praeface". Dee's belief in astrological influence provided the model for his belief (borrowed from al-Kindi and Roger Bacon) "that every creature in the universe is a source of radiation and the universe a vast network of forces."[139] And since these forces were themselves modelled on light rays, Dee was able to show

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136 Newton, *Opticks*, 404.
137 For example, Dear, *Discipline*; Niccolò Guicciardini, *Reading the* Principia*: The Debate on Newton's Mathematical Methods for Natural Philosophy from 1687 to 1736* (Cambridge, 1999).
138 Clulee, *John Dee's Natural Philosophy*, 72.
139 Lindberg, "Genesis," 13.

how the principles of geometrical optics were directly relevant to his physics and its theory of causation. I have argued that Dee was at the forefront, therefore, of the mathematization of natural philosophy in England, and I have indicated that, following Dee, this movement gathered in strength and came to be increasingly acknowledged as an enhancement of natural philosophy. If Newton's *Principia* was the culmination of this movement in England, Dee's *Propaedeumata* was the beginning.

As Peter Dear has written, "The significance of Newton's handling of experience makes sense only when seen in light of the story that leads up to it."[140] The foregoing has argued that a significant part in that earlier story was played by John Dee and his attempts to develop an astrological physics. When Newton made, in Dear's words, "a kind of mathematical natural philosophy that would, not long before, have been unthinkable", he was succeeding where Dee had failed. But Dee should be seen, not just as an occultist who believed he could speak to angels, but also as a thinker who was trying, long before Newton, to develop a mathematical natural philosophy.[141]

It seems, however, that their contributions to this new methodological movement were not the only similarities between them. There are also strong similarities between Dee's "light physics", and his belief that the world is "a vast network of forces", to use David Lindberg's characterisation,[142] and Newton's belief in light as an active principle at work in the world, and his belief in gravity as a non-mechanical immaterial force (that is to say, a force which cannot be reduced to force of impact, and seen merely as the result of the impact of a moving body upon another body,

[140] Dear, *Discipline*, 248.
[141] Ibid.
[142] Lindberg, "Genesis", 13.

which is the only kind of force acknowledged in the Cartesian system).[143] It might be expected that Dee's "light physics", which clearly derived from neo-Platonic emanationism and light metaphysics, and later ideas introduced by al-Kindi, Robert Grosseteste and Roger Bacon, would have quickly disappeared as the mechanical philosophy began to dominate natural philosophy throughout Europe. Generally speaking, this might have been true, but if we look at Newton's own beliefs about the nature of light, there are distinct echoes of the same neo-Platonic views that can be seen in Dee's work.

Consider, for example, the famous early alchemical work that Newton wrote in the early 1670s, and known as "Of Natures obvious laws and processes in vegetation".[144] Here Newton tries to account for the activity of matter by supposing an active aether which permeates all things: "This is the subtil spirit which searches the most hiden recesses of all grosser matter which enters their smallest pores & divides them more subtly then any other materiall power what ever." But he soon introduces light into the discussion, as an even more active principle:

> Note that tis more probable the aether is but a vehicle to some more active spirit. & the bodys may bee concreted of both together, they may imbibe aether as well as air in generation & in that aether the spirit is intangled. This spirit perhaps is the body of light 1 because both have a prodigious active principle both are perpetuall workers 2 because all things may be made to emit light by heat, 3 the same cause (heat) banishes also the vitall principle. 4 Tis suitable with infinite wisdom not to multiply causes without necessity 5 Noe heat is so pleasant & benign as the suns. 6 light & heat have a mutuall dependance on each other & noe generation without heat… 6 Noe substance so indifferently, subtily & swiftly pervades all things as light & noe spirit searches bodys so subtily percingly & quickly as the vegetable spirit.[145]

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[143] There is a strong tendency in the scholarship on force to consider only force of impact, and to see force as an aspect of mechanics, but Newton's gravity is no more a force of impact than magnetic attraction or repulsion, and is much more closely related to the immaterial forces which Dee envisages. On the standard treatment of force as merely mechanical, see, for example, Westfall, *Force in Newton's Physics*, and Boudri, *What was Mechanical about Mechanics*.

[144] Isaac Newton, "Manuscripts of the Dibner Collection MS. 1031 B, The Dibner Library of the History of Science and Technology, Smithsonian Institution Libraries, Smithsonian Institution," *The Chymistry of Isaac Newton*, accessed October 21, 2018, http://webapp1.dlib.indiana.edu/newton/mss/intro/ALCH00081.

[145] Newton, "Of Natures obvious laws", fol. 4*r*.

These comments cannot be dismissed as early speculations which he soon discarded. Similar ideas appear in his "Hypothesis explaining the Properties of Light" which he sent to the Royal Society in 1675. Newton begins by describing "various aetherial spirits" which account for electricity, magnetism, gravity and other occult phenomena. When he turns to the discussion of light, he first of all insists that it is not caused by aether, or supposed vibrations in the aether; light is "something of a different kind propagated from lucid bodies."[146] Light is held to be active, consisting "of rays differing from one another in contingent circumstances, as bigness, form, or vigour". Light and aether "mutually act upon one another", the impact of light acting as an efficient cause to set up vibrations in the aether: "Aetherial vibrations are therefore the best means by which such a subtile agent as light can shake the gross particles of solid bodies…" The aether acts through its vibrations, but those vibrations are initiated by self-moving light.[147]

Furthermore, even in Newton's mature work on light, his *Opticks*, light still appears as a self-moving efficient cause, capable of entering into the composition of material bodies and stimulating them into various actions. In Query 5, for example, we read: "Do not Bodies and Light act mutually upon one another… Light upon Bodies for heating them, and putting their parts into a vibrating motion wherein heat consists?" Admittedly, light rays consist of streams of material particles for Newton, and so it might be claimed that these interactions of light and matter are simply compatible with the mechanical philosophy. But Newton's light particles are self-moving; Newton does not offer a mechanistic account of what sets light particles in motion,

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[146] Newton, "Hypothesis Explaining the Properties of Light", in *Isaac Newton's Papers and Letters on Natural Philosophy*, 184.
[147] Newton, *Isaac Newton's Papers and Letters on Natural Philosophy*, 185, 188. We will return to Newton's vibrating aether in Chapter 5, below.

as Descartes did in his *Principia philosophiae*.[148] Furthermore, he believes that light particles and other bodies act upon one another at a distance:

> Pellucid Substances act upon the Rays of Light at a distance in refracting, reflecting, and inflecting them, and the Rays mutually agitate the Parts of those Substances at a distance for heating them; and this Action and Re-action at a distance very much resembles an attractive Force between Bodies.[149]

Similarly, in Query 30, Newton rhetorically asks: "may not Bodies receive much of their Activity from the Particles of Light which enter their Composition?" He also suggests in this Query that bodies can change into light, and light into bodies. This leads us into the final Query, where Newton suggests the particles of bodies (including particles of light) have "certain Powers, Virtues, or Forces, by which they act at a distance."[150]

David Lindberg's description of Roger Bacon's natural philosophy as a system in which "every creature in the universe is a source of radiation and the universe a vast network of forces", I have suggested could apply equally well to Dee's natural philosophy; but it could apply also to Newton's physics.[151] For all three of these great English thinkers, it was assumed that bodies could interact with one another by means of efficient forces emanating from bodies. Although for Bacon and for Dee those forces were most clearly represented by light, while for Newton they were most clearly represented by gravity, Newton himself acknowledged that the "attractive Force between Bodies" which he had established in the *Principia* "very much resemble[d]" the "Action and Re-action at a distance" between bodies and light.[152] Dee and Newton had more in common than a belief that there really are mathematical principles of natural philosophy.

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148 See, for example, Gaukroger, *Descartes' System*; Schuster, *Descartes-Agonistes*.
149 Newton, *Opticks*, 339, 370–71.
150 Ibid., 374, 375–76.
151 Lindberg, "Genesis," 13.
152 Newton, *Opticks*, 371.

Conclusion

This opening chapter has dealt with the English background to the major aspect of Newton's methodology—his use of mathematics as an aid to understanding and explaining the workings of the physical world. It was appropriate to begin with John Dee, who was effectively the first significant contributor to natural philosophy in England since the Middle Ages. Dee is known as an occult thinker, and is therefore illustrative of one of the main themes of this thesis—that occult ways of thinking played a significant part in the historical development of natural philosophy in England. But, this chapter also shows that Dee was the first thinker in England to promote the idea (opposed to scholastic assumptions) that mathematics can be used to help us to understand the workings of the physical world. The first section, "John Dee and the Mathematization of Natural Philosophy" established that Dee did indeed argue that mathematics should be regarded as an important part of natural philosophy, in both his *Propaedeumata aphoristica* and his "Mathematicall Praeface". It shows the origins of this way of thinking could be seen in Louvain, where Dee studied with leading mathematicians (Mercator, Frisius, Nunes, etc.), and in the magical works which he read (Ficino, Agrippa, Pico). Having argued in general terms in the previous section, the next section, "Geometrical Optics and Dee's Mathematical Treatment of Celestial Influence", showed precisely how Dee demonstrated the relevance of mathematics to natural philosophy. Dee offered a new physics based on rays of force, emanated by all bodies, and operating throughout the universe. This new concept of physics was based on Dee's belief in celestial influence and his belief that such influences operated in the same way that light rays did. Accordingly, geometrical optics could be extended to reveal not just the behaviour of light, but also the behaviour of occult influences. The section argued that although Dee was not a Copernican he was made aware of the importance for astrology of being able to establish the distances of the planets, and other heavenly bodies (to calculate their comparative strengths), and extended this to a concern with angles of incidence of rays of influence (which also affected the strength of the influences). Dee's new physics of rays of force could not be understood without understanding the mathematics of geometrical optics, and so Dee was committed to the view that mathematics was essential for natural philosophy.

The first two sections were concerned with Dee's methodology. The third one, "The Light Metaphysics Tradition and Dee's Astrological Physics", looked at the actual content of his new physics—how did the world actually work, according to Dee? Here it was confirmed that Dee really did believe that all bodies were emitting rays of influence, or rays of force, which were capable of affecting other bodies, and causing change. This is shown to be a new statement of an older Neoplatonic tradition, usually called "light metaphysics" by scholars, but which is really a tradition of light physics, or physics based on the behaviour of light, and by extension other rays of influence. The earlier tradition was summed up by David Lindberg as the belief "that every creature in the universe is a source of radiation and the universe a vast network of forces", and this section shows that Dee's new physics was based on the same assumptions.[153] Dee is usually thought to have been influential only in esoteric circles and among occult thinkers. The next section, "After Dee: The Mathematization of Natural Philosophy from Digges to Barrow", therefore, aimed to show that the kind of thinking developed by Dee can be seen, at least to some extent, even in more mainstream thinkers. It began with a mathematical follower of Dee, Thomas Digges, who is known as one of the earliest converts to Copernicanism, and who also promoted the view that mathematics should be incorporated into natural philosophy. The section then discussed a well-known manuscript of the 1630s, usually regarded by scholars as a foreshadowing of the

[153] Lindberg, "Genesis", 13.

mechanical philosophy, in which the tradition of light metaphysics was clearly prominent, and was also used to promote the use of mathematics in natural philosophy. Finally, the section showed that two later mathematicians, John Wilkins and Isaac Barrow were both committed to the view that mathematics was an essential constituent of reliable natural philosophy. The aim here was not to claim that Dee was a direct influence upon the later thinkers, as he was upon Digges; rather, the aim was simply to show that there was a continuous tradition in England from Dee onwards which regarded mathematics as an important aspect of natural philosophy.

It was noted in the last section that Newton too was in this same tradition, initiated in England by Dee, of regarding natural philosophy as having indispensable mathematical principles. But, more importantly for the thesis as a whole, this section also showed that elements of the light metaphysics tradition clearly appeared in Newton's own speculations about the natural world. These ideas can be seen not merely in early markedly occult writings by Newton, such as "Of Nature's Obvious Laws and Processes in Vegetation", and the "Hypothesis… of Light", but also in the *Opticks*, especially in the "Queries". Furthermore, Newton's concept of gravity as an immaterial and non-mechanical attractive force show marked similarities to the kind of speculations about immaterial forces, modelled upon supposed astrological influences, that can be seen in Dee's work. The section does not claim direct influence between Dee and Newton, but suggests that the light metaphysics tradition clearly had a significant presence in English thought in the seventeenth century, and was associated on the one hand with attempts to show the relevance of mathematics to natural philosophy, and on the other with belief in the real existence of occult influences.

Chapter 2: Experiencing Occult Principles: Francis Bacon and the Experimental Method

Introduction

Although Newton's *Principia* might suggest to modern readers that Newton was primarily what we would call a "mathematical physicist", Newton scholars have shown that he was also an experimental philosopher with a deep commitment to empiricism as the only reliable way of understanding the natural world.[1] It seems reasonable to ask, therefore, whether the work of Francis Bacon had any impact on the development of Newton's thought. It is Francis Bacon's name that is associated with the promotion of the experimental method, and its eventual establishment as a defining aspect of modern science. Francis Bacon did not invent empiricism, but he played a major role in making the experimental approach philosophically respectable, at a time when most university professors of natural philosophy rejected empiricism in favour of a speculative and contemplative approach to understanding the natural world.

The natural philosophy that was taught in the universities was still largely dominated by medieval scholasticism. Scholastic philosophy had developed throughout the Middle Ages as an essentially rationalist philosophy, based largely on the doctrines of Aristotle. Although Aristotle himself should be seen as an empiricist, his medieval followers took his conclusions for granted, and used them as the basis from which to reason about other natural phenomena. The aim of scholastic natural philosophy was

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[1] For example, Ernan McMullin, "The Significance of Newton's *Principia* for Empiricism," in *Religion, Science and Worldview*, ed. Osler and Farber (Cambridge, 1985), 33–59; William L. Harper, "Reasoning from Phenomena: Newton's Argument for Universal Gravitation and the Practice of Science," in *Action and Reaction: Proceedings of a Symposium to Commemorate the Tercentenary of Newton's* Principia, ed. Paul Theerman and Adele F. Seeff (London and Toronto, 1993), 144–82; William L. Harper, *Isaac Newton's Scientific Method: Turning Data into Evidence about Gravity and Cosmology* (Oxford, 2012); Zvi Biener and Chris Smeenk, "Cotes' Queries: Newton's Empiricism and Conceptions of Matter," in *Interpreting Newton: Critical Essays*, ed. Andrew Janiak and Eric Schliesser (Cambridge, 2012), 105–37; Andrew Janiak, "Isaac Newton," in *The Oxford Handbook of British Philosophy of the 17th Century*, ed. Peter R. Anstey (Oxford, 2013), 96–115.

to demonstrate the truth of claims about the natural world based on logical inference from already accepted presuppositions. In so far as empirical evidence was required, it had to be familiar and generally accepted, so that its role in the reasoning process was clear and uncontroversial. The outcome of any specially contrived experiment, therefore, could not be relevant to this process.[2] Knowledge acquired by experiment was not familiar to all, and so its relevance to a process of reasoning about nature could always be challenged. Furthermore, the achievements of so-called "empirics", artisans of various kinds, was seen by philosophers as being the result of trial-and-error, arrived at without any understanding of the underlying natural phenomena. This seemed to confirm that experimental approaches never could reveal the reasons why things happen the way they do, and were therefore irrelevant to the aims and objectives of natural philosophy.[3]

Although the experimental method was already being adopted by a number of pioneering thinkers in the early modern period, most famously, by William Gilbert and by Galileo, but also by various less well-known mathematicians, medical writers, and a few with occult interests, it was Francis Bacon who first developed a philosophical justification for the experimental method.[4] Although scholastics might be impressed by particular achievements of Gilbert's or Galileo's experimental approach, it was only by turning to Bacon's *Novum Organum* of 1620, that they could learn how and why the experimental method might be considered superior to their own contemplative methods. The "Organum", or "Instrument", was the collective name given to the works of Aristotle on logic and method, and Bacon's

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[2] Peter Dear, "Miracles, Experiments and the Ordinary Course of Nature", *Isis*, 81 (1990): 663–83.
[3] Trial and error experiments were seen as the practice of the so-called "empirics", whose approach was rejected by all learned men, including Bacon himself. See, Rossi, *Francis Bacon*.
[4] Ernan McMullin, "Conceptions of Science in the Scientific Revolution," in *Reappraisals of the Scientific Revolution*, ed. David C. Lindberg and Robert S. Westman (Cambridge, 1990), 27–92; Rose-Mary Sargent, "Baconian Experimentalism: Comments on McMullin's History of the Philosophy of Science," *Philosophy of Science* 68 (2001): 311–318.

Novum Organum was a clear announcement that he was offering an alternative to Aristotle's methods.[5]

Furthermore, Bacon's new experimental method was most influential in England, and can be seen to have been taken up, at least to some extent, by a number of different thinkers.[6] Perhaps the most committed follower of Bacon's new method, and the one who made it work most successfully, was Robert Boyle, but it was also adopted, at least in their public announcements if not always in practice, by the Fellows of the Royal Society of London.[7] It seems necessary, therefore, to include Bacon in our survey of the forerunners of Isaac Newton, to see if any aspects of Newton's work can be seen to have been foreshadowed in Bacon's works on natural philosophy.

The aim is not to suggest that Newton deliberately and self-consciously took some of his ideas directly from Bacon's writings. Rather, the aim is simply to show that some of Newton's methodological pronouncements, and other aspects of his natural philosophy, can be seen to reflect the earlier ideas of Bacon, and to share with Boyle, and other Fellows of the Royal Society, a number of aspects of the contemporary Baconianism which had become commonplace in English natural philosophy.

Although Bacon's new reformist scheme of natural philosophy was never completed, and remains underdeveloped, and even unclear in a number of respects, it is still possible to see Bacon's broader intentions. In what follows we will not restrict ourselves to Bacon's methodology, but we will also show how his method was closely linked to a belief in natural magic, and the implications of this for other

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[5] Francis Bacon, *The Oxford Francis Bacon XI: The Instauratio Magna Part II: Novum Organum and Associated Texts*, ed. Graham Rees and Maria Wakely (Oxford, 2004). Henceforth cited as Bacon, *Novum organum*. On Aristotle's logic, see, for example, Michael Ferejohn, *The Origins of Aristotelian Science* (New Haven, 1980).
[6] Webster, *The Great Instauration*.
[7] For example, Michael Hunter, *Science and Society in Restoration England* (Cambridge, 1981).

aspects of Bacon's philosophy, including his theory of matter. It will be seen that Bacon's theory of matter, arising from his intertwined magical and methodological views, assumed matter to be inherently active. The activity of matter in Bacon's philosophy was not a logical consequence of his philosophy—rather, it was simply an assumption on Bacon's part—but it was an assumption that could not be shown to be false, or untenable, within the terms of Bacon's own philosophy. To accept Bacon's philosophy was to accept that matter could be, and as a matter of fact is, inherently active.

At a time when the mechanical philosophy, based on a theory of matter as completely inert and passive, was rapidly gaining ground on the Continent, natural philosophers in England showed a marked tendency to assume that matter is inherently active, and is able to manifest its activity in various different ways (this will be seen repeatedly throughout this dissertation). The only significant exception to this widespread attitude was Thomas Hobbes, who insisted, like Descartes, that matter was completely passive and inert.[8] Given this marked contrast between the Cartesian Continent and England, the question arises as to why this should have been so. It is difficult to resist the conclusion that Bacon's theory of matter, with its assumption that matter was endowed with numerous varieties of in-built activity, was the deciding factor.[9] It is the contention of this thesis that the influence of Bacon's philosophy in England ensured that strictly inert and mechanistic theories of matter

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[8] Although Hobbes was accused of allowing unexplained activity in matter by Robert Boyle. See, John Henry, "Hobbes, Galileo, and the Physics of Simple Circular Motions," *Hobbes Studies* 29 (2016): 32–5.

[9] On the range of activities in matter in Bacon's writings, see Guido Giglioni, "Lists of Motions: Francis Bacon on Material Disquietude," in *Francis Bacon on Motion and Power*, ed. Guido Giglioni et al. (Dordrecht, 2016), 63–82; idem , "Francis Bacon," in *The Oxford Handbook of British Philosophy in the Seventeenth Century* (Oxford, 2013), 41–72. It might be objected that Epicurean atomism, which assumed inherent motions in atoms, might have been the deciding factor. But Epicureanism was revived by Pierre Gassendi, working in France, and any claim that he was more influential in England than on the Continent would itself need to be explained. The obvious explanation would be that Baconianism made Gassendi's active matter more acceptable to English thinkers than to Continental thinkers. So, Bacon is the real deciding influence, not Epicureanism.

never fully took hold. On the contrary, theories of matter in England tended to reflect Bacon's view that matter was inherently active, and that no explanation for this innate activity was either possible, or required.

The Origins of Experimental Method, from Natural History to Induction

Francis Bacon was raised by his father, Nicholas, Keeper of the Great Seal in Elizabeth I's administration, to follow in his footsteps as a statesman. Aspiring without success to various offices of state during Elizabeth's reign, he finally found favour with James I, being appointed Attorney General in 1613 and Lord Chancellor in 1618. Although Bacon produced most of his philosophical works, late in his life, during James's reign, he had evidently already begun to formulate his ideas for the reform of natural philosophy while aspiring to office under Elizabeth. It is perhaps not so surprising, therefore, that his plans for reform required the establishment of a new Department of State, a province, with himself at its head, directing a select group of civil servants.[10]

Although Bacon never succeeded in persuading Elizabeth or James to set up a new province of the civil service, towards the end of his life he managed to write an idealized account of what he had in mind in his Utopian work, *New Atlantis* (published shortly after his death, in 1626). Salomon's House, an autonomous research institute, details the various ways in which information about the natural world is collected, by various groups carrying out different tasks (some gathering original observations, others collecting information from books, others performing experiments, and so on); there is a division of labour, but all intended to result in the establishment of true science.[11] One of the most striking aspects of the work undertaken in Salomon's house is that it is widely collaborative. Bacon's reformed

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[10] Bacon, *Novum Organum*, 109.
[11] Rose-Mary Sargent, "Bacon as an Advocate for Cooperative Scientific Research," in *The Cambridge Companion to Bacon*, ed. Markku Peltonen (Cambridge, 1996), 146–71.

natural philosophy will not be the work of one man, but the result of a concerted effort by many working together. Unfortunately for Bacon, because he was never able to put his collaborative vision into practice, he had to try to illustrate how it would work by trying to do on his own what should have been done by many.[12] Clearly, Bacon never gave up on his dream of reforming natural philosophy.

Bacon's methodological principles were dictated by the collaborative reformist enterprise that he had envisaged early on in his career. Accordingly, he laid great stress on gathering accurate information about the natural world. This information was to be based entirely upon the senses, and not on any rational analysis. Information was supposed to be gathered without any theoretical preconceptions, or without any attempt to explain what was observed. Accordingly, what were called "natural histories" were to form a major part of Bacon's reforms. The more extensive these histories, the more useful they were deemed to be. Working on his own, Bacon compiled a *Historia ventorum* (1622), a *Historia densi et rari* and a *Historia vitae et mortis* (1623). More ambitiously, he tried to produce more wide-ranging histories to which he gave titles that gave an exaggerated idea of their scope: *Phaenomena universi* (1611), *Abecedarium novum naturae* (1622)— trying to suggest he is covering everything in nature from A, B, C, through to the end of the alphabet—and *Sylva sylvarum* (1626)—a forest compiled not of trees but of other forests, and therefore a massive source of information.[13]

Bacon's insistence that the information gathered for these natural histories should be untainted, or unencumbered, by theoretical presuppositions, or by hypothetical

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[12] See also Bacon, *Novum Organum*, Book I, Aphorism 113, for the importance of division of labour. Sargent, "Bacon as an Advocate"; Richard Yeo, "Hippocrates' Complaint and the Scientific Ethos in Early Modern England," *Annals of Science* 75 (2018): 73–96.

[13] Francis Bacon, *The Oxford Francis Bacon XII: The Instauratio Magna Part III: Historia Naturalis et Experimentalis: Historia Ventorum and Historia Vitæ & Mortis*, ed. Graham Rees and Maria Wakely (Oxford, 2007); Francis Bacon, *The Oxford Francis Bacon XIII: The Instauratio Magna: Last Writings*, ed. Graham Rees (Oxford, 2000).

explanations, has been dismissed as unworkable by modern philosophers of science, but it is easy to see why Bacon thought it was a good idea. In the *Novum organum*, he objected to the way philosophers jump to conclusions about the nature of the world too soon, before all the relevant information is available.

> Yet we should not let the intellect bounce and fly up from particulars to remote and almost the most general axioms (such as are the ones they call the principles of the arts and affairs); and from their fixed truth to prove and settle intermediate axioms, which is what has been done up to now, the intellect being inclined to that by natural impulse, and also by its indoctrination and training long since in syllogistic demonstrations.

So, "we should not supply the human intellect with wings but rather with leaden weights to curb all jumping and flying up. Now this has never been done before, but when it has been then indeed we may hope for better things from the sciences."[14]

It is this emphasis upon fact gathering, coupled with a refusal to jump to explanatory conclusions, which leads Bacon to reject the principle means of establishing truth in Aristotle's *Organum*, namely the syllogism. The deductive syllogism, as Bacon pointed out, "is made up of propositions, propositions of words, and words are markers of notions". The danger is, therefore, that "if the notions themselves (and this is the heart of the matter) are confused, and recklessly abstracted from things, nothing built on them is sound. The only hope therefore lies in true *Induction*."[15] Bacon follows this up by insisting that

> In notions nothing is sound, neither in logical ones nor in physical: *Substance, Quality, Acting, Suffering*, and even *Being* itself—none of these are reliable notions, still less are *Heavy, Light, Dense, Tenuous, Moist, Dry, Generation, Corruption, Attraction, Repulsion, Element, Matter, Form*, and other things of the kind; but all are fanciful and ill defined. [16]

Consequently, "The existing logic serves to entrench and firm up errors (themselves founded on common notions) rather than to investigate the truth, so that it does more harm than good."[17]

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[14] Bacon, *Novum Organum*, Book I, Aphorism 14, 69.
[15] Ibid.
[16] Ibid., Book I, Aphorism 15, 69.
[17] Ibid., Book I, Aphorism 12, 69.

We can perhaps see what Bacon means by this if we consider Aristotle's arguments against the possibility of void space. Aristotle rejected the atomists' claim that motion would be impossible if there was no empty space for bodies to move into, and insisted on the contrary that a "circumambient void" would make any motion impossible. The natural movements, upward and downward, to take a body to its natural place would be impossible in "an undifferentiated limitless void", because there can be no top or bottom and no differentiated directions of up or down. Forced motion would be impossible because the continued motion of a projectile after it has ceased contact with its initial mover was supposed by Aristotle to be caused by a "circulating thrust" of the displaced medium through which the projectile moves. It is easy for us to see that Aristotle's logic is based on false starting assumptions, and his use of logical argument is entrenching those errors.[18]

Bacon had another important objection to deductive logic. He also pointed out that the deductive syllogism could provide no help towards making new discoveries. "Just as the existing sciences are useless for discovering works," Bacon wrote, "so the existing logic is useless for discovering sciences."[19] It is easy to see what Bacon means. The way the argument works in a syllogism has little or nothing to do with the physical world. Truth or falsity is decided internally, within the syllogism itself. For Aristotle, the most important thing was to prove the truth of any given proposition, and by carefully selecting his syllogisms, he could always do that. He was evidently not interested in making new discoveries, and the fact that deductive logic was useless for discovering new truths about the physical world did not cause him to re-think what was the best form of logic.[20] For Bacon, however, the ability to

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[18] Aristotle, *Physics*, Book IV, Chapter 8, 214b 29–215a 16. I have used The Loeb edition, translated by P. H. Wicksteed and F. M. Cornford (Cambridge, Mass, 1970), 349–51.
[19] Bacon, *Novum Organum*, Book I, Aphorism 11, 69.
[20] On the importance of discovery for Bacon see Ibid., Book I, Aphorism 129. A new emphasis upon discovery has recently been proposed as a major reason for the Scientific Revolution, and was

make new discoveries was the most important feature of the new philosophy to which he aspired. It was essential for Bacon, therefore, to come up with an alternative form of logical argument.

The alternative form of logic that Bacon suggested, and which is a major feature of his *Novum organum* was, of course, induction. And it is surely no accident that induction is the kind of logic that can be used to good effect when dealing with extensive bodies of facts, as could be seen in Bacon's natural histories. Induction works by simple enumeration. Accordingly, it can help us to classify the observed items collected in a natural history—we can separate plants according to the colours of their flowers, or we can separate different creatures depending upon the number of their legs, and so forth.

But inductive logic was never regarded as certain as deductive logic, and that is why Aristotle rejected it, in favour of deduction. It was once held to be true, by induction, that all swans were white; but the discovery of black swans in Australia immediately proved this false. The truth of an inductive conclusion was never guaranteed, therefore. Bacon was fully aware of the drawbacks of induction. But it was so well suited for his emphasis upon natural histories and data collection that he would not abandon it. Instead, he tried to improve inductive logic to overcome its drawbacks. His first announcement indicates what is required:

> Now to set up our axioms we must think up a form of *Induction* other than the one in use hitherto, and one not just for grounding and discovering principles (as they call them) but also the lower and middle axioms and, indeed, all of them. For induction proceeding by simple enumeration is a childish affair, its conclusions are unsafe, it opens itself to the threat of the contradictory instance, and generally bases its verdict on facts fewer than necessary, and among these only the ones which are readily available. But the *Induction* to be employed for the discovery and demonstration of the sciences and arts ought to separate a nature out by due rejections and exclusions, and

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supposedly not found among earlier thinkers. See David Wootton, *The Invention of Science: A New History of the Scientific Revolution* (London: Allen Lane, 2015), Part One, Chapter 3, 57–109.

> then, after bringing enough negatives to bear, draw conclusions from affirmatives; which is something never yet done or attempted hitherto…[21]

Induction based on "facts fewer than necessary" is clearly inadequate. But Bacon's vision of natural histories compiled by large numbers of collaborating collectors will avoid this drawback. But this in turn might lead to another problem—including too much information. The way to avoid this is by what would now be called "checks and balances", or what Bacon calls "due rejections and exclusions". The "affirmatives", which allow us to establish axioms upon which to build secure knowledge, can only be reached after excluding "enough negatives". For this to work, Bacon continues, "more work must be put into this job than has so far been swallowed up by the syllogism", and "we must supply many things which have not hitherto crossed the mind of mortal man". In spite of the need for such extensive labour, which Bacon elsewhere acknowledges will take many years to complete, in "successions of ages" (certainly beyond Bacon's own lifetime), Bacon still believes that "it is in this form of *Induction* that our highest hopes lie." [22]

Bacon sees his new kind of induction as an important aspect of his new method. He compares the gifted artist, who can draw a circle and a straight line without any aids, with a man who can draw a circle and a line with the aid of a compass and a rule. Bacon's method is said to be like compass and rule—an aid to the mind so that anyone can contribute to the reform of knowledge. Again, this makes his reform possible by collaborative effort—not just by collaborations between advanced thinkers, but collaborations between ordinary men who can gather information using Bacon's method: "For my way of discovering sciences pretty well puts all talents on

[21] Bacon, *Novum Organum*, Book I, Aphorism 105: 163.

[22] Ibid. See also Book I, Aphorism 113 for the comment on "successions of ages". In Aphorism 116, Bacon writes: "Neither can I hope to live to complete the sixth part of the Instauration (which is destined for the philosophy discovered by the legitimate interpretation of nature)", but sees himself playing "my part towards the commencement of the great undertaking." On the importance of time for Bacon's reforms, see Yeo, "Hippocrates".

the same footing and leaves little to their individual brilliance, since everything is done by infallible rules and demonstrations."[23]

Bacon's new kind of induction depends upon the compiling of various kinds of "Tables" of information. The starting point, of course, is the information gathered in the natural and experimental histories: "we must prepare a sound and sufficient *Natural* and *Experimental* History, for that is the very foundation of our work. For our object is not to make up or invent what nature may do or allow, but to discover it."[24] But then the information in the histories must be organized to make it more accessible to the understanding:

> But *Natural* and *Experimental History* is so various and scattered that it may bewilder and distract the intellect unless it be set down and presented in suitable order. So we must fashion *Tables*, and *Structured Sets of Instances*, marshalled in such a way that the intellect can get to work on them.[25]

It is at this point in the *Novum organum* that Bacon begins to outline in detail how his method is supposed to work. If we wish to understand a particular phenomenon then we must take into account "all known instances". The natural and experimental histories should provide all the known cases, and these should now be arranged in a Table of Instances, which he also calls a "Table of Essence and Presence".[26] In order to compare these cases with instances where the phenomenon in question is absent, Bacon now proposes the compilation of Tables of absence. He is fully aware, however, that this would include everything in the world which is not in the particular Table of Essence, and so he narrows the scope down to those instances which "are most akin" to those in which it is present—that is to say, instances in which the phenomenon in question might have been expected to appear (because of various similarities), but do not. Bacon calls these "Table of divergence, or Absence

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[23] Bacon, *Novum Organum*, Book I, Aphorism 122: 185.
[24] Ibid., Book II, Aphorism 10: 215.
[25] Ibid.
[26] Ibid., Book II, Aphorism 11: 219.

in Proximity".[27] Finally, Bacon declares that "we must submit *to the tribunal of the intellect* instances in which the nature under investigation exists to a greater or lesser degree" These he calls "Tables of Degrees or Comparative Tables".[28]

After all this has been done, Bacon believes we would now be able to reach secure inductive conclusions:

> Now I have grown used to calling the office and function of these three tables the *Submission of Instances to the Tribunal of the Intellect;* and when *Submission* is complete, the work of *Induction* itself must be set in motion. For we must find, on *Submission* of every last one of the instances, a nature which is such that it is always present or absent when the given nature is, and increases or diminishes with it, and is (as I said above) a limitation of a more general nature.

This complex procedure will avoid the pitfalls associated with the way the mind usually works: "if the mind tries to proceed by affirmative instances from the start (which it always does when left to itself) the result will be phantasms, mere opinions, ill-defined and notional conclusions, and axioms altered daily…"[29] We need not pursue the details, but Bacon introduces various other "Supports to Induction" and other aids to his procedures, and clearly believes that all of these in combination will lead to "true and perfect Induction".[30]

The *Novum organum* was never completed, but Bacon perhaps felt he had said enough to show the importance of induction for scientific discovery, rather than deduction. As he wrote in the final Aphorism:

> But take heed that in this my *Organum* I deal with logic not philosophy. But since the end of my logic is to teach and instruct the intellect not to batten on and embrace abstract things with the mind's fragile tendrils (as common logic does), but really to slice into nature, and discover the virtues and acts of bodies, and their laws as they are determined in matter, in such a way that this science may emerge not just from the nature of the mind but from the very nature of things…[31]

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[27] Ibid., Book II, Aphorism 12, 220.
[28] Ibid., Book II, Aphorism 13, 237.
[29] Ibid., Book II, Aphorism 15, 253.
[30] Ibid., Book II, Aphorism 21, 273. See also Aphorisms 18–20, 257–61.
[31] Ibid., Book II, Aphorism 52, 443.

One of the ways to "slice into nature", and to discover the properties of bodies, Bacon believed, was by artificially set-up experiments. Careful observation was superior to embracing the kind of "abstract things" that were dictated by scholastic syllogisms, but it could only take you so far. Bacon believed that in some cases at least, more could be learned by carefully designed experiments. Usually seen as the application of his procedures as a leading lawyer, and eventually Attorney General, to the natural world, Bacon believed that experiment could reveal more than passive observation:

> For just as in affairs of state we see a man's mettle and the secret sense of his soul and affections better when he is under pressure than at other times, so nature's secrets betray themselves more through the vexations of art than they do in their usual course.[32]

Bacon seems to believe that by constraining natural processes in some way, in an experiment, more will be learned about those processes:

> For like as a Mans disposition is neuer well knowen, till hee be crossed, nor *Proteus* euer chaunged shapes, till hee was straightened and held fast: so the passages and variations of Nature cannot appeare so fully in the libertie of Nature, as in the trialls and vexations of Art.[33]

It is important to note, however, that Bacon's experiments are simply meant to provide further information for his "Natural and experimental histories". Nowhere in his writings does Bacon indicate that he sees experiments as a way of testing (or more usually, simply confirming) a presupposed theory—as can be seen in the work of William Gilbert, and Galileo. While Gilbert carefully contrived experiments with specially made spherical magnets to try to prove his theory that the spherical earth was a giant magnet, and while Galileo rolled balls down inclined planes to demonstrate the truth of his theory about how falling bodies accelerate, Bacon,

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[32] Ibid., Book II, Aphorism 98, 157. For the influence of Bacon's legal background on his natural philosophy, see Julian Martin, *Francis Bacon, the State, and the Reform of Natural Philosophy* (Cambridge, 1992); Peter Pesic, "Wrestling with Proteus: Francis Bacon and the 'Torture' of Nature," *Isis* 90 (1999): 81–94; Sophie Weeks, "Francis Bacon and the Art–Nature Distinction," *Ambix* 54 (2007): 117–45.

[33] Francis Bacon, *The Oxford Francis Bacon IV: The Advancement of Learning*, ed. Michael Kiernan (Oxford, 2000), Book II, 65.

averse to theorising, simply used experiments as a way of gathering further information for his natural histories.[34]

Bacon's unique approach to experiment can be seen in the "Plan of the Work", presented at the beginning of his Great Instauration. Discussing how the senses can deceive us, Bacon tells his readers that he introduces experiments as "helps for the sense":

> For the subtlety of experiments is far greater than that of the sense itself… In fact I set little store by the immediate and peculiar perception of the sense, but carry the matter to the point where the sense judges only the experiment whereas the experiment judges the thing.[35]

The experiment simply reveals a natural phenomenon, upon which the sense can then judge. Bacon provides a clear example of what he means in the *De augmentis scientiarum*:

> For instance, when fire works upon a natural body, one of two things has hitherto always happened: either that something flies out (as flame and smoke in common combustion), or at least that there is a local separation of the parts, and to some distance; as in distillation, where the dregs settle at the bottom, and the vapours, after they have had their play, are gathered into receptacles. But of what I may call *close distillation* no man has yet made trial. Yet it seems probable that the force of heat, if it can perform its exploits of alteration within the enclosure of the body, where there is neither loss of the body nor yet means of escape, will succeed at last in handcuffing this Proteus of matter, and driving it to many transformations…

It is clear from this that Bacon is not looking for a particular "transformation", but simply wants to see what "many transformations" might result from this kind of "close distillation." This is confirmed a few lines later when Bacon assures his readers that even if what is expected is not seen, that experimental result is still useful:

> no one should be disheartened or confounded if the experiments which he tries do not answer his expectation. For though a successful experiment be more agreeable, yet an unsuccessful one is oftentimes no less instructive.[36]

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[34] On Gilbert, see John Henry, "Animism and Empiricism: Copernican Physics and the Origins of William Gilbert's Experimental Method," *Journal of the History of Ideas* 62 (2001): 99–119. On Galileo, see, for example, Stillman Drake, *Galileo at Work: His Scientific Biography.* (Chicago, 1978).

[35] Bacon, "Plan of the Work", in Bacon, *The OFB XIII*, 33–5.

[36] Bacon, *De augmentis scientiarum*, Book V, Chapter 2, in Francis Bacon, *The Works of Francis*

Bacon did not imagine that experiments must be conducted to test various hypotheses or theories, but merely as a means of gathering information about natural phenomena which could not be gathered simply from passive observation. His experiments, therefore, were performed in order to provide more data for his natural histories—or rather, as he always called them, natural *and experimental* histories.[37]

Furthermore, this was also consistent with Bacon's view that the search for causes should be delayed. Experiments should not be used to confirm a cause which has been arrived at by "the speculations and dogmas of philosophy", but merely to gather information which can be used later in the search for causes. In the *Novum organum*, for example, he writes:

> And Celsus freely and wisely admits as much, namely that the experiments of medicine were invented first and only afterwards did men philosophize about them, and search out and assign the causes, and that it did not happen the other way round with the experiments themselves being discovered or produced from philosophy and knowledge of causes.[38]

I have noted here that Bacon's new method, including his particular method of experimentation, and his new focus on inductive logic, went together with, and was specifically developed for, his vision of a collaborative effort to compile comprehensive natural and experimental histories. But, it also went together with a belief in the value of natural magic, and the reality of occult qualities and principles. We turn to this in the next section.

Baconian Philosophizing, Experimentalism and Natural Magic

Bacon's belief in magic and the reality of occult powers is now becoming more widely accepted, although the extent to which these interests shaped his scientific work is still being debated. Paolo Rossi was the pioneer in uncovering magical

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Bacon, ed. James Spedding, R. L. Ellis, and D. D. Heath (London: Longman, 1857), iv: 421.

37 For example, the third part of the Great Instauration was entitled: "The Phenomena of the Universe, or Natural and Experimental History for the building up of Philosophy", and the *Novum organum* was published with *Parasceve ad historiam naturalem et experimentalem*; both in Bacon, *Novum Organum*, 27, 448–73.

38 Ibid., Book I, Aphorism 73, 117.

aspects of Bacon's work, but he paid as much attention to Bacon's criticisms of magic and magicians, as to his more positive attitudes. The result was a rather whiggish assessment in which Bacon's great achievements were not seen as the result of his interests in magic but in spite of them.[39] In a recent survey of "Bacon's idea of science", Rossi speaks of writing "many years ago about the *condemning of magic* and also the heritage of magic in Bacon's philosophy", and then goes on to present Bacon as rejecting magic and alchemy.[40] Most subsequent Bacon scholars have hardly been troubled by Bacon's interest in magic, because they have simply ignored it. Frances Yates tried to present Bacon as one of the Hermetic magi that she saw as prominent in the Scientific Revolution, but her work always remained controversial in the eyes of contemporary historians of science, and was easily dismissed.[41] Graham Rees was highly successful in establishing the details of Bacon's own substantive philosophy (as opposed to his methodology)—his cosmology, and his matter theory—and showing that they were highly occult, and based to a significant extent on the alchemical theories of Paracelsus.[42] But even his work has barely changed the face of Bacon studies. Rees's work has been easily side-lined by other Bacon scholars, because it reveals a highly esoteric aspect of Bacon's work which hardly appeared in his published output, and remained unknown even to his followers. The full extent of Bacon's interest in, and use of, magical traditions has recently been established in two doctoral dissertations: Sophie Weeks's

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[39] Paolo Rossi, "Hermeticism, Rationality and the Scientific Revolution," in *Reason, Experiment, and Mysticism in the Scientific Revolution*, ed. M. L. Righini Bonelli and William R. Shea (New York, 1975), 247–73.

[40] Paolo Rossi, "Bacon's Idea of Science," in *The Cambridge Companion to Bacon*, ed. Markku Peltonen (Cambridge, 1996), 30.

[41] Frances Yates, "The Hermetic Tradition in Western Science," in *idem*, *Ideas and Ideals in the North European Renaissance. Collected Essays*, vol. 3 (London, 1984), 227–46. For a rejection of Yates's work by contemporary historians of science, see, for example, Westman and McGuire, *Hermeticism*.

[42] Graham Rees, "Francis Bacon's Semi-Paracelsian Cosmology and the *Great Instauration*," *Ambix* 22 (1975): 81–101; *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, 1996), 121–145; *idem*, "Introduction," in *The Oxford Francis Bacon VI: Philosophical Studies c.1611–c.1619*, ed. *idem* (Oxford, 1996), xvii–cx; and *idem*, "Introduction," in *The OFB XIII: The Instauratio Magna: Last Writings* (Oxford, 2000), xix–xci.

"Francis Bacon's Science of Magic", and Doina-Cristina Rusu's "From Natural History to Natural Magic", but so far these remain unpublished.[43] In spite of the efforts of Rees and others, Bacon scholars continue to see Bacon as primarily a "philosopher of science", and a promoter of the experimental method, and therefore (they believe) still a "modern" thinker.[44]

In fact, it is easy to see that the two main innovatory, and supposedly "modern", features of Bacon's work—his promotion of the experimental method, and his belief that knowledge of the natural world should be put to practical use for the benefit of mankind—emerge directly from Bacon's interest in magical traditions. Bacon did not invent the experimental method; he merely proposed that it should be introduced into the exclusively contemplative natural philosophy of his day. Furthermore, it seems clear that the earlier tradition of experimenting of which Bacon was most aware, was the magical tradition. Historians have found the origins of the experimental method in the medical tradition, among mathematical practitioners, among elite craftsmen, and among practitioners of occult arts, such as alchemy.[45] It is immediately clear from Bacon's writings that it was the magical tradition, rather

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43 Sophie Victoria Weeks, "Francis Bacon's Science of Magic" (Ph.D. thesis, Leeds, 2007); Doina-Cristina Rusu, "From Natural History to Natural Magic: Francis Bacon's *Sylva Sylvarum*" (Ph.D. thesis, Nijmegen, 2013). See also John Henry, *Knowledge Is Power: Francis Bacon and the Method of Science* (Cambridge, 2002).

44 For example, Peter Urbach, *Francis Bacon's Philosophy of Science: An Account and a Reappraisal* (La Salle, IL, 1987); Brian Vickers, ed., *English Science, Bacon to Newton* (Cambridge, 1987).

45 On the role of elite craftsmen, see, for example, Edgar Zilsel, *The Social Origins of Modern Science*, ed. Diederick Raven, Wolfgang Krohn, and R. S. Cohen (Dordrecht, 2000); Pamela H. Smith, *The Body of the Artisan Art and Experience in the Scientific Revolution* (Chicago, 2004); Cesare Pastorino, "The Philosopher and the Craftsman: Francis Bacon's Notion of Experiment and Its Debt to Early Stuart Inventors," *Isis* 108 (2017): 749–68. On the role of the medical tradition in the establishment of empiricism, see, for example, Harold J. Cook, "The Cutting Edge of a Revolution? Medicine and Natural History near the Shores of the North Sea," in *Renaissance and Revolution: Humanists, Scholars, Craftsmen and Natural Philosophers in Early Modern Europe*, ed. J. V. Field and F. A. J. L. James (Cambridge, 1993), 45–61. On the role of the mathematical and the magical traditions see John Henry, "The Origins of the Experimental Method—Mathematics or Magic?," in *Departure for Modern Europe: A Handbook of Early Modern Philosophy (1400-1700)*, ed. Hubertus Busche and Stefan Heßbrüggen-Walter (Hamburg, 2011), 702–14. On the role of alchemy, see Newman, *Atoms and Alchemy*.

than either of the alternative sources, which led Bacon to experimenting, and to the belief that knowledge should be put to practical use.

Consider, for example, the list Bacon provides of *Magnalia naturae praecipue quoad usus humanos* (*Wondrous works of nature for the particular use of mankind*) (1626), a list of things to be expected from Bacon's "Great Instauration". The phrase "magnalia naturae" was evidently a favourite with Paracelsus, and Bacon himself also uses it in *De augmentis scientiarum* (1623), in the chapter entitled: "Division of the operative doctrine concerning Nature into Mechanic and Magic".[46] In spite of the fact that Bacon has been seen as a "philosopher of industrial science", it is easy to see that the "wondrous works" that Bacon has in mind do not foreshadow the later achievements of the scientific-industrial complex, but are the kind of things that magicians were traditionally supposed to be able to do, including: impressions of the air, and raising of tempests; the prolongation of life; the increasing of strength and activity; the altering of features; the increasing and exalting of the intellectual parts; conversions of bodies into other bodies; and force of the imagination, either upon another body, or upon the body itself.[47]

If the belief that knowledge of nature should bring practical benefits was inspired by the magical tradition, so was Bacon's belief in the importance of experiment. This is perhaps most clearly seen in the description of Salomon's House in *New Atlantis* (1626).[48] The Father of Salomon's House opens his description by saying that "The End of our Foundation is the knowledge of Causes, and secret motions of things; and the enlarging of the bounds of Human Empire, to the effecting of all things possible."

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[46] Francis Bacon, *De augmentis scientiarum*, Book III, Chapter V. The editors provide a note claiming this was a favourite phrase of Paracelsus. See, Bacon, *Works*, i: 573, n. 2.

[47] Bacon, *Magnalia naturae praecipue quoad usus humanos*, in Bacon, *Works*, iii: 167–68. See Benjamin Farrington, *Francis Bacon: Philosopher of Industrial Science.* (London: Lawrence and Wishart, 1951).

[48] Richard Serjeantson, "Natural Knowledge in the *New Atlantis*", in *Francis Bacon's 'New Atlantis'*, ed. by Bronwen Price (Manchester, 2002), 82–105.

This sounds like a summary of magical ambitions, and within a few lines he is talking of "coagulations, indurations, refrigerations, and conservations of bodies… the imitation of natural mines; and the producing also of new artificial metals, by compositions…" Clearly, the processes of alchemy were in Bacon's mind as he wrote this, but soon the account broadens out into a seemingly comprehensive account of the wonders usually attributed to natural magic, and the way they could be achieved—in some cases by the use of waters, or by qualifying the air, or by imitating meteors, and so forth.[49] Similarly, Bacon's *Sylva sylvarum* (1626) is a rich source of experiments gathered from the magical tradition—many of them from Giambattista Della Porta's *Natural Magick*.[50] Bacon's belief in the link between magic and his new useful method is summed up in the *De augmentis scientiarum* of 1623: "The aim of magic is to recall natural philosophy from the vanity of speculations to the magnitude of works."[51]

Although he saw natural magicians as experimentalists, Bacon pointed out that they had so far had "scanty success" from the experimental method. It is undeniable that Bacon is critical of the experimental method practised by alchemists and magicians, and this has been used by Rossi and other Bacon scholars to suggest that Bacon rejected magic, rather than that he wanted to make it more successful. We saw in the previous section of this chapter that Bacon's experimental programme fitted into his plans to produce comprehensive natural and experimental histories, which could then provide the information to be tabulated in his various tables of discovery. Given Bacon's commitment to his new way of reforming natural knowledge, he could not endorse the experimentalism of alchemists and magicians, which was much less systematic, and aimed only at producing individual results. Even so, there are a

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49 Bacon, *New Atlantis*, in *Works*, iii: 156–58.
50 See Rusu, "From Natural History to Natural Magic"; Giambattista Della Porta, *Magia naturalis* (Frankfurt, 1581).
51 Bacon, *Works*, iii: 289. On magic in the *De augmentis scientiarum* see Sachiko Kusukawa, "Bacon's Classification of Knoweldge", in Peltonen (ed.), *Cambridge Companion to Bacon*, 47–74.

number of places where Bacon makes it clear that he accepts completely the intellectual foundations upon which magic is based. Early in the *Novum organum*, for example, Bacon repeats a standard assumption of the natural magicians: "As for works man can do nothing except bring natural bodies together or put them asunder; nature does the rest from within."[52] This clearly summarises the starting assumption of natural magic, namely, that bodies have powers to affect one another, and that wonderful effects can be produced by putting together two bodies which affect one another, or by separating them. As Cornelius Agrippa wrote:

> Magicians are careful explorers of nature, only directing what nature has formerly prepared, uniting actives to passives and often succeeding in anticipating results so that these things are popularly held to be miracles when they are really no more than anticipations of natural operations.[53]

Furthermore, in *Cogitata et Visa* (1607), which begins with a dismissive critique of the sciences up to Bacon's time, it is only alchemists and magicians who are credited with coming close to the kind of "science productive of works" which Bacon hopes to achieve. On alchemists, for example, he writes (speaking of himself in the third person):

> It may occur to some reader that nothing is being said about the art or philosophy of the Alchemists, and he may interpret this silence as meaning that Bacon, out of respect for that art, is unwilling to include it among the unproductive philosophies, since, in fact, it has produced useful inventions, not a few for the benefit of mankind.[54]

Bacon does go on to criticise the alchemists, although he does say "their Triad of First Principles is not a useless discovery, for it has a certain affinity with things." Alchemists come off better than any other kind of thinker, except possibly magicians. Natural magicians explain everything by sympathies and antipathies, which are "idle

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[52] Bacon, *Novum Organum*, Book I, Aphorism 4, 65. This can be compared with very similar statements in Giambattista della Porta, *Natural Magick*, trans. Richard Gaywood (London, 1658), 2; Cornelius Agrippa, *De Incertitudine et Vanitate Scientiarum et Artium, Atque Excellentia Verbi Dei Declamatio* (Cologne, 1575), 42.

[53] Agrippa, *De Incertitudine et Vanitate Scientiarum et Artium, atque Excellentia Verbi Dei Declamatio*, 42.

[54] Bacon, *Cogitata et visa: De interpretatione naturae, sive de scientia operativa*, translated in Benjamin Farrington, *The Philosophy of Francis Bacon: An Essay on Its Development from 1603 to 1609* (Liverpool, 1964), 87.

and supine assumptions", he wrote, "But Bacon felt some indulgence even towards them. Among their many fancies they now and again produce a true effect."[55] Similarly, Bacon was critical of the way natural magic was practiced in his "Refutation of Philosophies" (1608), describing it as "an art which now dishonours its solemn and all but holy name."[56] It is clear, however, that what was being dishonoured was something which Bacon believed to be potentially very valuable—its "all but holy name" suggesting that Bacon saw natural magic as the knowledge of the occult powers which God had created.

Towards the end of the *Novum organum* Bacon seems to reveal his own belief in certain magical effects. He suggests that the achievements of magicians should not be dismissed simply because they are often tainted by "lies and fable",

> they should nevertheless be examined a little just in case any natural operation lurks or subsists in any of them, as in spells, fortification of the imagination, consent of things at a distance, and the transmission of impressions from one spirit to another, no less than from one body to another, and the like.[57]

It seems clear that Bacon believes that these magical beliefs, if not others, might be based in real operations of nature.

Furthermore, in the final paragraph of the *Novum organum*, he indicates that he regards the magical tradition as one of the most important sources for observations and experiments. Most of the second book of the *Organum* is concerned with describing what Bacon calls "Prerogative Instances". These are supposed to provide more useful or more beneficial information about the world than ordinary "instances", by which Bacon seems to mean observations, experiments, or familiar phenomena.[58] Bacon discusses twenty-seven kinds of Prerogative Instances, but in

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[55] Bacon, *Cogitata et visa*, in Ibid., 88.
[56] Bacon, *Redargutio philosophiarum*, in Ibid., 123.
[57] Bacon, *Novum Organum*, Book II, Aphorism 31, 305.
[58] I am agreeing here with Robert Leslie Ellis, "General Preface to the Philosophical Works," in *The Works of Francis Bacon*, ed. James Spedding, Robert Leslie Ellis, and Douglas Denon Heath, vol. 1

his final Aphorism he focuses upon a number of these kinds where collections of instances need to be made with more urgency than others. One of these kinds is magical prerogatives: “Of this kind are *Corresponding, Monadic, Deviating* and *Frontier Instances, Instances of Power* and *Access, Intimating, Multi-purpose*, and *Magical Instances*.”[59]

It is possible that Bacon’s acceptance of the value of the magical tradition was linked to the fact that its methodology was inductive, rather than deductive, and so coincided with (or perhaps even directed) Bacon’s own beliefs about the best form of logic for accumulating natural knowledge. In the magical tradition, induction went hand in hand with the aim to achieve practical benefits, rather than with any attempt to fully understand how those practical results were achieved. The deductive syllogism, as we saw earlier, was concerned to explain the conclusion—why is Socrates mortal? Because he is a man and all men are mortal. Inductive arguments merely point to regularities in nature, but offer no explanations. We can see this in an example of an inductive argument provided in Thomas Wilson’s textbook of logic, *The Rule of Reason* (1551):

> Renyshe wine heateth,
> Malvesey heateth,
> Frenchwine heateth,
> Neither is there any wyne that doth the contrary:
> Ergo all wine heateth[60]

The conclusion is potentially useful—if a patient is too cold we might give them some wine to drink. There is no indication, however, as to *why* wine heats the body in this way; it is simply recorded that it does. The fact that inductive arguments do not explain, and do not discuss causes, was another major factor in their rejection by scholastic Aristotelians.

(London: Longman, 1857), 43–5. See also Stephen Gaukroger, *Francis Bacon and the Transformation of Early-Modern Philosophy* (Cambridge, 2001), 153–55.

59 Bacon, *Novum Organum*, Book II, Aphorism 52, 445.

60 Thomas Wilson, *The Rule of Reason* (London,1551), sig. H5*v*; quoted from Henry, “Magic and Science”, 590.

Because wine was perceived to heat the body of the drinker, scholastics would simply have assumed that wine heated because its composition included the element of fire (which could be confirmed by the fact that the vapour given off by wine could be ignited). But there were many herbs and other medicines which were held to work in an occult way. The logic confirming the supposed occult powers of various plants, or animals, or their parts, could only be inductive, and it could offer no causal explanation of how these things worked.

Although the scholastics saw the lack of causal explanation as a major drawback of inductive logic, Bacon clearly saw this as one of its advantages. We saw in the previous section that Bacon associated deductive logic with the tendency of the understanding to "bounce and fly up from particulars to remote and almost the most general axioms". The results were too premature, and the scholastics were led into error. [61] The very fact that induction reached useful conclusions without making any premature assumptions about causes ensured that it fitted perfectly into Bacon's plan for reforming natural philosophy. As Bacon wrote: "the mind's recklessness in the discovery of causes" has "wondrously corrupted philosophy".[62]

This is not to say that Bacon completely rejected the attempt to understand causes. The final aim of the Great Instauration was to arrive at the true causes of things:

> But my route and plan (as I have often clearly declared, and am happy to declare again) does not lead me to extract works from works, or experiments from experiments (as empirics do) but to extract (as legitimate interpreters of nature do) from works and experiments causes and axioms, and in turn from causes and axioms new works and experiments.

He went on, however, to insist that it was too soon to arrive at causes just yet: "I frankly confess that the natural history currently available, whether from books or direct investigation, is not sufficiently abundant or rigorously verified to serve for

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[61] Bacon, *Novum Organum*, Book I, Aphorism 104, 161.
[62] Ibid., Book I, Aphorism 48, 85–7.

legitimate interpretation."[63] Correct interpretation of nature, including knowledge of causes, is only possible when all the relevant information has been gathered:

> But hope of further advancement of the sciences will be well grounded only when we take and gather into natural history many experiments of no use in themselves but which only contribute to the discovery of causes, which experiments I have grown used to calling *Light-bearing* as against *Fruit-bearing* ones.[64]

It was only by gathering natural and experimental histories, and by confining oneself to inductive, rather than deductive, logic that Bacon's plan would work. The search for causes must be delayed.[65] For Bacon the important thing was to establish a method which would lead to progress, even if final results were delayed. He was not, therefore, insisting on suspension of judgment for its own sake, but merely to avoid reaching the wrong conclusion by premature philosophising.[66]

Further proof of the importance of occult or magical principles to Bacon can be seen in the one example he provides of how his Tables of Discovery are supposed to work. The example Bacon chose was heat, and he first provided a list of "Instances which share in the nature of heat", that is to say, a list of phenomena where heat was produced (a Table of Presence). He then went on to provide what he called Tables of divergence, and of comparison.[67] As we saw earlier, it is only after having compiled these tables that induction is brought in.[68] The first process is to use the Tables to exclude various potential explanations of heat, and to draw up a Table of Exclusion. Bacon sees this as a way of improving on standard induction ("the foundations of true *Induction* rest on the *Exclusive* process").[69] At this point Bacon is ready to draw

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63 Ibid., Book I, Aphorism 117, 175–77.
64 Ibid., Book I, Aphorism 99, 157–59.
65 Admittedly, there are casual explanations in the Latin Natural Histories published in 1622 and 1623, but Bacon was aware that he would not live to see the completion of his Great Instauration, and so started to "bounce and fly" to general axioms, before it was too late. See Graham Rees, "Introduction," in *OFB XII*, *The Instauratio Magna Part III*, xxv–xxxiii. On the importance of a long time scale for the great Instauration, see Yeo, "Hippocrates".
66 Bacon, *Novum organum*, Book I, Aphorism 126, 189–91.
67 Ibid., Book II, Aphorisms 11–13, 217–53.
68 Ibid., Book II, Aphorism 15, 253 (quoted above, at note 29).
69 Ibid., Book II, Aphorism 19, 261.

conclusions about the nature of heat based on what he calls the "First Vintage", and concludes that heat is an "expansive motion".[70]

Bacon's choice of example, heat, is highly significant because heat was one of the scholastic *manifest* qualities. For the scholastics, heat did not need to be explained, it was a fundamental quality, and perfectly evident to the senses. But now, Bacon was showing that heat was by no means a fundamental feature of the world, and its true nature was not evident to the senses. Heat could be reduced to motion, even though motion was not always evident to the senses in all cases of heat.[71]

Bacon should be seen, therefore, as part of a wider movement in the late Renaissance to dismiss the scholastic distinction between manifest and occult qualities. Significantly, it was heat, or fire, which provided the main means of challenging the scholastic view. One of the earliest attacks appeared in Jean Fernel's influential attempt to reveal the importance of occult influences in the natural world, *De abditis rerum causis* (1548).[72] One of the speakers in Fernel's dialogue tells his friends that:

> A friend of mine recently imported from India a marvellously luminous stone, which glows all over as if fired with a wondrous brightness, and throws out rays that fill the air around with light in every direction. Intolerant of the earth, it flies away into the sky spontaneously, with no delay. And it cannot be closely confined, but must be kept in a wide open space. There is supreme purity in it, supreme sheen; it is fouled by no filth or stain, there is no sure form of its shape, but a varying and fast-changing one. And being extremely beautiful to look at, it does not let itself be handled, and if you keep trying it will hit hard; if a bit of it is taken away, it turns out no smaller. He also used to say that its power is for many [purposes] both useful and highly essential.[73]

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[70] Ibid., Book II, Aphorism 20, 265.

[71] See also, Millen, "Manifestation". Millen points out that in the scholastic tradition, heat provides the paradigm of a manifest quality, 206.

[72] Jean Fernel, *De abditis rerum causis libri II* (Paris, 1548); now translated in John M. Forrester and John Henry, *Jean Fernel's On the Hidden Causes of Things: Forms, Souls and Occult Diseases in Renaissance Medicine* (Leiden, 2005).

[73] John Henry and John M. Forrester, "Jean Fernel and the Importance of His *De Abditis Rerum Causis*," in Forrester and Henry, *Jean Fernel's On the Hidden Causes of Things*, 681.

The "stone" turns out to be fire or flame, and Fernel's point was to suggest that fire acts in such a mysterious way that it should not count merely as the embodiment of a so-called manifest quality.

A few years later, in 1553, a work *On Fire*, by Aristotle's successor as head of the Lyceum, Theophrastus, was translated by Adrianus Turnebus. Theophrastus argued that fire should not be called an element because it needed to be fed to survive, it is diverse in power, its action varies, and it is variable and even inconsistent in other respects. This was taken up by Girolamo Cardano, who argued in his *De subtilitate* (1560) that there are only three elements because fire is too active and changeable to be counted as an element.[74] Scepticism about the elemental nature of fire became so well known that even John Donne included it in a famous passage in his "Anatomy of the World" (1611), where he wrote of dramatic changes in traditional teachings about the natural world: "And new philosophy calls all in doubt," he wrote, "The element of fire is quite put out".[75] While denying fire its status as an element, Cardano also denied that heat should be counted as a manifest quality. So did the German physician and alchemist, Daniel Sennert, in his *Hypomnemata physica* of 1636. Pointing out that occult qualities are only known by their effects (while their causes remain unknown), Sennert nevertheless insists that "knowledge thereof will produce as certain science as that of first qualities." Because:

> the natural philosopher knows no more of heat but that it heats and that it flows from and depends upon the form of fire; and this form is as unknown to man as those from which the occult qualities arise.[76]

[74] Van Raalte Marlein, "The Nature of Fire and Its Complications: Theophrastus' *De Igne* 1–10," *Bulletin of the Institute of Classical Studies* 53 (2010): 47–97; Girolamo Cardano, *The De Subtilitate*, ed. John M. Forrester (Tempe, AZ, 2013), 72–77.

[75] John Donne, *An Anatomy of the World* (London, 1611), lines 205-6.

[76] Daniel Sennert, *Hypomnemata physica* (Frankfurt, 1636), 148. "Neque enim plus de caliditate Physicus notum habet, quam eam calefacere, &a forma ignis fluere ac depedere: quæforma æque, ut illae, a quibus qualitates occultæ oriuntur, homini ignota est."

Occult qualities could only be discovered by experience, and their range of operations could only be discovered by experiment. As Jean Fernel wrote in 1548, although occult qualities

> lie hidden, veiled in nature's secrets and in deep shadow, they are not to be let alone through ideleness, but investigated rather carefully, not through their taste, smell, sound or colour, but simply from their effects and actions, which are to be confirmed, both by long observation of performance and from the records of the best authorities.[77]

Bacon wanted to dispense with authorities of course, and to make a new start gathering information directly from nature. In the end, however, he could not put his collaborative fact-gathering ambitions into practice and had to compile natural histories on his own, and therefore, as Fernel suggested, he had to resort to the records of the best authorities; including, in the case of his *Sylva sylvarum*, Della Porta's *Natural Magick*[78]. But he did add to Fernel's suggestion of "long observation by performance", experimentation, as a quicker and more insightful way of discovering the properties of things, whether they be occult or manifest—a distinction which Bacon and others were now seeing as illegitimate and misleading.[79] Given that there could be no real distinction between occult and manifest properties, then experimental philosophy had to replace the deductive rationalism of scholastic natural philosophy. Bacon's experimental method and his promotion of inductive logic were both closely linked to his belief that the properties of bodies, were all effectively occult, and could only be understood by experience.

Baconian Matter Theory: Active and Motive

Bacon's theory of matter emphasised the occult properties of bodies. He pointed out, for example, that although we simply say that wood and stone are "solid", this overlooks the fact that there must be a "force which holds wood or stone together".

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[77] Henry and Forrester, *Jean Fernel's* On the Hidden Causes of Things, 735.
[78] See Rusu, "From Natural History to Natural Magic," especially chapter 4, 139–77.
[79] For further discussion of the breakdown of the distinction between manifest and occult qualities, see Hutchison, "Occult Qualities"; Millen, "Manifestation"; Newman, *Atoms and Alchemy*.

"There is," he wrote, "a property in bodies which makes them hold together."[80] Even this one example shows that Bacon recognised occult properties at work where other thinkers did not—for most of his contemporaries, stones were simply solid, but for Bacon stones must be held together by a force, and "the force by which they do this strikes us as something mysterious and ingenious."[81]

As Guido Giglioni has pointed out, Bacon even provided a list of nineteen of "the main species of motions or active virtues" in matter, in his *Novum organum*.[82] One of the most original aspects of Bacon's natural philosophy, according to Giglioni, is the claim that a limited number of motions, or powers, are capable of producing all material phenomena.[83] In Bacon's list of the active virtues, the "property in bodies which makes them hold together" is called the motion of continuity (*motus continuationis*), and he is careful to distinguish this from a motion of connection (*motus nexus*) by which one body will maintain continuity with other bodies around it: "This motion is the one the schoolmen call *motion to avoid a vacuum*, as when water is drawn upwards by suction, or syringes, and flesh by cupping glasses…."[84]

Bacon's distinctions are often very subtle. Later, for example, he distinguishes between motions of Greater Congregation and motions of Lesser Congregation. The former is similar to the scholastic idea of natural motion and accounts for the motion of all heavy bodies to the earth, while the latter explains why homogenous parts of a substance separate themselves from heterogeneous parts. Cream separates itself from the rest of the milk, rising to the top. But this is not because of gravity and levity,

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80 Bacon, *Cogitata et visa*, in Farrington, *The Philosophy of Francis Bacon*, 91.
81 Ibid.
82 Bacon, *Novum Organum*, Book II, Aphorism 48, 385. It should be noted that Bacon is using "motion" here in the traditional scholastic sense, to refer to *change*, not just to local motion. See Giglioni, "Lists of Motions." I draw heavily on Giglioni's work in this section.
83 Giglioni, "Lists of Motions", 63.
84 Bacon, *Novum Organum*, Book II, Aphorism 48, 383–417.

Bacon insists, but because "it has much more to do with the desire of homogeneous parts to come together and to unite".[85]

Not all of the active virtues apply to all bodies. The ninth motion is the "Magnetic Motion", and the seventeenth is "Spontaneous Motion of Rotation", which he attributes to the heavens, while acknowledging that some attribute it to the Earth.[86] But others are seen as being entirely general and found in all bodies. The Motion of Resistance (*motus antitypiae*), for example, is said to inhere in every single portion of matter and ensures that matter is never destroyed. Similarly, the "Motion for Gain, or Lack" (*motus ad lucrum, sive motum indigentiae*), by which bodies "attach themselves to bodies more like themselves" seems to apply to all bodies, and certainly accounts for all chemical interactions:

> if you can find a body proportioned and both more consentient and friendly to some solid body other than the one with which the solid is mixed as if by necessity, the solid instantly relaxes and opens itself, and takes the friendly body into itself, and rejects and shuts out its previous occupant.[87]

There are two very important aspects of Bacon's account of the nineteen different active virtues he claims to exist in matter. Firstly, it is evident that Bacon does not believe that any matter is inert—all matter has inherent activity.

> For in bodies here with us there is no true rest in wholes or parts save in outward appearance. Now this apparent rest is caused either by *Equilibrium*, or by absolute *Ascendancy* of motions—by the former, as in scales which stay level if the weights are the same; or by the latter, as in watering pots where the water stays still and is stopped from falling by the *Ascendancy* of motion of *Connection*. Yet we must (as I have said) note how far the yielding motions struggle on. For if someone is pinned to the ground in a wrestling bout, and bound hand and foot, or held down otherwise, and yet with all his strength still struggles to get up, his resistance is no less because it gets him nowhere.

The image of the wrestler who is pinned down but continuing to struggle against his opponent, provides the perfect metaphor for understanding how a body can seem to

85 Ibid., Book II, Aphorism 48, 393.
86 Ibid., Book II, Aphorism 48, 399, and 409–11.
87 Ibid., Book II, Aphorism 48, 385, and 391. For a complete summary of all Bacon's different motions, see Giglioni, "Lists of Motions": 71–7.

be at rest, but is in fact in a constant state of activity—for Bacon "there is no true rest" in matter. [88] As Giglioni suggest, for Bacon "matter finds itself in a constant state of agitation".[89]

Secondly, Bacon believes that by revealing the nineteen different kinds of active virtues operating on matter he has effectively covered a significant part of natural philosophy:

> Thus then have I set out the species or simple elements of the motions, appetites and active virtues which are in nature most catholic. And in so doing I have outlined a fair portion of natural philosophy.[90]

It seems that for Bacon, knowledge of the active virtues of matter was sufficient to making a major contribution to understanding natural philosophy. "We should look for the appetites and the inclinations of matter," he wrote. "They are the source of this large variety of effects and changes, which we see in both works of nature and art."[91] But his list of active virtues provides a classificatory scheme, and might therefore be considered closer to a natural history than to a genuine philosophy. Certainly, Bacon's list seems to be based on observation and experience, without any attempt to provide casual explanations of the motions he describes. We can see this, for example, in the fact that he includes magnetic motion, motion of rotation, and motion of trepidation. The latter, like motion of rotation, derives from what Bacon knows about astronomy: "to which (as the astronomers mean it) I attach little credence."[92]

There are no attempts to suggest causes of these motions; they are simply described. The closest we come to a discussion of causes appears in the account of Motion of

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[88] Bacon, *Novum Organum*, Book II, Aphorism 48, 417.
[89] Guido Giglioni, "Mastering the Appetites of Matter: Francis Bacon's *Sylva Sylvarum*," in *The Body as Object and Instrument of Knowledge*, ed. Charles T. Wolfe and Ofer Gal (Dordrecht, 2010), 154.
[90] Bacon, *Novum Organum*, Book II, Aphorism 48, 413.
[91] Bacon, *Cogitationes de rerum naturae* (1605), in *Works*, iii: 20; quoted from Giglioni, "Lists of Motions", 68.
[92] Bacon, *Novum Organum*, Book II, Aphorism 48, 411.

Configuration (*motus configurationis aut situs*), by which bodies seem to situate themselves in a particular way with respect to other bodies. Bacon admits that "this motion is very abstruse and not well investigated. Indeed, in some things it seems to lack a cause, though in fact (as I think) that is not the case." But his own attempt to suggest a cause is merely speculation: "I think that this arises from a certain harmony and consent of the world not so far noticed."[93] In the cases of the other eighteen motions, Bacon does not even speculate about a cause. Clearly, Bacon does believe, as in the case of motion of configuration, that there must be causes of these motions, but it seems equally clear that he believes speculation on those causes at the time of writing the *Novum organum* would be premature.

Thanks largely to the work of Graham Rees, we now know that Bacon also developed a speculative theory of matter, which he believed to be close to the true theory of matter which would emerge in the final stage of the Great Instauration, the so-called "Philosophy to Come, or The Active Science". Rees sees this speculative natural philosophy as "an elaborate guess at the kind of science the method was expected to create", and believes that Bacon intended to write this up for the fifth part of the Great Instauration, "Precursors, or Anticipations of the Philosophy to Come".[94] We need not pursue the details of this theory here. The important thing for us to note, however, is that, even though Bacon abandons his strictures against premature theorising, and forgets to confine himself to observation and experiment, and his method of induction, he nevertheless develops a highly occult theory of matter. Furthermore, as Rees has suggested: "so far did his [Bacon's] thinking about the [speculative] system stamp itself on his writings that it is very difficult to find one that was not in some way touched by his speculative preoccupations".[95] Bacon's

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[93] Ibid., Book II, Aphorism 48, 408.
[94] Rees, "Bacon's Speculative Philosophy", 121. See Bacon, "Plan of the Work", in Bacon, *Novum Organum*, 27.
[95] Rees, "Bacon's Speculative Philosophy"; Rees, "Semi-Paracelsian Cosmology".

writings were thoroughly committed to an occult matter theory in which matter was held to be inherently active.[96]

Returning to the *Novum organum*, we can see that Bacon's treatment of matter was perfectly in keeping with his inductive, experiential, and magical approach—based on observation and Bacon's kind of experimenting, and relying on induction, without trying to provide any causal explanations for the motions in matter that he observed. In the *Novum organum* Bacon was focussing upon the means to reform natural knowledge—how to investigate nature, how to organise our knowledge, and finally how to move from tables of discovery to the "First Vintage" of understanding, and so forth, supposedly without any prior commitment to theory. Even so, it is clear that Bacon, in spite of his own warnings against flying to premature conclusions, was committed to a view of matter which was heavily influenced by natural magic and other occult philosophies (including those reforming medical movements developed by iatrochemists, and other occult thinkers, such as Fernel, and Fracastoro). His matter theory was bound up with his plans to restore what he called "the true Natural Magicke".[97]

Manifest Qualities, Occult Causes, and Newton

Given Bacon's powerful influence on following generations of English natural philosophers, it is hardly surprising that few of them ever fully embraced the austere theory of completely passive and inert matter that Descartes developed in his *Principia Philosophiae* of 1644. English natural philosophers, with the exception of Hobbes, accepted the idea of active matter. Furthermore, these theories of active matter often repeat, or are similar to, ideas found in Bacon's *Novum organum* or

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[96] Rees, "Semi-Paracelsian Cosmology"; Rees, "Matter Theory." See also the introductory materials in Francis Bacon, *The OFB VI: Philosophical Studies c.1611–c.1619*; and Bacon, *Novum Organum*.
[97] Bacon, *The OFB IV*, Book II, 90.

other writings, and drew upon Bacon's methodology to justify their use of unexplained activities in matter.

Bacon himself was writing at a time before the new mechanical philosophies began to appear, when it still seemed to reforming natural philosophers that the natural magic which had been revived in the Renaissance, by Marsilio Ficino and others, offered the best hope for replacing scholastic natural philosophies. His followers, writing later in the seventeenth century, however, were aware of the alternative, more mechanistic, approaches developed by Galileo, Pierre Gassendi, Thomas Hobbes, and especially René Descartes. Consequently, where Bacon might simply have referred to occult properties, his followers had to be much more cautious in attributing phenomena to the occult principles which had been so vigorously rejected by the highly influential Descartes. Towards the end of his comprehensive account of natural philosophy, Descartes insisted that he had shown that all physical phenomena can be explained by reference to the "figure, magnitude, situation, and motion of particles of matter", and therefore "that there are… no forces so secret, no marvels of sympathy or antipathy so astounding, and finally no effects in all of nature… the reasons for which cannot be deduced from these same principles."[98]

Descartes was never as influential in England as he was in Continental Europe, and this was certainly due, at least in part, to Bacon's very different influence. We can see this, for example, in the response of William Petty to Henry More's admiration for Descartes. Petty points out that no practical benefits have resulted from Descartes's philosophy, thereby showing his own Baconian outlook. He also makes it clear that he believes, with Bacon, that knowledge of nature should be based on many experiments:

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98 René Descartes, *Principles of Philosophy*, trans. V. R. Miller and R. P. Miller (Dordrecht: D. Reidel, 1983), Part IV, § 188, 275.

> I believe that judicious Men vexed in Multitudes & vexieties of Experiments… may better see the defects or uselesnes of Descartes his philosophy then such as know noe more experiments, then what hee himselfe hath pickt out, and tells them off to verify his own Imaginations.

Dismissing Descartes's "Imaginary principles", Petty claims to have performed many experiments and as a result: "I better understand Nature now, than when I puzled myselfe in… Bookes, although I doe not as yet pretend to have found out Axioms." His Baconian approach is clear in his wish

> that the great witts of these times could employ themselves in collecting & setting downe in a good order & Method all Luciferous experiments & not bee too buisy in making inferences from them till some volumes of that Nature are compiled…[99]

Petty can stand representative of many natural philosophers in England, who preferred the experimental philosophy to the mechanical philosophy.[100] Nevertheless, English philosophers were aware of Descartes's influence in France and the Netherlands, and seem to have avoided the kind of overt discussions of occult qualities that appear in Bacon's own writings. But on those occasions when they did resort to occult, or unexplained principles, English writers could draw on Bacon's own ways of justifying this. In his essay on "The Masculine Birth of Time", Bacon had dismissed "the narrow-minded Galen, who deserted the path of experience and took to spinning idle theories of causation…"[101] Baconians could easily have said the same about Descartes.

We shall come back to Petty, and will also look at other Baconian experimental natural philosophers in England before Newton in later chapters, here let us concentrate on the culminating figure in our story, and show how Newton himself

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[99] William Petty, "Mr. Petty's letter in answer to Mr. More", February 1648/49, in Charles Webster, "Henry More and Descartes: Some New Sources," *The British Journal for the History of Science* 4 (1969): 367–8. For more on Descartes's comparative lack of influence in England, see G. A. J. Rogers, "Descartes and the English," in *The Light of Nature: Essays in the History and Philosophy of Science Presented to A. C. Crombie*, ed. J. D. North and J. J. Roche (Dordrecht, 1985), 281–302; John Henry, "The Reception of Cartesianism," in *The Oxford Handbook of British Philosophy in the Seventeenth Century*, ed. Peter R. Anstey (Oxford, 2013), 116–43.
[100] On Bacon's influence in England, see Webster, *The Great Instauration*.
[101] Bacon, "The Masculine Birth of Time", in Farrington, *The Philosophy of Francis Bacon*, 64.

inextricably linked occult qualities, and active matter, with his Baconian defence of the experimental method. Isaac Newton did not say much about his methods in his published writings, but what he did say can be seen to reflect the same kind of Baconian justifications for allowing actions at a distance, matter with inherent active principles, and similar occult or unexplained notions. In the "General Scholium", which he added to the second edition of the *Principia* (1713), for example, he defended the fact that he had provided no explanation of the cause of gravity, simply by saying that, "In this experimental philosophy, propositions are deduced from the phenomena and made general by induction."[102] He then goes on to say that it is enough for him to have shown that gravity really exists, and behaves in the detailed ways he has shown. To attempt to provide a cause for gravity, would be premature; as he wrote a few lines earlier, "I have not yet been able to deduce from phenomena the reason for these properties of gravity". "Not yet", suggests it may be possible in the future, but just now it is too soon.

Like Bacon, Newton, even in his mature works, insisted that bodies were invested with active principles and could attract, repel, and perform various other physical and chemical operations which could not be reduced to mechanical processes. In "Query 31" at the end of the second English edition of the *Opticks* (1717), for example, Newton suggested that "God in the Beginning form'd Matter in solid, massy, hard, impenetrable, moveable Particles of such Sizes and Figures, and with such other Properties, and in such Proportion to Space, as most conduced to the End for which he form'd them",[103] Newton was including gravitational attraction among those "other Properties".[104] Furthermore, in noting that "the parts of all homogeneal hard bodies which fully touch one another, stick together very strongly", Newton dismissed earlier mechanical accounts of how bodies cohere, declaring instead that "I

[102] Newton, *The Principia*, 943.
[103] Newton, *Opticks*, 400.
[104] Newton, *Opticks*, 401.

had rather infer from their [bodies'] Cohesion, that their Particles attract one another by some Force, which in immediate Contact is exceeding strong, at small distances performs the chymical Operations above mention'd, and reaches not far from the Particles with any sensible effect."[105] Throughout Query 31, Newton continually writes in terms of "some Power of the Body," bodies acting on other bodies, "an attractive Force between Bodies," bodies with "attractive powers, or some other Force," or bodies having "some kind of attractive virtue lodged in… the Particles," and so on.[106] And it is not surprising therefore, when he finally tells us that matter is not completely passive and inert, as Descartes had insisted, but active due to the active principles endowed upon it by God:

> The *Vis inertiae* is a passive Principle by which Bodies persist in their Motion or Rest, receive Motion in proportion to the Force impressing it, and resist as much as they are resisted. By this Principle alone there never could have been any Motion in the World. Some other Principle was necessary for putting Bodies into Motion; and now they are in Motion, some other Principle is necessary for conserving the Motion…

Active principles, Newton insisted, were necessary to "conserve" and "recruit" motion, otherwise the whole world would lose its motions and grind to a halt.[107] While Descartes claimed that the amount of motion in the world would always remain constant, Newton believed that it would inevitably dissipate and diminish, and the activity of the world could only be maintained if matter had its own principles of activity. While Descartes rejected the idea that bodies could be endowed with mysterious non-mechanical "powers", Newton freely spoke of the powers of bodies, such as the "gravitating Power of the Sun," "the power of Bodies to reflect" (at a distance). Similarly, he had no qualms about claiming that "Bodies

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[105] Newton, *Opticks*, 388, 9.

[106] Newton, *Opticks*, 266, 339, 371, 372, 373. See also the famous opening of Query 31: "Have not the small Particles of Bodies certain Powers, Virtues, or Forces, by which they act at a distance…", 375–6. More discussion can be found in McMullin, *Newton on Matter and Activity*, and in McGuire, "Force, Active Principles, and Newton's Invisible Realm".

[107] Newton, *Opticks*, 397, 8.

attract one another", that chemical "Ingredients" have a "mutual Attraction," and that "Metals dissolved in Acids" have "attractive Force."[108]

After discussing various supposed "active Principles" in material particles, Newton insisted that "These Principles I consider, not as occult Qualities", because their real existence was suggested by observed phenomena "though their Causes be not yet discover'd." He went on: "For these are manifest Qualities, and their Causes only are occult." Newton means that they are manifest qualities in so far as they are revealed by familiar observations (he does not mean manifest qualities in the scholastic sense: hot, cold, wet, and dry). He went on to indicate that the causes of these active principles may be discovered in the future, but to attempt to allocate causes now would be too soon:

> To tell us how the Properties and Actions of all corporeal Things follow from those manifest Principles, would be a very great step in Philosophy, though the Causes of those Principles were not yet discover'd: And therefore I scruple not to propose the Principles of Motion above-mentioned, they being of very general Extent, and leave their Causes to be found out.[109]

Newton's active principles, his "Principles of Motion" are similar therefore, and of a similarly "general Extent", to Bacon's kinds of motion found in matter, as discussed above.

Shortly after, Newton describes the "Method of Analysis" in natural philosophy, and again echoes of Bacon can be heard.

> This Analysis consists in making Experiments and Observations, and in drawing general Conclusions from them by Induction, and admitting of no Objections against the Conclusions, but such as are taken from Experiments, or other certain Truths…

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[108] Newton, *Opticks*, 267, 276, 376, 385, 395. Examples of similar locutions in Newton's works could easily be multiplied. There can be no denying that Newton believed matter could be, and was, inherently active. See also McMullin, *Newton on Matter and Activity*; and McGuire, "Force, Active Principles, and Newton's Invisible Realm".

[109] Newton, *Opticks*, 401–2.

Newton went on to say that even though arguing from experiments by induction cannot be used to provide logical proofs, "it is the best way of arguing which the Nature of Things admits of."

Interestingly, Newton is here applying what he calls "the Method of Analysis", a mathematical method to natural philosophy, and suggests that the method of analysis "consists in drawing… Conclusions… by Induction". But Newton clearly believes that "by this way of Analysis we may proceed… from Effects to their Causes." This can perhaps be seen as similar to Bacon's brief outline of his procedure in the *Novum organum*: "But my route and plan… [leads me] to extract (as legitimate interpreters of nature do) from works and experiments causes and axioms…"[110]

Although Newton is willing to concede in the *Opticks* of 1717 that induction is a flawed method ("the arguing from Experiments and Observations by Induction be no Demonstration of general Conclusions"), he clearly agreed with Bacon that it was the best way of arguing in natural philosophy. It seems, however, that Newton must have been aware of continuing objections to his relying on induction, because he added a further defence of it, in the third edition of the *Principia* (1726). He had added three "Rules for the study of natural philosophy" to the second edition of 1713. Although not incompatible with Bacon's views, these rules clearly address issues that were not directly addressed by Bacon. In 1726, however, he added Rule 4:

> In experimental philosophy, propositions gathered from phenomena by induction should be considered either exactly or very nearly true notwithstanding any contrary hypotheses…

Clearly, Newton's *Principia* was still being subjected to criticism from mechanical philosophers who objected to gravity as an action at a distance and offered their own hypothetical mechanical explanations. We can see this from the single brief comment

[110] Ibid., 404–5; Bacon, *Novum Organum*, Book II, Aphorism 117, 175.

added to justify the introduction of this rule: “This rule should be followed so that arguments based on induction may not be nullified by hypotheses.”[111]

Addition of Rule 4 to the third edition of the *Principia* suggests that it was still subject to complaints from some readers that Newton did not offer a cause of gravity. For Newton, however, at the current state of his understanding of gravity, any proposed cause would merely be hypothetical, because the cause cannot be “deduced from the phenomena.” And, as he famously wrote, “hypotheses non fingo ”—“ I do not feign hypotheses”. But perhaps even this famous pronouncement echoes Bacon’s earlier claim: “But I, trusting to the evidence of things, repudiate all taint of fiction and imposture.”[112]

It can be seen, therefore, that like Bacon, and as in the natural magic tradition from which Bacon drew, Newton used empiricism, and inductive logic, to justify his acceptance of occult principles—in Newton’s case attraction at a distance, and other unexplained principles of activity in matter—and refused to offer causal explanations, because, as Bacon had said earlier, “the time for that is not yet ripe”.[113]

This is not to say that Newton consulted the *Novum organum* before writing the penultimate paragraph of the General Scholium, or that he was reading the *Advancement of Learning* when he introduced methodological arguments into Query 31. The point I wish to make is simply that the influence of Bacon’s methodological teachings was so pervasive in seventeenth-century England that it should be seen as part of the intellectual background against which Newton was developing his own ideas. Furthermore, Newton recognised (perhaps unconsciously) the need to use

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[111] Newton, *Principia*, 796. We can also infer from the addition of this rule, that Newton’s famous reply in the General Scholium of 1713 to Cartesians who wanted an explanation of gravity based on causes, “I do not feign hypotheses”, was not sufficiently forceful.

[112] Ibid., 943; Bacon, *Novum Organum*, Book I, Aphorism 122, 183.

[113] Bacon, *Novum Organum*, Book I, Aphorism 116, 175.

these Baconian ways of thinking, and did indeed put them to good use. Even if Newton did not read Bacon, he certainly read Boyle, and could certainly have picked up from him, and from other contemporary English thinkers, the Baconian way of justifying belief in occult phenomena.

Conclusion

We have now considered the background to the other important aspect of Newton's method—the experimental method. It has been appropriate here to focus on Francis Bacon, who arguably did more than any other thinker to establish the relevance of experiments to natural philosophy. But this chapter has also shown the strong links between Bacon's experimental method and his own belief in occult influences at work in the world. In particular, the chapter shows that Bacon's experimental method was bound up with a belief in the inherent activity of matter. As will be seen, this sets the scene for the rest of this thesis where concepts of active matter, in contrast to the passive matter of Cartesian mechanical philosophy, play a continuous and ubiquitous role in English natural philosophy.

The first section, "The Origins of Experimental Method, from Natural History to Induction", showed the importance of fact-gathering, to compile extensive "natural histories", for Bacon's reformist scheme. It then showed that this was linked by Bacon to a new emphasis upon the importance of inductive logic, rather than deductive, for his reformation of natural history. It was also shown that one important aspect of this emphasis upon induction was that Bacon believed that the search for causes in natural philosophy should be postponed until all the relevant data has been collected. Bacon did not emphasise the importance of discovering causes, the way the scholastics did. Moreover, his version of experimentalism was not aimed at discovering causes, the way Gilbert's and Galileo's experiments were.

The second section, “Baconian Philosophizing, Experimentalism and Natural Magic” showed that the postponement of causal explanations, and the associated emphasis upon induction (which offers no causal explanations), were both bound up with Bacon’s belief that the principles and procedures of natural magic offer the best hope for the successful reform of natural philosophy. The magical aspects of Bacon’s “Tables of Discovery” were brought out by showing that his illustration of how they work, trying to establish the nature of heat, placed Bacon among those earlier and contemporary thinkers who wished to dismiss the scholastic distinction between manifest and occult qualities. Bacon was one of those thinkers who wished to argue that all qualities were effectively occult because their existence and effects could only be discovered by experience.

The next section “Baconian Matter Theory: Active and Motive” showed the implications of Bacon’s new approach for his matter theory. Basing his account on experience, and rejecting any pre-conceived casual theories about the nature of matter, Bacon discerned nineteen kinds of inherent motions or “active virtues” in matter. Bacon’s approach was once again natural historical—he saw himself as merely reporting the facts about the different motions of matter, and offered no explanation as to what causes these motions. It seems clear, however, that Bacon regarded matter as endowed with innate powers and virtues, and it was essentially the view of matter which was assumed in the natural magic tradition.

The last section, “Manifest Qualities, Occult Causes, and Newton”, suggested that Bacon’s influence, already dominant before the mechanical philosophy began to take hold, prevented English thinkers from ever fully adopting strict mechanical principles, in which matter was always completely passive and inert. Following chapters will show the dominance of views of active matter in English natural philosophy, and these are here attributed to the powerful influence of Bacon. The section then focuses on Newton and shows that his defence of the fact that he did not offer causal explanations of gravity and other phenomena fully conforms to Baconian tradition, as is his emphasis upon induction. Newton was accused by Continental critics of introducing occult qualities back into natural philosophy (after Descartes had excluded them), and he defended his use of occult principles in entirely Baconian terms.

Part II: Magnetism

Having looked at the historical background in England to the two major innovations in Newton's methodology—his belief that mathematics is relevant to helping us to understand natural philosophy, and his radical experimentalism—we now turn to the background against which the substantive content of his natural philosophy can be understood. The next two parts of this dissertation are concerned with the English background from which the occult, or at least non-mechancial, aspects of Newton's natural philosophical theories emerged. In this part, we consider two different, but related, aspects of what scholars have called the "Magnetic Cosmology", or the "Magnetic Philosophy", and how they can be seen to have impacted upon Newton's own work. In the first of two chapters in this Part, we consider how gravity came to be seen as an attractive force similar to magnetism, and how this played an indirect role in Newton's universal principle of gravitation. The second chapter is concerned with those aspects of contemporary English matter theory which used phenomena of magnetism to indicate that matter could be active, thereby rejecting the inert matter that was an essential feature of the mechanical philosophy as it was developed by Descartes and other strictly mechanical philosophers.

It might seem strange to devote two chapters to magnetism, given that Newton himself is not known to have made any significant contribution to the study of magnets and their effects. In what follows, there is no attempt to uncover a supposedly overlooked interest in magnetism in Newton's work. Rather, the aim is to show that earlier and contemporary work on the various occult phenomena of magnetism can be seen to be linked, either directly or indirectly, with ways of thinking that culminated in the work of Isaac Newton. The first chapter is largely concerned with developing ideas of attraction as a physical force capable of acting at a distance—ideas which featured prominently in Newton's *Principia*. The second considers how magnetic studies impacted on matter theory, and led to ideas of matter as active; a theory of matter which again became characteristic of Newton's natural philosophy.

Chapter 3: The Tradition of Magnetical Cosmology and the Universal Principle of Gravitation

Introduction

One of the most important natural philosophical movements in seventeenth-century England, was initiated single-handedly by the so-called "father of magnetic science", William Gilbert.[1] Gilbert's theories of magnetism, and to a lesser extent, his theories of electricity, proved to be highly influential and gave rise to a recognisable tradition in English natural philosophy. Scholars have called this tradition "magnetical philosophy" or "magnetical cosmology", and it is important to note that it was not simply an exercise in continuing Gilbert's own ideas. On the contrary, the later magnetical philosophers adapted Gilbert's original ideas, to make them conform to their own notions of what constituted sound natural philosophy. To some extent, this was influenced by Continental thinkers who took up Gilbert's ideas, Simon Stevin, Marin Mersenne, Pierre Gassendi, Galileo Galilei, and, most notably, Johannes Kepler. In England, the leading contributors to the tradition that have been noticed by historians of science, were John Wilkins, Walter Charleton, John Wallis, Christopher Wren, and Robert Hooke. Although short lived, the movement was highly important, because it gave rise to a persistent analogy between magnetism and gravity. Attempts to understand gravity as an occult attractive force closely analogous to magnetism led to Robert Hooke's statement in 1679 of what later came to be called the universal principle of gravitation. The magnetical cosmology tradition then achieved its culminating point when Newton provided a mathematical demonstration of the correctness of Hooke's speculation. The main claim to fame of Newton's *Principia mathematica* (1687), the universal principle of gravitation, can

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[1] Christopher Wren referred to Gilbert as "the sole Inventor of Magneticks"; see Christopher Wren, *Parentalia; or, Memoirs of the Family of the Wrens* (London, 1750), 204.

be seen, therefore, as the final triumph of the Gilbertian tradition of magnetic cosmology, even though magnetism itself nowhere figures in the *Principia*.[2]

In what follows, however, we shall see that a previously unnoticed but highly important part was played by Francis Bacon. The influence of Bacon on this tradition is crucial, and can be seen to be largely responsible for the differences between Continental thinkers who took inspiration from Gilbert, and the English tradition which was much more ready to accept, on Baconian experimental grounds, that magnets operated in an occult way. While the mechanical philosophy of Descartes increasingly dominated the new natural philosophies on the Continent, in England Bacon's followers were still ready to accept occult qualities and influences provided they could be demonstrated to really exist by experimental means. It was the old occult belief that magnets acted at a distance, endorsed by Bacon (but not, as we will see, by Gilbert), which gave rise to the view that gravity too might be an attractive force capable of operating at a distance. The fact that the belief in action at a distance was implicit in the magnetical philosophy is what marks it out as such a historically important tradition in English natural philosophy. One of the most remarkable aspects of Newton's new physics was that it relied upon the assumption that bodies could act upon one another across a distance of empty space. Remarkable as this was (indeed, for many on the Continent, it was simply unacceptable), when seen from the English perspective it was not so surprising. Newton's new philosophy was similar to that developed in the English tradition of magnetic philosophy. It is difficult to resist the conclusion that Newton had to be an Englishman, and that no other European thinker might have come up with a philosophy which depended so much on action at a distance.

[2] The fullest treatments of the English tradition of magnetic philosophy are: Stephen Pumfrey, "Magnetical Philosophy and Astronomy, 1600-1650", and James A Bennett, "Magnetical Philosophy and Astronomy from Wilkins to Hooke", both in *Planetary Astronomy from the Renaissance to the Rise of Astrophysics, Part A: Tycho Brahe to Newton*, ed. Rene Taton and Curtis Wilson (Cambridge, 1989), 45–53 and 222–30, respectivly. I have drawn heavily upon these two works in what follows.

This chapter hence details the development of this so-called “magnetical cosmology” from Gilbert, through Bacon, to the immediate precursors of Newton, including John Wilkins, John Wallis, Walter Charelton, and Robert Hooke. The first focus here is on attempts to understand gravity as a variation on magnetism, or by analogy with magnetism. The second and more important focus is to discuss the claim that differences between the philosophical scene in England and on the Continent, made a Newton possible, and also ensured that Newton had to be English. The key point here is that those English Gilbertian-Baconian philosophers all followed the Baconian experimental method, and as a result were able to accept claims based on the assumption of occult influences or powers. Additionally, it will be argued that Newton’s unprecedented success depended largely upon a ready acceptance of various occult ideas (including action at a distance), all of which were already accepted (even if only in a speculative way) in English natural philosophy.

Gilbert’s Magnetical Cosmology

Very little is known about William Gilbert’s life. He graduated as MD from St John’s College, Cambridge, in 1569, and established a medical practice soon after in London. He was a very successful physician, who rose to the Presidency of the Royal College of Physicians in 1600, and the following year was appointed as personal physician to Elizabeth I. He had already been attending Elizabeth’s court from the early 1680s, and may well have shared his natural philosophical interests with John Dee and Francis Bacon, who were also present at court over this period. Certainly, Gilbert is known to have been friends with other mathematicians, such as Thomas Blundeville and Edward Wright, at a time when Dee was the leading mathematician in England, and certainly the leading mathematician at Elizabeth’s court. Bacon refers to Gilbert several times in his writings, and owned a manuscript copy of Gilbert’s unpublished, *De mundo nostro sublunari, nova philosophia contra*

Aristotelem (*On our sublunary world, a new philosophy against Aristotle*).[3] It is not known how or why Gilbert developed ambitions to replace Aristotle's philosophy with a new philosophy of his own, but it may have been stimulated by his acceptance of Copernican cosmology. Certainly, Gilbert was one of the earliest converts to Copernican theory, and his major claim to fame, his *De magnete* (1600, *On the magnet*), was a highly influential attempt to defend Copernicanism against its critics and to show how the Earth could be in perpetual motion (a problem in physics which Copernicus himself never addressed).[4]

Although historians of science have tended to regard Gilbert as a great pioneer in the study of magnetism, and as one of the first to develop the experimental method, in order to understand magnets,[5] the main aim of the work, as far as its author was concerned, was to provide a solution to the unsolved problem as to how the Earth could move. As one of the earliest committed Copernicans, Gilbert definitely believed that the earth was truly in motion, spinning on its axis, and revolving around the Sun. The other early converts were all astronomers, but Gilbert evidently recognized the problems the Earth's motion posed for natural philosophy, and believed that the phenomena of magnetism could help him solve this problem.

The reasoning behind Gilbert's solution to this Copernican problem is surprisingly simple and entirely original. The spontaneous rotatory movement of lodestones and magnetized iron indicated to Gilbert that magnets are capable of moving themselves.

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[3] Stephen Pumfrey, "Gilbert, William (1544?–1603), Natural Philosopher," *Oxford Dictionary of National Biography*, 1603, accessed September 9, 2018, http://www.oxforddnb.com/view/10.1093/ref:odnb/9780198614128.001.0001/odnb-9780198614128-e-10705;jsessionid=6CACE8A064D37DCAF7C37161BC9B3D33.

[4] William Gilbert, *De Magnete*, trans. P. Fleury Mottelay (New York: Dover, 1958). See Henry, "Animism and Empiricism"; Stephen Pumfrey, *Latitude and the Magnetic Earth* (Cambridge, 2003). R. S. Westman discerned only ten Copernicans before 1600, but did not include Gilbert in his list. But it is now clear that Gilbert was one of the first eleven converts to Copernicanism. See Westman, "The Astronomer's Role".

[5] For example, Edgar Zilsel, "The Origins of William Gilbert's Scientific Method," *Journal of the History of Ideas* 2 (1941): 1–32; Duane H. D. Roller, *The De Magnete of William Gilbert* (Amsterdam, 1959).

Accordingly, if the earth itself was a giant lodestone, it would also be capable of moving itself, and could therefore make the required Copernican rotatory movements in the same spontaneous way. Consequently, the main task for Gilbert in his book was to show that the Earth itself *is* a giant Magnet. So, how did Gilbert demonstrate this hypothesis? He proved it by analogy with the behaviour of small magnets (specially shaped into spheres, and called by Gilbert *terrellae*—little earths). By performing experiments on the *terrellae*, Gilbert could show that the large sphere of the Earth behaved in the same way. Gilbert might have concluded that magnets and the Earth both exhibited occult powers of attraction and other mysterious phenomena, but he rejected this course, preferring to conclude that the behavior of a magnet "imitates a soul".[6]

Although Gilbert was able to point to Aristotle's claim that the earliest natural philosopher, Thales of Miletus, believed that the magnet must have a soul, Gilbert's own animist view of magnets (and therefore of the Earth) seems to be highly original and unique.[7] Before Gilbert, it was generally agreed that magnets were the supreme exemplars of a range of "occult qualities". Galen used magnetism to justify his theory that the natural faculties of the human body, such as digestion and excretion, worked by attraction. Medieval and Renaissance Aristotelians recognized that the four primary qualities of Aristotelian doctrines could by no means explain occult qualities, as made plain by the phenomenon of magnetism. Thomas Aquinas, for example, had no explanation for magnetism but admitted that "the loadstone does not attract iron by means of heat or cold or any such quality... but by means of its participation in the heavenly virtue".[8] Although Gilbert said that Aquinas's theory

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[6] Gilbert, *De Magnete*, Book V, Chapter 12, 308. On Gilbert's use of *terrellae* to represent the Earth in his experiments, see especially, Book II, Chapters 5 to 10, 115–27.

[7] Ibid., Book V, Chapter 12, 312. See Aristotle, *De Anima*, Book I, Chapter 2 in Aristotle, *On the Soul, Parva Naturalia, On Breath*, trans. W. S. Hett, revised edition., Loeb Classical Library (Cambridge, MA, 1957), 405a 20–22.

[8] Saint Thomas. Aquinas, *Quaestiones de Anima* (Pontifical Institute of Mediaeval Studies, 1968), 60.

was not fully "ill-conceived", he disagreed with Aquinas significantly.[9] Indeed, he rejected every other theory of magnetism, thereby leaving only his own for his readers to accept. Following the revival of Neo-Platonism and the natural magic tradition, many sixteenth-century writers (including John Dee) were convinced that the occult qualities of magnets obviously had a celestial cause, such as an astrological emanation from stars or planets. Virtues of heavenly origin, were thought of as emanations from planetary souls, and were supposed to permeate the whole world. Rays of astrological influence, as John Dee believed, suffused lodestones and iron, and gave them occult virtues. Gilbert, on the other hand, wanted to reject this Neo-platonic theory, no less than he wanted to reject theories based on Aristotelian occult qualities, because neither implied that magnets, including the Earth, must be capable of self-movement—only his own theory of animate magnets could guarantee self-movement.[10]

Having presented an encyclopedic natural history of the loadstone and of iron in Book I of *De magnete*, Gilbert started Book II with his own meticulous experiments on magnetic movements, and scrupulously made several comparisons between the Earth and his experimental spherical magnets, or *terrellae*. It becomes perfectly clear in Book II that it was the spontaneous rotatory movement of lodestones that convinced Gilbert that the magnets were simply moving themselves, and he then supposed that if the Earth itself was a giant lodestone, it therefore could, and did, move as Copernican theory demanded. Gilbert demonstrated his bold speculation by a series of experiments throughout almost the whole of Books II to V. Finally, he was able to draw the conclusion in Book VI that the Earth was a giant loadstone and,

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"Super has autem sunt formae mixtorum corporum, quae praeter praedictas operationes, habent aliquam operationem consequentem speciem, quam sortiuntur ex corporibus caelestibus; sicut quod adamas attrahit ferrum, non propter calorem aut frigus aut aliquid huiusmodi, sed ex quadam participatione virtutis caelestis."

[9] Gilbert, *De Magnete*, Book II, Chapter 3, 104.

[10] Ibid., Chapter 3, 97–104.

like all magnets, must have it own soul, and therefore the ability to move itself.[11] The ingenuity of Gilbert's experiments was remarkable. In particular, he showed how tiny iron needles behaved in relation to the spherical surface of the loadstone, and then pointed out that exactly the same behaviour could be seen in bar magnets, and compass needles in relation to the spherical surface of the Earth. The analogies were so close, it seemed hard to deny that the Earth too must be acting as a giant *terrella*, or that the *terrella* really was a little Earth.

The Beginnings of the Magnetical Cosmology Tradition

So, by making use of ingeniously designed experiments, Gilbert was able to prove that the earth itself was a giant loadstone, and therefore (he believed) ensouled, and capable of self-movement. In spite of its uniquely (and radically) different approach from other speculative replacements for Aristotle's philosophy, Gilbert's demonstration of the supposedly magnetic motions of the Earth was quickly embraced by other leading Copernicans. As Stephen Pumfrey has written, "before the inertial mechanics of Galileo and Descartes became established in mid-century, many [Copernicans] sought answers in the 'magnetical philosophy' of William Gilbert (1544–1603)."[12] Gilbert's intention in writing his seminal work, *De magnete* (1600), was to provide an explanation for the Copernican motions, but his own solution to the problem was never entirely adopted by any subsequent thinker. Gilbert's animistic approach was evidently unacceptable even to the immediately succeeding generation of natural philosophers. And Gilbert's original magnetical

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[11] This was in fact a generally accepted Aristotelian view—that the only things capable of moving themselves are creatures with souls. Although Gilbert was vigorously anti-Aristotelian, he accepted this particular Aristotelian doctrine. Aristotle discusses this in *Physics*, Book VIII. See David Furley, "Self-Movers", and Mary Louise Gill, "Aristotle on Self-Motion", both in *Self Motion from Aristotle to Newton*, ed. Mary Louise Gill and James G. Lennox (Princeton, 1994), 3–14 and 15–34, respectively.

[12] Pumfrey, "Magnetical Philosophy," 45; idem, *Latitude*; idem, "Mechanizing Magnetism in Restoration England—the Decline of Magnetic Philosophy," *Annals of Science* 44 (1987): 1–21; Bennett, "Magnetical Philosophy"; idem, "Cosmology and the Magnetical Philosophy, 1640–1680," *Journal for the History of Astronomy* 12 (1981): 165–177; idem, "Hooke and Wren and the System of the World: Some Points towards an Historical Account," *The British Journal for the History of Science* 8 (1975): 32–61.

philosophy was turned into a more naturalistic system, albeit one which (necessarily) remained highly occult. For Gilbert, magnets—and the "great Earthly magnet"—were animate beings, but for his followers they were, as they had always been, exemplary occult objects. Magnets were capable of self-movement, but not because they were animated, merely because they possessed the occult qualities of magnetism.

In the most famous case, for example, namely the magnetical cosmology of Kepler, the Sun was envisaged as being able to act on the surrounding planets, sweeping them around itself as it rotated on its axis, by rays of magnetic force. Additionally, Kepler supposed that the Sun was a unique kind of magnet, with only one pole. The planets, however, were envisaged as having a north and south pole, just like the Earth. By assuming that the planets' different poles continually changed their alignment to the Sun's single pole, Kepler claimed that the planets during their orbit would be alternately attracted to and repelled from the Sun, and would therefore not move in perfect circles around the Sun, but in ellipses.[13] Kepler's account depended on occult forces acting at a distance, but it was entirely dynamic and naturalistic; there was no suggestion (by contrast with Gilbert) that his planets were capable of moving themselves, like animals or other more intelligent beings, by virtue of possessing a soul. As Kepler himself wrote to a correspondent in 1605, he intended to write of the "celestial machine… not on the model of a divine, animate being, but on the model of a clock":

> In [that machine] almost all the variety of motions [stems] from one most simple, physical magnetic force, just as in the clock all motions stem from a most simple weight. [14]

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[13] Pumfrey, "Magnetical Philosophy," 48–9; Alexandre Koyré, *The Astronomical Revolution: Copernicus, Kepler, Borelli*, trans. R. E. W. Maddison (Paris, 1973); Bruce Stephenson, *Kepler's Physical Astronomy* (Princeton, 1994).

[14] Johannes Kepler to Herward von Hohenberg, 10 February, 1605; quoted from Michael Mahoney, "The Mathematical Realm of Nature," in *The Cambridge History of Seventeenth-Century Philosophy*, ed. Daniel Garber and Michael Ayers, 2 vols (Cambridge, 2000), ii: 706.

It is important to note, however, that underlying Kepler's mechanical image of a clockwork universe is an *occult* driving force, "a single corporeal magnetic force."

The development of the magnetical cosmology in England followed a similar course. Although the English followers of Gilbert differed from Kepler, accepting that the force which kept the planets in their orbits could not be the same force as magnetism, which all too obviously operated only between magnets and ferrous bodies; they nevertheless drew close parallels between the operations of these forces and sometimes came close to referring to magnetism as though it was the force that guided the planets. Walter Charleton, for example, described gravity as "a certain Magnetick attraction of the Earth" and elsewhere declared that "the Terrestrial globe is naturally endowed with a certain Attractive or Magnetique Virtue." Similarly, Robert Hooke, in his *Cometa* (1678) suggested that the planets "may be said to attract the Sun in the same manner as the Load-stone hath to Iron."[15] But there is no suggestion in any of the English magnetic cosmologists that magnetism, or gravity, indicated that a soul was at work; it was simply believed that they were endowed with an occult magnetic virtue which was an attractive power, and in some circumstances, a repulsive power.

But this was not the only way that Gilbert's English followers differed from the founder of their tradition. By rejecting Gilbert's notion of a magnetic soul, and reverting to earlier ideas of occult magnetic virtues, the new magnetic philosophers also accepted pre-Gilbertian views that magnets operated at a distance upon one another, and upon iron.

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[15] Walter Charleton, *Physiologia Epicuro-Gassendo-Charltoniana: Or a Fabrick of Science Natural upon the Hypothesis of Atoms* (London, 1654), 227, 289; Robert Hooke, "COMETA, or, Remarks about Comets," in *Lectures and Collections: Cometa, Microscopium* (London, 1678), 12. For further examples of the analogy between magnetism and gravity see Bennett, "Magnetical Philosophy".

The belief in action at a distance which is a feature of the magnetic philosophy, was assumed by both Stephen Pumfrey and James Bennett to have had its origins in Gilbert's own work. Pumfrey, for example, has suggested that Gilbert believed "magnetism was an enduring action at a distance". While Bennett seemed to imply that Gilbert, like his contemporaries, regarded magnetism as "the great exemplar of invisible influence at a distance", and considered magnetic influence to be "a very pure example of action at a distance."[16] A closer reading of Gilbert, however, reveals that he categorically rejected the concept of action at a distance.

We can see this most clearly, perhaps, in his rejection of the "Opinions of Others Concerning Magnetic Coition, which they call Attraction", which is the title of Book II, Chapter 3.[17] Gilbert's choice of the word "coition" to refer to the coming together of two magnets, or a magnet and iron, was bound up with his rejection of the occult notion of "attraction": "Coition, we say, not attraction, for the term attraction has wrongfully crept into magnetic philosophy".[18] Gilbert even adds: "if we have at any time spoken of magnetic attraction, what we meant was magnetic coition." Dismissing the talk of magnetic attraction by Orpheus, Thales, Anaxagoras, and Epicurus, Gilbert insists that no real attraction takes place. Furthermore, he is equally dismissive of those, such as Plato, Lucretius, Galen, and Plutarch who claim that the supposed attraction is caused by impulsion, or by "circumpulsion"—in which "air, driven round in a circle and returning to the part whence the air was displaced, forcibly carries the iron with it." Gilbert concludes that "the loadstone does not thus

[16] Pumfrey, "Magnetical Philosophy," 47; Bennett, "Magnetical Philosophy", 222; Bennett, "Cosmology", 166. See also, Pumfrey, *Latitude*, 127. And his article on Gilbert in the *Oxford Dictionary of National Biography*, where he writes, "Magnets were capable of attracting and repelling ferrous bodies across empty spaces": Pumfrey, "Gilbert, William".
[17] Gilbert, *De Magnete*, Book II, chapter 3, 97–104.
[18] Ibid., 97–98.

attract, and there is no impulsion; neither is the principle of motion found in vapours and their return movements."[19]

Turning to the moderns, Gilbert dismisses those, such as Girolamo Cardano, Cornelius Gemma, and Giambattista della Porta, who invoke some kind of occult influence to account for magnetic movements. At one point he says that those who say the "loadstone draws iron to itself by means of invisible rays… tack on a story of the sucking-fish and the catablepas."[20] And a little later he says that those who "postulate rays imperceptible to the senses… in very many ways, make a sad misuse of a term first employed by mathematicians." It seems that for Gilbert it is acceptable to use the concept of rays in geometrical optics, but not to invoke them as real physical entities.[21] Gilbert takes the same line against the concept of attraction in his unpublished *De Mundo*, where Book I, Chapter 34 critically examines concepts "Of natural attraction" (*De Attractione naturali*). "Many sciolists," Gilbert writes, "when they cannot find the cause of some effect, flee to a certain faculty of attraction, thinking that these attractions exist in nature, and are as well known as violent motions are in mechanics."[22] The truth is, Gilbert soon insists, "no attractions are produced in natural bodies".[23]

Gilbert's opposition to the notion of attraction clearly stemmed from his belief that attraction was an occult notion which depended upon action at a distance. Where possible, Gilbert developed explanations of physical phenomena which relied upon

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[19] Ibid., 98–100.
[20] Ibid., 101. The sucking-fish is the remora, said to be capable of holding a ship stationary; and the catablepas is a buffalo-like creature capable of turning a man to stone, or killing him, simply by looking at him—both supremely occult beasts. See Brian P. Copenhaver, *Magic in Western Culture: From Antiquity to the Enlightenment* (Cambridge, 2015).
[21] Gilbert, *De Magnete*, Book II, chapter 3, 103.
[22] William Gilbert, *De Mundo nostro sublunari philosophia nova* (Amsterdam, 1651), Book I, Chapter 34, 95. "plurimique scioli cum effectus alicujus rationem nullam invenire possunt, ad attractionis facultatem aliquam confugiunt, existimantes in naturaita esse familiares attractiones, atque in mechanicis violentæ."
[23] Ibid., 96.

material contact, either directly or indirectly, between reacting bodies. In the case of electrical attractions and repulsions, for example, he developed explanations based on the assumption that electrical bodies issued streams of material effluvia, which stuck to the "attracted" body, carrying it back to the electric as the effluvia returned to their source. Again, even the title of the chapter dealing with electrics suggests Gilbert's opposition to attraction: "Of the Attraction exerted by Amber, or more properly the attachment of bodies to amber".[24] After dismissing all earlier explanations of electrics which depend on attraction, Gilbert develops the idea that friction stimulates the emission of effluvia from the electric:

> A breath, then, proceeding from a body that is a concretion of moisture or aqueous fluid [i.e. an electric body], reaches the body that is to be attracted, and as soon as it has reached it is united to the attracting electric; and a body in touch with another body by the peculiar radiation of effluvia makes of the two one: united, the two come into most intimate harmony, and that is what is meant by attraction.[25]

Shortly after, Gilbert confirms that action at a distance is impossible: "For as no action can be performed by matter save by contact, theses electric bodies do not appear to touch, but of necessity something is given out from the one to the other to come into close contact therewith…"[26]

In spite of the claims of Pumfrey and Bennett that Gilbert assumed magnets were exemplary occult objects, and capable of acting at a distance, it is clear that Gilbert rejected action at a distance and other accounts of magnetism which he regarded as occult. The question arises, therefore, as to how Gilbert explained what looks like magnetic attraction. He himself pointed out the vast difference between the operations of electrics on the one hand, and of magnets on the other. Electrical effects could be all too easily stopped by even the thinnest of barriers, but magnets could operate without impairment through even dense barriers such as stone or

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[24] Ibid., 74.
[25] Ibid., 91.
[26] Ibid., 92.

non-ferrous metals. Clearly, magnets did not work by emitting effluvia, so, how did they work, if action at a distance was not allowed?

The answer lies in Gilbert's substitution of the word "attraction" by his concept of "coition." At the end of his chapter on the "Opinions of others concerning magnetic coition, which they call attraction", Gilbert discusses the ideas of two thinkers who he believed came close to the correct answer. The first is Thomas Aquinas who, Gilbert tells us, suggested that "the loadstone give[s] to iron some quality through which it is moved to the loadstone." The second is Cardinal de Cusa, that is Nicolaus Cusanus, philosopher, theologian, and mystic. Quoting Nicolaus (though without providing a source), Gilbert writes: "while the loadstone by its presence excites the heavy and ponderous iron, the iron is, by a wonderful longing, raised above the natural motion… and moves upward, uniting in its principle."[27] If we recall that Gilbert believed magnets were ensouled and therefore capable of self-movement, it is easy to see that Gilbert believed that magnets, and pieces of iron within the sphere of influence of a magnet, were capable of moving themselves towards one another. Their movements were not compelled by a physical force of attraction, but were closer to the voluntary movements an animal, or human, might make when attracted to something it desires—something for which, as Nicolaus Cusanus said, it had a "wonderful longing". Gilbert wrote of magnetic coition as a "mutual action", "a concerted action", and "a mutual agreement." A piece of iron "flies to", or "rushes headlong on the loadstone", it is not drawn to it by a physical power. "Thus the magnetic coition," Gilbert wrote, "is the act of the loadstone and of the iron, not one of them alone."[28] For Gilbert, there was no attractive force operating between magnets, but they spontaneously moved themselves to unite with one another.

[27] Ibid., 104.
[28] Ibid., 109–10.

Even though later members of the tradition of magnetic philosophy occasionally refer to magnetic "coition", using Gilbert's term, there is no indication in any of their writings that they accepted Gilbert's arguments and agreed with him that magnets did not attract, and did not operate at a distance. They always use "coition" merely as an alternative to "attraction". As we shall see, like Kepler, Gilbert's English followers reverted to earlier assumptions about magnets as occult objects which attracted other magnets and iron at a distance.

Furthermore, there was another crucially important difference between Gilbert and later English natural philosophers in the tradition of magnetic cosmology. One of the most characteristic aspects of the later tradition, as we shall see, was the development of analogies between magnetic and gravitational attraction. But Gilbert himself made no such analogies. On the contrary, Gilbert maintained that terrestrial gravity is caused not by magnetism but by effluvia emanating from the Earth. If there was an analogy between gravity and other phenomena that seemed to involve attraction, for Gilbert, it was with electrics, not with magnets. During the course of his discussion of electrics, Gilbert announces that "All bodies are united and, as it were, cemented together by moisture". He illustrates this by considering the way bodies are united by gravity:

> Air, too (the earth's universal effluvium), unites parts that are separated, and the earth, by means of the air, brings back bodies to itself; else bodies would not so eagerly seek the earth from heights. The electric effluvia differ much from air, and as air is the earth's effluvium… and each peculiar effluvium has its own individual power of leading to union, its own movement to its origin, to its fount, and to the body that emits the effluvium.[29]

If we take Gilbert's philosophy on its own terms, therefore, there was no need whatever for him to invoke action at a distance to explain either terrestrial gravity or the movements of the planets. Terrestrial gravity could be explained by material effluvia making contact with heavy bodies and pulling them down to Earth, as they

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[29] Ibid., 92.

returned to their origin. With regard to the orbits of the planets, on the other hand, he was able to imply that they were all self-moving bodies like the magnetic Earth, endowed with souls that were superior to the errant fallen souls of humans and so capable of maintaining themselves in their allotted spheres.[30]

In a nutshell, Gilbert "invented" a tradition of magnetical philosophy, which was the foundation for the following natural philosophers. But Gilbert's own magnetical philosophy differs significantly from his so-called followers. On the one hand Gilbert's animated explanation of magnetism had never been fully adopted. On the other hand, Gilbert not only denied action at a distance but also denied any analogy between magnetism and gravity, so the disconnect between Gilbert and his supposed "followers" becomes all too apparent. The question then arises as to why subsequent writers in the supposedly Gilbert-inspired tradition of magnetical cosmology should all write as though action at a distance is a plausible idea? After all, this idea had always been regarded as a completely unacceptable principle in natural philosophy.[31] Similarly, why should these same writers have unanimously developed the idea that gravity might be analogous to magnetic attraction?

Both Pumfrey and Bennett noted that the analogy between magnetic and gravitational attraction was the most persistent feature of magnetical cosmology. And Pumfrey also acknowledged that Gilbert never regarded gravity and magnetism as in any way related to one another.[32] But, Pumfrey seems simply to see the analogy as based on a unanimous misreading of Gilbert by the magnetical

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[30] On the superiority of the Earth's soul to the human soul, see Gilbert, *De Magnete*, Book. V, chapter 12, 308–12. I assume that Gilbert wished to extend his theory about a magnetic Earth to the planets, although he says little about this in his more wide-ranging *De mundo*. The planets were, in some medieval cosmologies, already held to be animated, or to be moved by angels, and Gilbert used this as a rhetorical argument for supposing that the Earth should also be animated. It would be odd, therefore, if he then tried to deny that the other planets were animated.

[31] Mary Hesse, *Forces and Fields A Study of Action at a Distance in the History of Physics* (London: Nelson, 1961).

[32] Pumfrey, "Magnetical Philosophy", 53.

cosmologists and therefore does not ask whether it might have derived from another source. As we shall see in the next section, there was in fact a "missing link" between Gilbert on the one hand and the later magnetical cosmologists on the other. That is to say, a link which has not previously been noticed by historians of science. This missing link was none other than Francis Bacon, and it was he who not only drew the analogy between magnetism and gravity, but also treated action at a distance as a feasible physical concept.[33]

Francis Bacon, Magnetic Cosmologist

Bacon is well known to have been an early reader, and critic, of Gilbert.[34] Among other things, he took issue with Gilbert's notions of the cause of gravity and of magnetic power. In his *History of Heavy and Light*, for example, Bacon mocked Gilbert by saying that "he has himself become a magnet; that is, he has ascribed too many things to that force, and built a ship out of a shell." Even so, elsewhere in the *History of Heavy and Light* Bacon seemed to regard Gilbert as pointing the correct way: "Gilbert therefore has not unscientifically introduced the matter of magnetic force."

Whatever the role of Gilbert in his conclusions, Bacon certainly came to link terrestrial gravity with magnetism. In *Novum organum*, for example, he wrote that

> heavy or weighty bodies either tend from their intrinsic nature to the centre of the Earth by means of their proper schematism, or they are *attracted* or seized by the corporeal mass of the Earth itself, as to a gathering of connatural bodies, and are carried to it by consent. Now if the latter is the case, it follows that the closer heavy bodies get to the Earth, the more strongly and vigorously they are carried towards it, and the further away the more weakly and slowly (as happens in *magnetic attractions*).[35]

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[33] Xiaona Wang, "Francis Bacon and Magnetical Cosmology", *Isis* 107 (2016): 707–21.

[34] Sister Suzanne Kelly, *The De Mundo of William Gilbert* (Amsterdam1965), 75–96; Marie Boas, "Bacon and Gilbert," *Journal of the History of Ideas* 12 (1951): 466; Mary Hesse, "Gilbert and the Historians (II)," *British Journal for the Philosophy of Science* 11 (1960): 130–42; Duane H. D. Roller, "Did Bacon Know Gilbert's *De Magnete*?," *Isis* 44 (1953): 10–13; Bacon, *The Works of Francis Bacon*, iii: 193–97.

[35] Francis Bacon, "Preface to History of Heavy and Light," in Bacon, *Works*, v: 202; Bacon, *Novum*

Clearly, Bacon saw gravity as an attractive force, similar to the magnetic force. We can see this more clearly in the following Aphorism (37):

> In the same way, let the natures under investigation be the corporeal nature, and natural action. For it seems that we find no natural action which does not subsist in some body. Yet maybe there is some *Instance of Divorce* relating to this matter, i.e. the magnetic action, which draws iron to a loadstone, and heavy bodies to the globe of the Earth.[36]

And even more clearly in Aphorism 45:

> Again, if there be any magnetic power which operates by consent between the Earth and heavy bodies, between the globe of the Moon and the seas … or between the stellar heavens and the planets by which the latter are summoned and drawn to their apogees, then all these operate at very long distances indeed.[37]

We can see this in Bacon's later work *Sylva sylvarum* as well. While considering various reasons for "attractive virtue," Bacon sees magnetism and gravity as both caused by "consent with the Globe of the Earth":

> The fourth [cause] is the emission of spirits, and immateriate powers and virtues, in those things which work by the universal configuration and sympathy of the world; not by forms, or celestial influxes (as is vainly taught and received), but by the primitive nature of matter, and the seeds of things. Of this kind is (as we yet suppose) the working of the loadstone, which is by consent with the globe of the earth: of this kind is the motion of gravity, which is by consent of dense bodies with the globe of the earth…[38]

It was Bacon, not Gilbert, who was the first natural philosopher to draw an analogy between magnetic and gravitational attraction. It can be argued, therefore, that the subsequent tradition of magnetic cosmology (where, according to Bennett and Pumfrey, the analogy between magnetic and gravitational attraction was the most persistent feature[39]) owed more to Bacon than it did to Gilbert.

Organum, Book. II, Aphorism 36, 329.

[36] Bacon, *Novum Organum*, Book. II, Aphorism 37, 340. "Instances of Divorce," for Bacon, "point to separations of those natures which very often meet together," and he seems to be suggesting here that magnetism/gravity might be a natural action that is separable from body.

[37] Ibid., Book. II, Aphorism 45, 370-1.

[38] Francis Bacon, *Sylva sylvarum*, Cent. X, §907, in Bacon, *Works*, ii: 644.

[39] Pumfrey, "Mechanizing Magnetism", 53; Bennett, "Cosmology".

Furthermore, in sharp contrast to Gilbert, Bacon explicitly described magnetism and gravity as exemplars of action at a distance. In Aphorism 45 of the *Novum Organum*, for example, he wrote:

> But there are other virtues which operate at a distance though an extremely small one, and so far few of these have been observed as there are still many more than people imagine, as when (to take common examples) amber and jet attract straws; bubbles merge when they come together; certain purgative medicines draw humours down from above; and things of that kind. Again, the magnetic virtue by which iron and loadstone or one loadstone and another come together, operates within a definite though small orb of virtue. But on the other hand, if any magnetic virtue exists coming from just below the Earth's surface and works on an iron needle in respect of verticity, the operation takes place at a great distance.

When Bacon wrote of a magnetic power operating between the Moon and the seas, or between the stellar heavens and the planets (as we saw above in our first quotation from Aphorism 45), he pointed out that if this were the case, "then all these operate at very long distances indeed."[40]

Unlike Gilbert or the majority of other philosophers, Bacon evidently had no strict objection to the concept of action at a distance. He even included a positive discussion of action at a distance in the *Wisdom of the Ancients*, his most frequently published philosophical work during his own lifetime. In the essay "Pan, or Nature," for example, he wrote:

> The body of Nature is most elegantly and truly represented as covered with hair; in allusion to the rays which all objects emit; for rays are like the hairs or bristles of nature; and there is scarcely anything which is not more or less radiant. This is very plainly seen in the power of vision, and not less so in all kinds of magnetic virtue, and in every effect which takes place at a distance. For whatever produces an effect at a distance may be truly said to emit rays. But Pan's hair is longest in the beard, because the rays of the celestial bodies operate and penetrate from a greater distance than any other.[41]

Similarly, in the essay "Cupid, or the Atom," he wrote:

> His [Cupid's] last attribute is archery: meaning that this virtue is such as acts at a distance: for all operation at a distance is like shooting an arrow. Now whoever

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[40] Bacon, *Novum Organum*, Book II, Aphorism 45, 369, 370-71.

[41] Francis Bacon, *The Philosophical Works of Francis Bacon*, ed. John M. Robertson (London, 1905), 710.

> maintains the theory of the atom and the vacuum… necessarily implies the action of the virtue of the atom at a distance; for without this no motion could be originated, by reason of the vacuum interposed; but all things would remain fixed and immovable.[42]

In fact, Bacon kept his mind open to all the possible ways of actions, not only by contact, but also by action at a short distance and action at a long distance, depending upon the size of a body's sphere of activity. We can see this in his unpublished work *Abecedarium novum naturae*.[43]

> ...measure of distance or the orb of virtue is the distance which the powers of bodies may travel to, stop at, build up to and die down from— whether the operation occur by contact alone, or at a (greater or) lesser distance….[44]

Francis Bacon's Cosmology and Magnetism

It seems perfectly clear that although Gilbert rejected action at a distance and never considered the possibility that terrestrial gravity was similar to magnetic power, Bacon explicitly embraced both these ideas. Bacon's differences from Gilbert on these issues were no doubt bound up with his rejection of Gilbert's animistic theory of magnetism. Rejecting Gilbert's notion of magnetic "coition" and the idea that magnets came together not as the result of an attractive force but as a result of a kind of volitional self-movement, Bacon reverted to the view that magnets were the supreme exemplars of occult objects and *could* act at a distance.[45] We can see Bacon's more naturalistic view in Aphorism 36, which we have already quoted more fully above, where he noted that "the closer heavy bodies get to the Earth, the more strongly and vigorously they are carried towards it, and the further away the more weakly and slowly (as happens in magnetic attractions)."[46]

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[42] Ibid., 730–1. Bacon's suggestion that atomism implies an acceptance of action at a distance will be discussed in detail in Chapter 6.

[43] Now published in, Bacon, *OFB XIII*, 171–225.

[44] Bacon, *Abecedarium novum naturae,* in Ibid., 211–3.*OFB XIII*, 211-13.

[45] Admittedly, Bacon does use Gilbert's term, "coition," here and there, but he uses it loosely as an equivalent to "attraction." See, e.g., Aphorism 25: "let the nature under investigation be the attraction *or* coition of bodies." Bacon, *Novum organum*, Book. II, Aphorism 25, 283.

[46] Bacon, *Novum organum*, Bk. II, Aphorism 36, 329.

This seems similar to Kepler's well-known comment rejecting Gilbert's animistic notion of magnetism in favour of a more naturalistic account:

> If you substitute the word "force" for the word "soul," you have the very principle on which the celestial physics in the *Commentary on Mars* is based. For I formerly believed completely that the force moving the planets is a soul, having indeed been imbued with the teaching of J. C. Scaliger on motive intelligences. But when I recognized that this motive cause grows weaker as the distance from the Sun increases, just as the light of the Sun is attenuated, I concluded that this force must be, as it were, corporeal.[47]

It is worth reiterating at this point that belief in action at a distance was very far from being an acceptable philosophical position, and so Bacon's ready and explicit use of it was quite remarkable. It seems highly likely, therefore, that the *implicit* acceptance of action at a distance in the succeeding generation of English magnetical cosmologists was encouraged by Bacon's promotion of it in his *Wisdom of the Ancients* and the *Novum organum*. But before turning to this point, there is one more thing that needs to be clarified.

It would be wrong to suppose, that Bacon had a fully developed magnetical cosmology. It seems clear that he saw magnetism as offering a possible means of understanding terrestrial gravity, the Moon's influence on the tides, and the movement of the planets, but he never committed himself to this view. In fact, Bacon had an alternative explanation for these phenomena that emerged out of his own unique philosophical system, his "semi-Paracelsian" cosmology.[48] This being the case, it is perhaps worth asking ourselves why Bacon bothered to hint at an alternative magnetic explanation of these phenomena. I offer some suggestions here, but this section is necessarily speculative.

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[47] Johannes Kepler, *Mysterium Cosmographicum*, ed. F. Hammer, vol. 8, *Gesammelte Werke* (Munich: Beck, 1938), 113; Johannes Kepler, *The Secret of the Universe*, ed. A. M. Duncan (New York: Abaris Books, 1979), 203. I have used the translation provided in Richard S. Westfall, *The Construction of Modern Science: Mechanisms and Mechanics* (Cambridge, 1978), 9–10. Although Kepler mentions the widely read Scaliger here, rather than the less well known Gilbert, his comment indicates his divergence from Gilbert as much as from Scaliger.

[48] Bacon, *Novum organum*, Book. II, Aphorism 45, 370–71; and Rees, "Semi-Paracelsian Cosmology".

The first thing we need to note is that Bacon, unlike Gilbert, was not a Copernican and did not need to use magnetism to explain the motion of the Earth.[49] It is possible, however, that he saw magnetism as a means of driving the motions of the other heavenly bodies. The move here would be similar to Kepler's suggestion (which of course has no precedent in Gilbert's writings) that lines of force emanating from a magnetic and rotating Sun would sweep the surrounding planets around as the Sun rotated. In Bacon's case, however, the Sun is just one more heavenly body whose motions need to be explained. For Bacon, it is the magnetism of the outermost stellar sphere that seems to move the other planets: "Again, if there be any magnetic power which operates by consent … between the stellar heavens and the planets by which the latter are summoned and drawn to their apogees, then all these operate at very long distances indeed."[50]

This is in keeping with Bacon's more idiosyncratic cosmology in which the stellar sphere moves around the Earth once every twenty-four hours, while successive spheres, moving downward from Saturn to the Moon, move increasingly slowly. Bacon's cosmos is homocentric about the Earth and so is in the tradition deriving from Eudoxus (although Bacon actually follows the eleventh-century Arabic astronomer known to the West as Alpetragius) rather than from Ptolemy. Whereas in Ptolemy's scheme all the heavenly spheres move from east to west once every twenty-four hours, while the planets continuously move at different speeds from west to east, Bacon (following Alpetragius) simply absorbs the eastward motions of the planets into the diurnal westward motion. So, while the fixed stars make a complete circuit in twenty-four hours, Saturn just fails to make a compete circuit (because of what Ptolemy sees as its eastward motion, taking thirty years to complete, but which

49 For Gilbert's use of magnetism to explain the motion of the Earth see Henry, "Animism and Empiricism".
50 Bacon, *Novum organum*, Book. II, Aphorism 45: 370–71.

Bacon simply sees as its slightly slower westward motion). By the time we get to the Moon, we can see that it will take significantly longer to complete a westward circuit (because, in Ptolemy's terms, it is moving eastward once every twenty-seven days, but in Bacon's terms it is simply moving westward correspondingly more slowly). According to Alpetragius, the Moon, which has the shortest distance to cover to orbit the Earth, takes twenty-five hours to make a complete westward circuit around the Earth, so it must be moving considerably more slowly than Saturn.[51]

Bacon's favoured explanation for the successively slower motions of the planetary spheres depended on his complex matter theory, and we need not go into all the details here. Suffice it to say that sidereal fire, the most active substance in the world system, has its seat in the stellar sphere and supposedly drives the motion of the stellar sphere and the planetary spheres. But its power is increasingly attenuated the farther it is from the stellar sphere, and so successive spheres are moved increasingly slowly. Although Bacon might have favoured this complex theory, he may well have been inspired by his reading of Gilbert to consider magnetism as a possible cosmic alternative. Magnetism too becomes weaker as distance from the magnet increases.[52] Consequently, just as Kepler used the Sun's rotation, and "rays" of magnetism connecting the rotating Sun to the planets, to explain the motions of the planets, it is highly possible that Bacon saw magnetic force as a means of transmitting the rotation of the sphere of fixed stars to the planets below, although the transmission became less efficient as the distance increased.

Bacon might have been encouraged to think along these lines by the realization that magnetism is a better candidate for explaining terrestrial gravity than the Earth's

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[51] For details, see Rees, "Semi-Paracelsian Cosmology". Rees later dropped this designation, preferring to present Bacon's own natural philosophy as essentially unique (which it was—though still highly occult in nature). On homocentric, or concentric, astronomy see, for example, Olaf Pedersen, *Early Physics and Astronomy: A Historical Introduction*, Revised edition. (Cambridge, 1993).
[52] For example, Bacon, *Novum Organum*, Book. II, Aphorism 36, 329.

effluvia, as suggested by Gilbert. After all, Gilbert himself had pointed to the fact that electrical effluvia can easily be prevented from working by a barrier (even something as insubstantial as paper) but magnetism can pass through any barrier except iron.[53] Presumably commitment to theory prevented Gilbert from seeing what was evidently obvious to Bacon—that gravity is even harder to shield than magnetism and so cannot plausibly be said to operate by means of material effluvia.

It remains only to explain the remarkable fact that Bacon readily accepted what most natural philosophers regarded as completely untenable—action at a distance. It seems that here we need look no further than the fact that Bacon's attempt to reform natural philosophy was much indebted to the natural magic tradition. "Naturall Magicke," Bacon wrote, "pretendeth to cal & reduce natural Philosophie from variety of speculations to the magnitude of works." And he wrote of reviving and reintegrating "the misapplyed and abused Name of Naturall Magicke, which in the true sense, is but Naturall Wisedome, or Naturall Prudence." It was Bacon's willingness to accept the major tenets of natural magic that ensured his easy acceptance of actions at a distance.[54] Magnetism again played an important role here. Always regarded as the supreme exemplar of an occult quality, magnetism seemed undeniably to act at a distance and so made it easier to accept other actions at a distance, such as the astrological influence of the stars and the like. In explicitly discussing actions at a distance in the positive way that he did, Bacon was simply showing once again his endorsement of the natural magic tradition.

The Later Magnetical Cosmologists

All in all, as Pumfrey and Bennett correctly suggested, the analogy between magnetic and gravitational attraction with the granted presupposition of action at a

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[53] Gilbert, *De Magnete*, Book. II, Chapter 2, 92; Chapter 3, 98.
[54] Francis Bacon, *The Advancement of Learning* (1605), in Bacon, *OFB IV*, Book I, 27 and Book II, 80. See also Rossi, *Francis Bacon*; Weeks, "Francis Bacon's Science of Magic."

distance became highly influential in seventeenth-century England. Where they were not correct, however, was in seeing these ideas as deriving from Gilbert. Like Bacon but unlike Gilbert, the subsequent English natural philosophers, including John Wilkins, John Wallis, Christopher Wren, and Robert Hooke, did in fact treat gravity as closely analogous with magnetism and at least covertly seemed to accept *actio in distans*.

We can see this, for example, in Wallis's insistence that

> the Load-stone and Iron have somewhat equivalent to a Tye; though we see it not, yet by the effects we know. … How the Earth and Moon are connected; I will not now undertake to shew… but, That there is somewhat, that doth connect them, (as much as what connects the Load-stone, and the Iron, which it draws) is past doubt to those, who allow them to be carryed about by the Sun, as one Aggregate or Body.[55]

It is possible that Wallis added this comment in response to criticisms from fellows when he first read his paper at a meeting of the Society. One of the objections recorded in the minutes was that "it appeared not, how two bodies, that have no tie, can have one common center of gravity, upon which the whole hypothesis of Dr. Wallis is founded."[56] It is surely significant that in response to this, in the printed version, Wallis does not try to provide a mechanistic account of the "tie" between the Earth and Moon, but merely asserts that there is "somewhat, that doth connect them". It looks as though Wallis is accepting the possibility of action at a distance, as seen in the example of magnetism.

In the first part of his *Discovery of a New World* (1640), "That the Moon May Be a World", John Wilkins rejected the Aristotelian notion of "natural places" and replaced it with a concept of gravity as an attractive force:

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[55] J. Wallis, "An Essay of Dr. John Wallis, Exhibiting His Hypothesis about the Flux and Reflux of the Sea, Taken from the Consideration of the Common Center of Gravity of the Earth and Moon; Together with an Appendix of the Same, Containing an Answer to Some Objections, Made by Severall Persons against That Hypothesis," *Philosophical Transactions of the Royal Society of London* 1 (1665): 281. Quoted in Bennett, "Cosmology", 172–73.

[56] Thomas Birch, *The History of the Royal Society of London*, 4 vols (London, 1756), ii: 89.

> But now the true nature of gravity is this. 'Tis such a respective mutual desire of union, whereby condensed bodies when they come within the sphere of their own vigour, do naturally apply themselves one to another by attraction or coition.[57]

Although he uses Gilbert's term, "coition", he uses it, as Bacon did, as just another word for attraction. Moreover, as he continues, Wilkins leaves us in no doubt that he sees gravitational attraction as closely similar to magnetic attraction:

> The meaning of this will be more clearly illustrated by a similitude. As any light body (suppose the Sun) does send forth its beams in an orbicular form; so likewise any magnetical body, for instance a round loadstone, does cast abroad his magnetical vigour in a sphere… Now any other body that is like affected coming within this sphere… will presently descend towards the centre of it, and in that respect may be styled heavy.[58]

Wilkins concludes:

> This great globe of earth and water have been proved by many observations, to participate of magnetical properties. And as the loadstone does cast forth its own vigour round about its body, in a magnetical compass, so likewise does our earth. The difference is that it is another kind of affection which causes the union betwixt the iron and loadstone, from that which makes bodies move unto the earth.[59]

It is clear that the magnetical property Wilkins has in mind here, is attraction. If we recall that Gilbert himself did not regard attraction as a real power of magnets ("the loadstone does not thus attract "[60]), and never drew an analogy between magnetism and gravity, we can see that already the tradition of magnetic cosmology has moved away from the beliefs of its first founder.

Similarly, in his *Discourse Concerning a New Planet* (1640), Wilkins wrote:

> We say, though some parts of this great Magnet, the Earth, may, according to their Matter, be severed from the whole; yet are they always joined to it by a communion of the same Magnetical Qualities; and do no less observe these kind of Motions when they are separated from the whole, than if they were united to it.[61]

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[57] The publishing history of this work is confused. I have used John Wilkins, *The Discovery of a New World*, in John Wilkins, *The Mathematical and Philosophical Works of the Right Rev. John Wilkins, Late Lord Bishop of Chester, 2 vols* (London, 1802), i: 114.
[58] Ibid., i: 114-5.
[59] Ibid., i: 115.
[60] Gilbert, *De Magnete*, Book II, Chapter 3, 100.
[61] John Wilkins, *A Discourse Concerning a New Planet* (London, 1640), 120; Wilkins, *Mathematical and Philosophical Works* , i: 217.

Although Wilkins talks of the Earth being "united" to a "severed" or "separated" lesser part, it is clear that the part is united to the Earth only by "magnetical qualities"—always held to be occult qualities—and not by some material connection; so the implicit suggestion is one of action at a distance. Certainly, there is no attempt by Wilkins to develop a mechanical account of gravity; he simply seems to assume it is as occult a phenomenon as magnetism.

In his revival of Epicurean philosophy, the *Physiologia Epicuro-Gassendo-Charltoniana*, Walter Charleton also draws a parallel between gravity and magnetism. Rejecting Copernicus's view that gravity "is an Appetency of Union, implanted originally in the parts of the Earth", Charleton declares that "the greatest weight of Reason" favours the view that gravity is "an Imprest Motion, Caused immediately by a certain Magnetick Attraction of the Earth."[62] Returning to the topic later on, Charleton dismisses the idea that gravity is caused by "impulsion", and concludes:

> What, therefore, can remain, but that it must be by ATTRACTION? And because no other Attractive Force, which might begin and continue the Downward motion of a stone, can be imagined unless it be that Magnetique Virtue of the Earth, whereby it Draws all Terrene Bodies to an Union with it self, in order to their, and its own better Conservation, we may lawfully Conclude, that the Cause of the Downward motion of all Heavy Bodies, is the Magnetique Attraction of the Earth.[63]

In spite of the lack of evidence concerning Christopher Wren's scientific activities, it is known that he was interested in Kepler's use of magnetism as a way of explaining how the planets were maintained in their orbits. But there are also suggestions that he was involved in attempts to draw an analogy between magnetism and gravity. In Wren's inaugural lecture as Professor of Astronomy at Gresham College, he praises Gilbert as "the Father of the new Philosophy" and a thinker who should be praised "for giving Occasion to Kepler (as he himself confesses) of introducing Magneticks

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62 Walter Charleton, *Physiologia Epicuro-Gassendo-Charltoniana: or, A Fabrick of Science Natural, upon the Hypothesis of Atoms* (London, 1654), Book I, Chapter XI, Section 2, 277.

63 Ibid., Book IV, Chapter II, Section 2, 450.

into the Motions of the Heavens, and consequently of building the elliptical Astronomy."[64] And certainly, Wren is known to have worked closely with Robert Hooke when Hooke himself was developing his own magnetical cosmology.

Hooke might be considered to have brought this magnetical cosmological tradition to its most fruitful conclusion. Thinking about what kept the planets in their orbits, Hooke did not invent a mechanical explanation but noted the mysteriousness of the problem: "I have often wondered, why the planets should move about the sun according to Copernicus's supposition, being not included in any solid orbs … nor tied to it, as their center, by any visible strings; and neither depart from it beyond such a degree, nor yet move in a strait line, as all bodies, that have but one single impulse, ought to do." Again, he turned to the occult phenomenon of magnetism to suggest a likely solution. He supposed the gravitating power of the Sun to "have an attractive power upon all the bodies of the planets, and of the earth that move about it, and that each of those again have a respect answerable, whereby they may be said to attract the Sun in the same manner as the Load-stone hath to Iron, and the Iron hath to the Load-stone."[65]

Hooke tried on numerous occasions to detect a difference in the weight of bodies measured at ground level and at various heights.[66] In March 1666, for example, experiments were reported with the explicit aim of checking whether gravity decreased with distance in the same way that magnetic power was seen to decrease:

> ...so if this analogy between the decrease of the attraction of the one, and of the gravity of the other, be found real, we may perhaps by the help of the load-stone, as it were, epitomise all the experiments of gravity, and determine, to what distance the gravitating power of the earth acts…[67]

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[64] Wren, *Parentalia*, 204.
[65] Birch, *The History of the Royal Society of London*, ii: 91 (quoting Hooke); Hooke, "COMETA, or, Remarks about Comets," 12.
[66] Bennett, "Hooke and Wren", 41–2.
[67] Birch, *The History of the Royal Society of London*, ii: 72.

We can learn about the occult power of gravity, Hooke says, by experimenting with magnets. Although Hooke failed to detect any diminishing of weight with height, he did not abandon the analogy with magnetism but merely suggested that experiments with pendulums might prove to be more sensitive to the slight changes involved. Some years later, in December 1673, Hooke tried to develop an apparatus "for determining the force of the loadstone's attraction at certain distances", though again with little success. These efforts were still on-going in January 1680.[68]

Later in that same year, in his "Lectures of Light", Hooke made it explicit that he was thinking of gravity and magnetism as occult actions at a distance:

> Possibly there may be many other motions and Operations of Bodies at a distance, and several other ways by which the Bodies of the World may influence one another, though it has pleased God not to give us Organs or Senses to discover them, and thereby many things that are accounted Sympathetick or Magical may be done by Natural Causes and Powers of which we have no Organs to make us sensible.[69]

One of the most direct indications of the inspiration of Bacon, rather than Gilbert, for the later magnetical philosophers can perhaps be seen in what Michael Cooper has recently referred to as "Hooke's twenty-year obsession with experiments to measure the earth's gravitational attraction and the way it changes with height above the earth's surface." Certainly, at one point Hooke refers to his own research in this area as "in prosecution of my Lord Verulam's experiment."[70] The experiment to which Hooke was referring was proposed by Bacon in Aphorism 36 of the second part of the *Novum organum*:

> So on this subject a *Crucial Instance* might take this form: take one clock of the kind driven by lead weights and another of the kind driven by an iron spring, and make sure that they keep exactly the same time. Then put the clock with weights at the top of the very tallest church, and keep the other clock at the bottom, and

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68 Robert Theodore Gunther, *Early Science in Oxford, Vols 6-7, The Life and Work of Robert Hooke.* (Oxford, 1930), vii: 415, 569.

69 Robert Hooke, *The Posthumous Works… Containing His Cutlerian Lectures, and Other Discourses*, ed. Richard Waller (London, 1705), 79.

70 Michael Cooper, *"A More Beautiful City": Robert Hooke and the Rebuilding of London After the Great Fire* (Stroud: Sutton Publishing, 2003), 54.; and Birch, *History of the Royal Society*, i: 163. See also Bennett, "Hooke and Wren", 39–44, 59.

> note carefully whether the former runs more slowly than usual on account of the reduced virtue of the weights. … And if we find that the virtue of the weights slackens up above but grows below ground, then we may take it that *the cause of weight is the attraction exerted by the Earth's corporeal mass*.[71]

Bacon's suggestion was completely impractical, given the inaccuracy of spring-driven watches in his day. If it was to be carried out with any measure of success, spring-driven clocks would have to be dramatically improved—as indeed they were, thanks to the inventive efforts of Robert Hooke. It is usually said that Hooke tried to improve spring-driven watches as a means of solving the longitude problem, but he may also have seen this work as a way of helping him to bring his twenty-year obsession with measuring gravity to a successful conclusion, by finally performing the experiment Bacon described. Meanwhile, he also performed numerous experiments with pendulums in the "very tallest church" in London, St. Paul's Cathedral.[72]

It was these prolonged efforts to understand gravity, and his experiments involving pendulums that eventually led to the greatest achievement of the tradition of magnetical philosophy. This was Hooke's hypothesis about orbital dynamics, which in turn he developed into what later became known as the universal principle of gravitation. Hooke surmised that "all the phenomena of the planets seem possible to be explained" by assuming that the Sun is "an attractive body placed in the centre; whereby it continually endeavours to attract or draw [the planet] to itself." Immediately, he proposed demonstrating this by pendulum experiments: "This… I shall endeavour to explicate from some experiments with a pendulous body."[73] By 1674, Hooke had developed this idea to such an extent that he supposed all bodies

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[71] Bacon, *Novum organum*, Bk. II, Aph. 36: 329.

[72] A. R. Hall, "Robert Hooke and Horology," *Notes and Records of the Royal Society of London* 8 (1951): 167–177; Cooper, *"A More Beautiful City",* 54–65. This was Old St. Paul's, destroyed in the Great Fire of London (1666), not Wren's cathedral.

[73] Hooke, "A Statement of Planetary Movements" [1666], in Gunther, *Early Science in Oxford*, vi: 266. For a fuller discussion see Michael Nauenberg, "Robert Hooke's Seminal Contribution to Orbital Dynamics," in *Robert Hooke: Tercentennial Studies*, ed. Michael Cooper and Michael Hunter (Aldershot, 2006), 3–32.

attracted one another in accordance with the inverse square law (that is, inversely proportional to the square of the distance between the particles).[74] Although there is no mention of magnetism here it is impossible to separate these speculations of Hooke's from his on-going attempts to show the similarities between magnetic attraction and gravitation. Hooke's brilliant idea can be seen, therefore, as the culmination of his own studies within the tradition of magnetic cosmology, and therefore, as the highly successful culmination of the tradition itself.

From Magnetic Philosophy to Newton's Universal Principle of Gravitation

Although these later thinkers never openly discussed the concept of "action at a distance", the way Bacon had done, they never denied it; they simply chose to avoid discussing the issue in any detail. We should not be surprised about this; indeed, it is what we might expect. Bacon was writing at a time when the natural magic tradition seemed to offer the best hope of replacing scholastic Aristotelian natural philosophy and so he had no reluctance about invoking *actio in distans*.[75] Wilkins, Wallis, Charleton, Wren, Hooke, and their contemporaries, were all too aware, by contrast, of the anti-occult new philosophies emerging on the Continent, especially in the highly influential work of Galileo and Descartes. Consequently, the later magnetical cosmologists left action at a distance as an implicit and undeveloped aspect of their linked theories of magnetism and gravity.

It seems equally clear, however, that they were never persuaded that gravity, or magnetism, could be explained by the new contact-action mechanical philosophy, and they continued to promote the occult Baconian version of the magnetical philosophy. As Bennett notes, Wallis had to "profess a kind of agnosticism on the

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[74] Robert Hooke, *An Attempt to Prove the Motion of the Earth: From Observations Made by Robert Hooke Fellow of the Royal Society* (London, 1674), 27–8.

[75] Bacon's involvement in the revived natural magic tradition is famously discussed in Rossi, *Francis Bacon*. See also Rusu, "From Natural History to Natural Magic"; Weeks, "Francis Bacon's Science of Magic."

one hand, while drawing support from the magnetical analogy on the other"; while Hooke, whose language occasionally "uses notions of attractive force," "needed to be able to 'launder' his attractive forces from time to time by appealing to a mechanical explanation."[76]

The later magnetical cosmologists frequently referred to Gilbert's *De magnete* to support their claims, but they also referred to Bacon. Given the fact that it was Bacon who first dismissed Gilbert's magnetic voluntary "coition" in favour of attraction, and who then drew the analogy between magnetic attraction and gravity, it seems safe to conclude that Bacon played at least as big a role in the subsequent development of magnetical cosmology as William Gilbert. It has always been accepted that the later magnetical cosmologists required stringent measures in order to adapt Gilbert's animistic scheme to their own purposes—dropping his animism in favour of a more physicalist account of how magnets work. But what has not been noticed is that Bacon had already made the necessary adaptations for the later thinkers to adopt. It is even possible that the later thinkers read Gilbert through Baconian spectacles and therefore failed to notice that their reading differed markedly from the animistic cosmology of the nominal founder of their movement. According to Hooke, for example, writing in 1666, "Gilbert began to imagine it [gravity] a magnetical attractive power, inherent in the parts of the terrestrial globe."[77] Hooke seems unaware (or perhaps prefers not to acknowledge) that Gilbert denied "attraction" in favour of "coition" and that he spoke not of magnetic "power" but of the magnetic "soul." Whether the later thinkers in this movement explicitly referred to Bacon or not, every time they drew an analogy between gravity and magnetism they were echoing Bacon, not Gilbert. Similarly, whenever they wrote as though magnetism or gravity exerted an occult physical influence on surrounding

[76] Bennett, "Cosmology", 173.
[77] Birch, *History of the Royal Society*, ii: 70.

bodies, they were echoing Bacon's actions at distance, not Gilbert's independently self-moving animated magnets.

We have seen that it was Bacon who first suggested that magnetism may be responsible for the fall of heavy bodies to Earth, for the effect of the Moon on the tides, and was second only to Kepler in suggesting magnetism drove the planets in their orbits (though his proposal was very different from Kepler's): "if there be any magnetic power which operates… between the stellar heavens and the planets by which the latter are summoned and drawn to their apogees, then all these operate at very long distances indeed."[78] But these ingenious speculations echoed through the subsequent tradition, and finally achieved their most fruitful expression in Hooke's bold suggestion

> That all Coelestial Bodies whatsoever, have an attraction or gravitating power towards their own Centers, whereby they attract not only their own parts… but that they do also attract all the other Coelestial Bodies that are within the sphere of their activity…[79]

Hooke's speculations regarding magnetical cosmology can be seen to culminate, arguably, in his realization that Kepler's laws of planetary motion might be explained simply by assuming the tangential movement of the planet and an attractive force operating between the Sun and the planet (a force that diminishes in inverse proportion to the square of the distance between them). This in turn led to the universal principle of gravitation, as it was developed by Newton in his *Principia mathematica*. It might be suggested, therefore, that Newton was the beneficiary of this distinctive tradition in English natural philosophy. It is also interesting to note that the tradition began with Bacon explicitly invoking actions at a distance, passed through a phase where actions at a distance remained strictly implicit and were not

[78] Bacon, *Novum organum*, Bk. II, Aphorism 45, 370–71.
[79] Hooke, *An Attempt to Prove the Motion of the Earth*, 27.

overtly discussed, and ended with Newton explicitly discussing actions at a distance once again.[80]

Before going any further, it is perhaps important to note that this does not suggest Newton's *direct* debt to the magnetic cosmological tradition in the shaping of his universal principle of gravitation.[81] On the contrary, Newton never directly or openly consented to the Gilbertian magnetic cosmology while talking about gravity. Before the *Principia*, Newton's notion of gravity was based largely on an aether theory, which he might have adopted, and adapted, from Hooke (see chapter 5). Besides, Newton never committed to a particular theory of magnetic attraction either.[82] In an unpublished manuscript, "Miscellaneous notes on gems and other subjects"[83] dating from 1666/7, Newton's theory of magnetism seems essentially Cartesian. In Query 31 of the *Opticks* of 1717, however, "magnetick and electrick Attractions" are mentioned as "manifest Qualities" whose causes are occult, and it is evident that Newton's magnetic theory had become less Cartesian and less mechanical over time. It is easy to see, however, that Newton did not accept that the movement of heavenly bodies might be attributed to magnetism. We can see this very clearly in his dispute with John Flamsteed in 1681 about recent observations of a comet, or two comets.

In November 1680, a bright comet became visible in the sky; it lasted for a few weeks and disappeared, before "another" comet appeared again in early 1681.

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[80] Ofer Gal, *Meanest Foundations and Nobler Superstructures: Hooke, Newton and the Compounding of the Celestiall Motions of the Planetts* (Dordrecht, 2002). On Newton and actions at a distance see Henry, "Gravity and *De Gravitatione*".

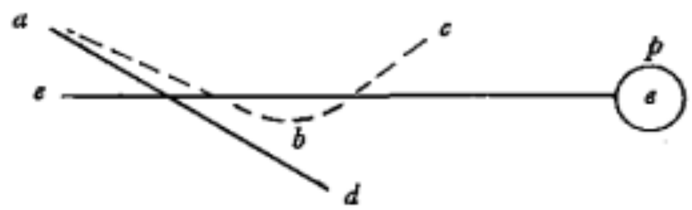
[81] See D. W. Hugue, "The 'Principia' and Comets", *Notes and Records of the Royal Society, 42* (1988), 53–74; R. W Home, "Newtonianism and the Theory of the Magnet", *History of Science* 15 (1977): 252–66.

[82] R. W. Home, "Force, Electricity, and the Powers of Living Matter in Newton's Mature Philosophy of Nature." In *Religion, Science and Worldview: Essays in Honor of Richard S. Westfall*, edited by Margaret J. Osler, and Paul Lawrence Farber, 95–119. Cambridge: Cambridge University Press, 1985.

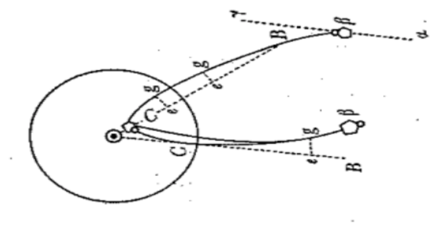
[83] Newton, MS Add. 3974, Cambridge University Library, 1b(r), 1b(v), 2b(r), 2b(v), 3b(r).

Natural philosophers came up with theories to figure out their orbits, and whether what seemed to be a pair of comets might in fact be one comet appearing at different times. An agreed view of a number of Newton's contemporaries was that it was only one comet: initially the comet had travelled towards the Sun, attracted by the Sun's magnetic force, and subsequently, as a supposed realignment of magnetic poles, it had been repelled by the Sun and re-appeared in the sky as it moved away from the glare of the Sun. The Astronomer Royal John Flamsteed accepted that it had to be the same comet which was firstly attracted by the Sun in the same way as all "bodys that come within our Vortex", and was then twisted by the vortex of the Sun, so that it began to be repelled by the Sun. So, according to Flamsteed, the Sun

> …drew the Comet by its northerne pole, the line of whose motion was at first really inclined from the North into the South part of the heavens but was by this attraction as it drew nearer to him bent the Contrary way, as if *ee* were the plane of the Ecliptick, p ye North pole of ye Sun, and ye line of its first inclination which by ye attraction of ye pole p is bent into ye curve abc in which Gallet observed it to move [see picture below]. The Comet was then to ye North of ye Solar Equator & perhaps here the contrary motion of ye Vortex might helpe to beare it up from ye plaine of ye Ecliptick into ye Northerne latitude…



So, when the comet came closest to the Sun, it was twisted and the attractive power was then changed into a repulsive power, when "ye comet" "comes to the Sun (C)", Flamsteed continued, "it moves contrary & crosse ye motion of ye Vortex till haveing ye contrary End opposite to ye Sun hee repells it as ye North pole of ye loadstone attracts ye one end of ye Magnetick needle but repells ye other…" This act of repulsion, as he sees it, is perfectly plausible and offers "no reason why wee may not admitte it [the comet] to have run from Sun nearely in a Streight line…"[84] (see picture below).



It is not hard to infer from the above that Flamsteed holds the idea that the Sun was like a magnet, and the comet a piece of iron. Clearly, this is chiefly inspired by the views of Kepler, although the mention of "our Vortex" also suggests the influence of Descartes. Newton totally disagreed, however, and insisted that there were two comets. He was in dispute with Flamsteed through the intermediary of James Crompton.[85] In two letters written on 28 February and in April 1681, Newton offered arguments against Flamsteed and rejected Flamsteed's magnetic account. Newton said that he "can easily allow" that "ye attractive power of ye Sun" could make the comet deviate from its original path, but he "do[es] not understand how it [the Sun] can make ye Comet ever move" in such a way that it ends up in "the line of direction" passing through "ye center of ye Sun", "much less can it make ye line of direction verge to ye other side ye sun". In other words, a single comet which had turned in front of the Sun, would have had to change its direction, and thus would not be moving as the astronomers had observed.[86]

More important and relevant to our discussion here is Newton's second account. He argued that even if he could accept that the Sun could exert some centrally attracting

[84] Newton, *Correspondence*, Flamsteed to Halley 17 Feb 1680/1, 337-9
[85] J. A. Ruffner, "The snare of simplicity: the Newton–Flamsteed correspondence revisited", In *Archive for History of Exact Sciences*, 67(4), 2013, 415-55.
[86] Newton to Crompton for Flamsteed, 28 Feb, 1681, 341.

power, which would bend the planets away from the straight line, this power could not possibly be magnetic attraction, because

> magnetick bodies when made red hot lose their vertue. A red hot loadstone attracts not iron, nor any Loadstone a red hot iron, nor will a loadstone propagate its vertue through a rod of iron made red hot in ye middle. Whence probably ye Earth were it made red hot would lose its magnetism; & ye Sun being more then red hot, must be less capable of it.[87]

Moreover, even if the sun's attraction were like a magnet and the comet a piece of iron, no explanation had been offered by Flamsteed about how and why the Sun could switch from attracting to repelling dramatically. In short, on the assumption of the one comet theory, no known or persuasive mechanical, magnetic, vortical or other cause offered an explanation of how it could turn in its observed path either in front of, or behind the Sun - a Path behind the sun was the best fit for the data, but at that time there was no known physical mechanism to account for it, and so it made no sense.

In a further letter in April 1681, Newton remarked that "a great magnet exercising its directive vertue more strongly then its attractive on a small one, it holds in all cases I had opportunity to observe & till a contrary instance can be brought, I am inclined to believe it holds generally."[88] So the comet, according to Flamsteed, should always be attracted by the magnetic force of the Sun and would always be in the same position – never being repelled. Moreover, even if there were a repulsive magnetic force emitted by the Sun (S), it would have begun to repel the comet some time "a little sooner as at K (before perihelion). The comet would have continued on its journey, accelerating away from the Sun on its other side.[89]

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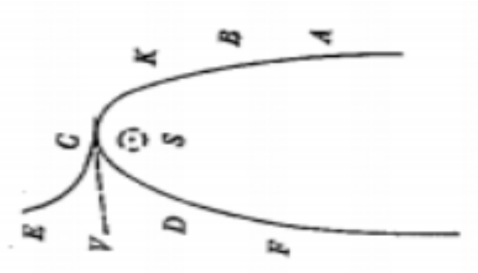
87 Ibid, 341-2.
88 Newton to Crompton, April, 1681, 358-9.
89 Ibid, 360-1.



We have seen that the analogy between magnetic attraction and gravitational attraction had offered the best hope of an explanation of the motion of planets from Bacon to Hooke. But, Flamsteed does not draw on this analogy, but rather uses magnetic attraction itself to explain the path of the comet (showing the influence o fKepler, perhaps, rather than Baconian influence). Newton can easily dismiss Flamsteed’s theory as a result of his awareness that a heated magnet loses its power. Newton’s knowledge of magnets can be traced back to his student notebook, “Certain Philosophical Questions”, and to his “Miscellaneous notes on gems and other subjects”.[90]

Perhaps at this point it is worth considering what Newton wrote to Flamsteed at the end of the April letter. On the assumption of the one comet solution, Newton accepted that the comet might be made to move away from the Sun after being attracted towards it: “the *vis centrifuga* at C [see picture above] overpow’ring the attraction & forcing the Comet there notwithstanding the attraction, to begin to recede from ye Sun.”[91] Newton held this view for three more years, before turning to a more mature dynamics in *Principia*, but here his notion of continuous attraction was at least opening the door to his universal principle of gravitation.[92] He was almost there, but still needed Hooke and Halley to get closer to realizing the universal principle of gravitation.

[90] Newton, MS Add. 3974, Cambridge University Library.
[91] Newton to Crompton, April, 1681, 361.
[92] Ruffner, “The Snare of Simplicity: The Newton–Flamsteed Correspondence Revisited.”

Indeed, although Newton himself never played a direct role in the magnetical cosmology tradition, he benefitted very much from the tradition through Hooke, because his *Principia* was essentially founded on Hooke's claim that the Keplerian laws of planetary motion could all be explained simply by assuming that the inertial movement of a planet is bent into an elliptical orbit around the Sun by an attractive force operating across the distance between these heavenly bodies. Hooke wrote to Newton in November 1679 to ask Newton's opinion of this very hypothesis.[93] It seems evident from the brief exchange of letters between Newton and Hooke, following Hooke's opening letter, that Newton did not at first see the importance of Hooke's idea. But he became aware of its importance in conversation with Edmund Halley in August 1684.[94] Newton's mathematical proof of the correctness of Hooke's speculation subsequently became the most important aspect of the *Principia mathematica*. Given that Hooke's theory was the culmination of his work within the tradition of magnetic cosmology, it seems fair to say that Newton, in spite of his own earlier rejection of Flamsteed's Keplerian version of magnetic cosmology, was ultimately influenced by the Baconian tradition of magnetic cosmology as a result of his exchange with Hooke in 1679.

More importantly, for our purposes, this was a major turning point in Newton's natural philosophy. Where previously his natural philosophy made no assumptions that actions at a distance were possible, by the time he came to write the *Principia* he shared essentially the same views about attraction that were displayed by the magnetic cosmologists. That is to say, like them, he clearly accepted that attraction took place at a distance but he did not explicitly discuss it. Unlike his immediate predecessors, however, he did come close to openly discussing actions at a distance

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93 Westfall, *Never at Rest*, 382–88; Gal, *Meanest Foundations*; Nauenberg, "Seminal Contribution".
94 Newton later claimed to have proved Hooke's speculation at the time of this correspondence, but the evidence suggests that he did not prove it until after speaking with Halley. See, Westfall, *Never at Rest*, 402–4.

in draft papers originally written for inclusion in the *Principia*.[95]Moreover, in his later career, Newton did discuss actions at a distance openly in print in his *Opticks* (1704, 1706, 1717).

This is very remarkable. After all, action at a distance was rejected as impossible by Aristotle, and this remained the dominant view throughout the Middle Ages and the Renaissance. Aristotle stated it explicitly in *De generatione et corruptione*: "For action and passion (in the proper sense of the terms) can only occur between things which are such as to touch one another", and in the *Physics*, and his view was authoritatively confirmed by Thomas Aquinas when he insisted "no agent can operate immediately where it is not".[96] In spite of a brief weakening of the opposition to this view during the Renaissance revival of natural magic, or perhaps *because* of that weakening, Descartes and other mechanical philosophers strongly reaffirmed their opposition to action at a distance. Before being thoroughly converted to Newtonianism, even John Locke accepted the standard view, writing in his widely-read *Essay Concerning Human Understanding* (1690), that it is "impossible to conceive that body should operate on what it does not touch (which is all one as to imagine it can operate where it is not)."[97]

Given this, it would be very extraordinary, indeed essentially incomprehensible, if Newton should single-handedly turn against this traditional view, and become a lone voice promoting action at a distance. But Newton's endorsement of action at a

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[95] Ibid., 388. The "Conclusio" and the "Preface" can be consulted in Isaac Newton, *Unpublished Scientific Papers of Isaac Newton: A Selection from the Portsmouth Collection in the University Library, Cambridge*, ed. A. Rupert Hall and Marie Boas Hall (Cambridge, 1962), respectively 321-47, 302-08. On the historical origins of Newton's ideas on action at a distance, see Henry, "Gravity and *De Gravitatione*".

[96] Aristotle, *De Generatione et Corruptione*, trans. C. J. F. Williams (Oxford, 1982), I, 6, 322b, 21; see also 323a 22; Aristotle, *Physics*, trans. P. H. Wicksteed and F. M. Cornford, vol. 2 (London: William Heineman, 1934), VII, 2, 243a, 217; St Thomas Aquinas, *Summa Theologica, Volume 4 (Part III, First Section)*, trans. Fathers of the English Dominican Province (New York: Cosimo, Inc., 2013), Part III, Q. 64, Art. 1, Obj. 3, 2360.

[97] John Locke, *Essay Concerning Human Understanding* (London, 1690), Book II, Chapter 8, §11.

distance is by no means so extraordinary, and not in the least bit incomprehensible, historically speaking, when seen against the background of the magnetic philosophy from which it emerged.

Conclusion

This chapter has argued that Newton's universal principle of gravitation and its implicit belief in action at a distance was the culmination of a short-lived tradition in English thought, beginning with William Gilbert and Francis Bacon. The magnetic cosmology initiated by Gilbert gave rise to a movement in English natural philosophy to understand planetary movements and other aspects of gravity, which seemed to depend on an attractive force analogous to magnetic attraction. This eventually led Robert Hooke to speculate that an attractive force between the planets might account for Kepler's laws of planetary motion—an idea which he later communicated to Newton. Another important aspect of this chapter is that it has revealed the role of Francis Bacon in transforming Gilbert's animistic theory of magnets and a self-moving Earth into a theory of magnets with attractive power. It was Bacon's adaptation of Gilbert's ideas which proved more influential, leading to later views in which gravity, by analogy with magnetism, was seen as an attractive force operating between the heavenly bodies.

The first section "Gilbert's Magnetical Cosmology" provided an introduction to Gilbert's theory of the magnet and his application of that theory to explain the Copernican motions of the Earth. Gilbert believed that because magnets could spontaneously move themselves they must have souls—only creatures with souls are capable of self-movement. He established that the Earth was a giant magnet and therefore could spontaneously move itself. The main aim of the second section, "The Beginnings of the Magnetical Cosmology Tradition" was to show that the magnetic cosmology tradition differed in significant ways from Gilbert's original teachings. Kepler and others dropped Gilbert's animistic view of the magnet and suggested instead that magnets simply had a power of attraction. One very important aspect of this different opinion was that it returned to pre-Gilbertian views of magnets, in which they were always assumed to act at a distance. This section shows that one reason why Gilbert insisted on his animate view of magnets was that he could reject suggestions that magnets acted at a distance. Magnets did not *attract*, they simply moved themselves towards another magnet or piece of iron. Rejecting Gilbert's view, his followers tacitly accepted actions at a distance, although the scholastic opposition to actions at a distance, and the equally strong opposition to it from mechanical philosophers, meant that the English magnetical philosophers did not explicitly mention actions at a distance. This section also confirmed the claims of earlier scholars that one of the most persistent features of the magnetical cosmology was the analogy between magnetic and gravitational attraction.

The third section "Francis Bacon, Magnetic Cosmologist" showed that there was one important exception to the claim that English magnetical philosophers did not explicitly mention actions at a distance, namely, Francis Bacon. Bacon, like Kepler, quickly dismissed Gilbert's animistic view and re-affirmed the earlier view that magnets were endowed with occult powers of attraction and repulsion. Furthermore, Bacon was the first thinker to suggest that gravitational attraction might be understood as related to magnetism in some way, or perhaps a similar phenomenon to magnetism. Accordingly, Bacon was the primary source for the later tradition in which gravity was seen as analogous to magnetic attraction (Gilbert himself, as has been shown, saw gravity as an earthly phenomenon, and explained it in terms of material effluvia from bodies). Furthermore, Bacon's rejection of scholastic ideas, and easy acceptance of magical ideas, led him to explicitly suggest that gravity, like magnetism, could act at large distances.

It was then shown that Bacon was not a Copernican and the next section "Francis Bacon's Cosmology and Magnetism" examines the implications of that for Bacon's magnetic cosmology. It is shown how Bacon's magnetic cosmology was adapted to fit in with his own homocentric theory of the heavenly spheres (derived from the theories of the Arabic astronomer Alpetragius). It was speculated that this might have led Bacon to see the link between terrestrial gravity and the motions of the heavenly spheres. Finally, it was suggested that Bacon's sympathy towards magical ideas led him to explicitly accept the possibility of action at a distance. And of course, it should be remembered that he was writing before the mechanical philosophy re-emphasised the old scholastic opposition to actions at a distance as impossible.

The next section "The Later Magnetical Cosmologists" considered the contributions to this new tradition by John Wallis, John Wilkins, Walter Charleton, Christopher Wren, and especially Robert Hooke. It was shown that the analogy between magnetic attraction and gravity was always prominent in these discussions, and action at a distance was never explicitly denied, and if it was not always made explicit, it was always implicit. The main aim of the last section, "From Magnetic Philosophy to Newton's Universal Principle of Gravitation" was to point out that Newton's implicit acceptance of action at a distance in his *Principia* was by no means a unique and isolated example of a thinker accepting this possibility. As we have seen, it was an obvious, albeit an unstated, aspect of the magnetic cosmology. This concluding section shows that Newton's theory grew directly out of Hooke's speculation that Kepler's laws could be explained by assuming that gravity was an attractive force. Hooke's speculation was the culmination of his attempts to confirm Bacon's suggestions for testing the similarity between magnetism and gravity, and so Newton's acceptance of action at a distance can be seen to have derived from Bacon's version of the magnetical cosmology. It was also shown, however, that Newton was not a *direct* participant in the tradition of magnetic cosmology, because he rejected the claims of Flamsteed that cometary motions might be explained in terms of magnetic attraction between a comet and the Sun. Insisting upon the empirically-based knowledge that magnets lose their power when heated, Newton denied the possibility that the Sun, or any other star, could be a magnet. Accordingly, Flamsteed's claims were untenable.

Chapter 4: From Magnetic Cosmology to Active Matter

Introduction

As shown in the last chapter, the analogy between magnetic and gravitational attraction became highly influential in seventeenth-century England. The Gilbertian and Baconian natural philosophers had all sought to understand gravity, both terrestrial and celestial, by analogy with magnetism. The speculation on magnetical cosmology, in spite of its difference from Gilbert's original animate magnetic philosophy, gradually became a "familiar device" to the seventeenth-century English natural philosophers.[1] This in turn seems to have inspired another innovative use of magnetism as the mainstay of a new system of natural philosophy, namely, that of one of the most active fellows of the Royal Society, Sir William Petty (1623–1687). In Petty's *New Hypothesis of Springing or Elastique Motions* of 1674, Gilbert's "little earths", his spherical *terrellae*, became spherical atoms.[2]

Remarkably, Sir William Petty's "atomic magnetism" has attracted very little attention from scholars. While Gilbert used spherical magnets to make it easy for him to draw the analogy between little magnets and the Earth, Petty took the analogy in the other direction—atoms are like extremely tiny *terrellae*. Focusing on this point, the first intention of this chapter is to expound Petty's magnetical philosophy. From there, we will go on to show that his belief that matter had in-built principles of activity by virtue of its magnetic nature, far from being untypical and eccentric, was simply a highly ingenious variation on other theories of matter propounded in England.[3] In the later parts of this chapter, therefore, we will begin to demonstrate

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1 Pumfrey, "Magnetical Philosophy". On Gilbert's own, highly animated, magnetical philosophy, see Henry, "Animism and Empiricism."

2 Sir William Petty, *The Discourse Made before the Royal Society the 26. of November 1674: Concerning the Use of Duplicate Proportion in Sundry Important Particulars : Together with a New Hypothesis of Springing or Elastique Motions* (London, 1674).

3 See, Henry, "Occult Qualities".

this by considering other theories of active matter developed in England during this time.

Apart from Petty's "atomic magnetism", there were other essentially atomist, or corpuscularian, theories of matter that were evidently inspired by (or combined with) the Gilbertian and Baconian tradition of magnetic philosophy. This distinctly non-Cartesian (perhaps even anti-Cartesian) way of developing corpuscularist philosophies forms an important part of the background from which Newton's distinctive natural philosophy emerged. One way of understanding Newton's great innovation in natural philosophy is to see it as shifting the focus from the inertial motions of matter (and their impacts, collisions, and entanglements) to the supposed forces and powers of matter, so that bodies "are moved by certain active Principles, such as is that of Gravity, and that which causes Fermentation, and the Cohesion of Bodies."[4] We have already seen (in chapter 3) that his universal principle of gravitation had its origins in the tradition of magnetical cosmology as it was first conceived by Gilbert, and modified by Bacon and later English thinkers. And the aim of this current chapter is to show that Newton's theory of matter, no less than his theory of gravity, shows continuities with the earlier speculations of Petty, Charleton, Boyle, and others.

We will begin then, with an examination of Petty's magnetic atomism as presented in his *New Hypothesis*. This will lead us to a wider survey of the use of magnetic effluvia in contemporary English natural philosophy. Finally, we shall look even wider at the use of supposed non-specific effluvia, streaming perpetually out of bodies and responsible for some of the effects attributed to those bodies. The occult aspect of such active effluvia is perhaps indicated by the common suggestion that the effluvia surround the body in a "sphere of activity" or "sphere of virtue".

[4] Newton, *Opticks*, 401.

Furthermore, there is hardly ever any attempt to explain the perpetual motions of these effluvia in mechanistic terms. It might still be argued, however, that the effluvia operate by their motions—rushing out of one body and interacting with another. This being so, it might be argued that effluvial explanations can still be reduced to Boyle's two great "Catholick" principles: matter and motion. This cannot be said of William Petty's *New Hypothesis*, however, and it could be argued that even before Newton switched focus from the motions of the particles to their interparticulate forces of attraction and repulsion, Petty had already done so over a decade earlier.[5]

Sir William Petty's Atomic Magnetism

Until relatively recently, William Petty was perhaps best known as a political economist and a pioneer of social surveys, and his reputation still rests largely on these aspects of his career.[6] From the perspective of historians of science, however, his identity as an originator of "political arithmetic" should not occlude his interests in natural philosophy.[7] In many respects Petty was a quintessential representative of the seventeenth century "new philosophy". He was a member of the reformist circle brought together by Samuel Hartlib, an associate of leading thinkers in Mersenne's circle, an experimentalist, a staunch believer in Baconian pragmatism, when circumstances demanded it a mathematical analyst in Galilean mode, and a founder member of the Royal Society.[8] But, he was also a contributor to the magnetical philosophy.[9]

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5 Newton, *Principia*, Preface, 382–83.

6 For example, Ted McCormick, *William Petty: And the Ambitions of Political Arithmetic* (Oxford, 2009); Antoin E. Murphy, *The Genesis of Macroeconomics: New Ideas from Sir William Petty to Henry Thornton* (Oxford, 2009).

7 Rhodri Lewis, ed., *William Petty on the Order of Nature: An Unpublished Manuscript Treatise* (Tempe, AZ: Centre for Medieval and Renaissance Studies, 2011), 6.

8 Lindsay G. Sharp, "Sir William Petty and Some Aspects of Seventeenth-Century Natural Philosophy" (D.Phil. thesis, Oxford, 1977); Robert Hugh Kargon, "William Petty's Mechanical Philosophy", *Isis* 56 (1965): 63–6.

9 Stephen Pumfrey, "William Gilbert's Magnetic Philosophy, 1580-1684: The Creation and Dissolution of a Discipline" (Ph.D., the Warburg Institute, 1987), 325–6; Pumfrey, "Mechanizing

With this background, Petty was invited to give a lecture to the Royal Society in November 1674, and this was so well received that it was published by order of the Society as the *Discourse…on Duplicate Proportion* (1674). The *Discourse* is an interesting piece in itself, concerning the nature of "duplicate proportion" (or the inverse square law) and its application to the practical solution of various problems. But it is the short appendix which was subsequently printed together with the *Discourse*, entitled "a New Hypothesis of Springing or Elastique Motions", which interests us here. As Petty tells us in the "Epistle Dedicatory"[10], both Henry Oldenburg and Lord Brouncker, President of the Society, called upon him to give "a second Entertainment upon that excellent Subject so ingenuously… begun, of Elasticity".[11] As the title of this appendix indicates, Petty meant to provide a solution for the problem of the elasticity, or as it was then called, "the spring" of the air, and he did so from the starting point of a uniquely original atomist matter theory.

Right at the outset, the reader is told that matter is composed of atoms "immutable in magnitude and figure" which are the smallest bodies in Nature.[12] More importantly, in spite of his initial training under Hoogehlande at Leiden and Regius at Utrecht, the two leading Cartesian medical writers, Petty nevertheless was never so admiring of Descartes.[13] As he suggested in the *Discourse*, his aim was not to add to the unnecessary complexity of the new philosophy, but only to "explain the fundamental notions of the mechanical hypothesis in a simple and understandable manner". Significantly, Petty does not hesitate thereafter to assume that matter is not passive and inert, but "all Juncture of Atoms is made by their innate motions". He then

Magnetism".

[10] Petty, *Discourse*, sig. A4*r*.

[11] A. Rupert Hall and Marie Boas Hall (eds), *The Correspondence of Henry Oldenburg*, vol. XII, 1675–1676 (Madison, 1966), 48. See M. D. Slatter, *Report on the Literary, Personal and Official Correspondence and Papers of Sir William Petty (1623-1687) and on Related Collections, 17th-20th Century* (London, 1980).

[12] Petty, *Discourse*, 17.

[13] Webster, "Henry More and Descartes."

proceeds to pinpoint the specific kinds of innate motions he has in mind. "These atoms", Petty declares, "may have each of them such Motions as Copernicus attributes to the Earth, or more". Here the justification for Petty's claim that atoms must have some innate motions, which "Copernicus attributes to the Earth", was explained subsequently by supposing that, "Every atom" is "like the Earths Globe or Magnet"[14] Accordingly,

> all atoms have, like a Magnet, two motions, one of Gravity whereby it tendeth towards the Center of the Earth, and the other of Verticity, by which it tendeth towards the Earths-Poles…[15]

Although highly ingenious, familiarity with Copernicus's suppositions and the Gilbertian background enables us to recognize the obvious source of Petty's inspiration here. It was simply Gilbert's magnetical philosophy and the experiments underpinning it. In short, Gilbert's argument for the innate motions of the Earth was dependent on an analogy with magnets: the Earth is a great magnet hence could self-move just like a magnet (or a little *terrella*); the Earth and the magnet display the same motions because they have the same innate principles of motion (indeed, the Earth *is* a magnet).[16] In the last chapter, I pointed out John Wilkins's, John Wallis's, and others' sympathy towards and dependence upon the magnetical programme. Sir William Petty pursued the programme in his own way, with the unique innovation that he extended Gilbert's idea into the atomic scale, arguing that all atoms were themselves magnets: "every Atome may move about his own Axis, and about other Atoms also, as the Moon does about the Earth." The kinship is undeniable. Petty could only be adapting the magnetic cosmology when he declared that "every atome" by virtue of its magnetic nature

> may move about his own Axis, and about other Atoms also, as the Moon does about the Earth; Venus and Mercury about the Sun, and the Satellites Jovis about Jupiter, &c.[17]

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[14] Petty, *Discourse*, 18.
[15] Ibid., 128–29.
[16] Gilbert, *De Magnete*, 68.
[17] Petty, *Discourse*, 126.

Another crucial proof of his descent from Gilbert was offered by the supposition in Petty's outline of vital principles:

> Lastly, I might suppose (even without a Metaphor) that Atoms are also Male and Female, and the Active and Susceptive Principles of all things; and that the above-named Byasses [the magnetic poles] are the Points of Coition: For, that Male and Female extend further than to Animals, is plain enough; the fall of Acorns into the ground, being the Coition of Oaks with the Earth. Nor is it absurd to think, that the words in Genesis, [Male and Female created he them] may begin to take effect, even in the smallest parts of the first Matter. For although the words were spoken onely of Man; yet we see they certainly refer to other Animals, and to Vegetables in manner aforesaid, and consequently not improbably to all other Principles of Generation.[18]

Petty's "Active and Susceptive Principles", his male and female atoms with generative powers, may seem somewhat outlandish, but it is perhaps worth noting that in the year following the publication of Petty's *Discourse*, Isaac Newton's "Hypothesis of Light" appeared with its postulate of "aetherial spirits… which, by virtue of the command, increase and multiply, become a complete imitator of the copies set her by the protoplast".[19] Most of all, they become less bizarre if we note that Gilbert had also described magnetic poles as male and female, and replaced the concept of magnetic "attraction" with the notion of magnetic "coition". Thus the attribution of sexuality to Petty's atomic magnets has obvious antecedents in *De Magnete*.[20]

Like the writers we looked at in the last chapter, Petty remains completely tacit as to whether action at a distance is involved in the interactions between his atomic particles. This is not surprising, given the impact Descartes has made on contemporary philosophy, and given the fact that one of the proudest boasts of the Cartesians is that they have removed occult qualities from natural philosophy. It seems clear, nevertheless, that Petty's working assumption must be that his atomic

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[18] Ibid., 130–2. See Genesis, 1, 27.

[19] Isaac Newton, "An Hypothesis explaining the properties of light, discoursed of in my several papers" [1675], in Newton, *Papers & Letters on Natural Philosophy*, 180.

[20] Gilbert, *De Magnete*, Book II, Chapter 4, 105–15.

magnets can operate on one another at a distance, just as larger, everyday, magnets were held to do in the tradition of magnetic cosmology. We will come back to this in the next section. But there is at least one allusion to action at a distance in the *Discourse*, when he seems to suggest a belief in celestial influence:

> this Consideration I pitch upon, as one of the grounds whereupon I would build a Doctrin concerning the Influence of the Stars, and other Celestial or remote Bodies upon the Globe of the Earth, and its Inhabitants, both Men and Brutes.[21]

In a nutshell, then, Petty determined to apply magnetic philosophy to the microscopic motions of atoms, assuming that every atom was like "the Earth's Globe or Magnet". In doing so, Petty firmly believed atoms had in-built principles of activity, by virtue of their magnetic nature. As has been said, Petty utilised the occult, unexplained virtues of magnetism to account for the behaviour of his atoms and the "forces" which he believed may well be operating, even over distances, between them.

The occult nature of Petty's *New Hypothesis* is highlighted if we compare it with Descartes's own account of magnetism in the *Principia Philosophiae* of 1644. Descartes was concerned to eject all occult qualities from his mechanical philosophy, and to explain everything in terms of the motions of particles, and the transference of motions between particles. Magnets and magnetism, always seen as exemplary cases of occult objects and their operations, presented a significant challenge for Descartes. Consequently, he devoted many numbered paragraphs to them towards the end of the final book of the *Principia* (Book IV, §§ 133–187).[22] We need not go into the details of Descartes' account of magnetism here, but suffice it to say that he tries to give a mechanistic account, depending upon invisibly small effluvial particles flowing out from one pole of the magnet and circulating back to the other pole. The aim is to persuade the reader that what looks like a magical effect is in fact simply the result of the perpetual movements of invisible circulating particles. It is crucial for Descartes,

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[21] Petty, *Discourse*, 76.
[22] Descartes, *Principles of Philosophy*, 242–75. The final numbered paragraph is § 207: 288, so magnetism is one of the last topics that Descartes discusses.

therefore, that the invisible particles are not themselves magnets—to explain magnetism by the behaviour of invisibly small magnets would lead only to an infinite regress. Petty, by extreme contrast, does the exact opposite to Descartes. He proposes magnetism as a way to "solve all the Phaenomena of Elasticity… of Hardness, Fixedness, Tenacity, Fluidity, Heat, Moisture, Fermentation, and the rest", and he does so simply by assuming that the invisibly small particles which constitute all bodies are themselves magnets. Accordingly, there is no attempt to explain magnetism—magnetism must be taken for granted as a fundamental aspect of the world, and of the fundamental particles of matter.

Petty's 'Elastique Motion' and Baconian Experimentalism

So far, we have seen that Petty's *New Hypothesis* relied upon a particulate matter theory, in which the constituent atoms of all bodies were endowed with certain innate motions by virtue of being invisibly small magnetic *terrellae*. Petty's atomistic hypothesis is short and somewhat elliptical, but it enables him to account for "elastique motions" in an ingenious way, by drawing upon a recognized tradition in English natural philosophy. "Supposing every Body to have a Figure or Posture of its own, out of which it may be disturbed by External Force", he explains, then elasticity was "the power of recovering that Figure, upon removal of such Force".[23]

At this point, Petty described the problem of elasticity or spring as a "Hard rock in Philosophy…which has long lain thwart Us in the way of Our Enquiries".[24] The great difficulty, it should be realized, is not to explain the elasticity of springs, ropes or bands. Rather, one of the most intractable problems confronting the corpuscular philosophy in the seventeenth century was to explain what Boyle referred to as "the spring of the air". Indeed, if air were held to consist of innumerable inert spherical

[23] Petty, *Discourse*, 123–24.
[24] Ibid., 4.

atoms, then there could be no "spring" or springiness in the air. The atoms would simply fall to their lowest level and accumulate, like liquid. However, as Boyle's experiments with the air-pump demonstrated, air is capable of spreading or stretching itself out to fill a much greater space than it ordinarily would. Consider the behaviour of a sealed deflated bladder (that is to say, a bladder containing only a very small amount of air) when held in the evacuation chamber of an air-pump. As the air is sucked out of the chamber the bladder inflates itself to fill the space vacated by the surrounding air.[25] Sir Mathew Hale (1609–1676), a leading jurist with a keen interest in natural philosophy, made the point most succinctly when he said that what we see here "is no forced tension of the Air, but a free natural expansion of itself".[26]

Robert Boyle at one time vacillated between two explanations of this phenomenon. One was crudely mechanistic, relying on the supposition that air corpuscles were like tiny springs. Normally held in compression, these springs were capable of expanding greatly under reduced pressure.[27] Alternatively, Boyle tended to suggest that we could conceive of air particles striving by their innate motions to gain for themselves as much room as possible. Under reduced pressure the air particles in a deflated bladder (no longer striving against the contrary motions of external air particles) have sufficient power in their motions to greatly inflate the bladder.[28] Robert Boyle also remained noncommittal about the true explanation of the springiness of the air in the course of his piecemeal publications of experimental research on air, but was finally quick to insist that this did not signify a failure of his method. On the contrary, his intention was not to assign "the adequate cause of the spring of the air", but only

[25] This problem is always one of the most intractable for atomists. Aristotle dismissed the idea of what he called "self-determined voids" in *Physics*, 216b 30-35. This is more fully discussed in chapter 6, below.

[26] Matthew Hale, *Difficiles Nugæ: Or, Observations Touching the Torricellian Experiment, and the Various Solutions of the Same, Especially Touching the Weight and Elasticity of the Air*, The second edition, with some occasional additions. (London, 1675), 184.

[27] Robert Boyle, *New Experiments Physico-Mechanical Touching the Spring of the Air and Its Effects* (London, 1660). Now reprinted in Boyle, *Works*, vol. i.

[28] For example, Boyle, *Works*, i: 165-66.

"to manifest that the Air has a Spring, and to relate some of its effects".[29] Boyle's subsequent experimental programme with the air-pump can be seen, therefore, as a protracted attempt to establish a Baconian atheoretical methodology. The spring of the air was, in other words, one of those phenomena which Newton would later say "are manifest Qualities, and their causes only are occult."[30] Similarly, Boyle's last and final intention was not to give unprovable speculations about the occult causes of springiness, but merely to make the phenomenon of spring and its effects manifest.

The outcome of this kind of enterprise, of course, was the establishment of a fruitful experimental research programme in England.[31] This is a valuable conclusion that points to a rather neglected dimension of Petty and his atomical theory. Indeed, it is in the light of this experimental programme that we must reconsider Petty's *New Hypothesis*. In his "Epistle Dedicatory" to the Duke of Newcastle, Petty claimed that one of the major concerns of the Royal Society was "to explain the Intricate Notions, or *Philosophia prima* of Place, Time, Motion, Elasticity… In a way which the meanest Member of adult Mankind is capable of understanding".[32] In the Conclusion he made it clear why he believed that his *New Hypothesis* could fulfill this desideratum:

> My matter is so simple, as I take notice of nothing in each Atome, but of three such Points as are in the Heavens, the Earth, in Magnets, and in many other Bodies. Nor do I suppose any Motions, but what we see in the greater parts of the Universe, and in the parts of the Earth and Sea.[33]

In other words, although his theory depends on the fine structure of atoms which are so small that "perhaps a Million do not make up one visible Corpusculum",[34] Petty

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[29] Ibid., i: 166.
[30] Newton, *Opticks*, 401.
[31] Paul B. Wood, "Methodology and Apologetics: Thomas Sprat's History of the Royal Society," *The British Journal for the History of Science* 13 (1980): 1–26.
[32] Petty, *Discourse*, Sig. A4v.
[33] Ibid., 132–33.
[34] Petty, *Discourse*, sig. A5*r*. For a fuller statement of Petty's methodological principles see his "The Practise and Theory of Pharmacy…", a manuscript fragment reprinted in Sir William Petty, *The Petty Papers: Some Unpublished Writings of Sir William Petty*, 2 vols (London, 1927), ii: 167-8.

felt fully justified because he was extrapolating only from perfectly familiar everyday phenomena.[35] What made this such a promising foundation upon which to build, of course, was the crucial fact that it appeared to be fully amenable to experimental investigations:

> Again, all the motions I fancy in my Atoms, may be represented in gross Tangible Bodies, and consequently may be made intelligible and examinable.[36]

Obviously, Petty envisioned a new *De Magnete* in which the same kind of careful experimentation that Gilbert applied to discovering the properties of the "great magnet of the Earth" could now be used to uncover the secrets of the microcosmic atomic magnets. Petty was completely undaunted by the fact that his theory rested on the "occult" quality of magnetism. Here again he only had to point to Gilbert as his exemplar in experimental philosophy. Gilbert insisted that his detailed experimental investigation of magnetism had shown it to be "a cause that is manifest, sensible and comprehended by all men".[37] And it seems to me that Gilbert and Petty would have said of magnetism what Newton said of "active principles": "these are manifest Qualities and their Causes only are occult".[38]

Petty's hypothesis, however, contains no descriptions of experiments already undertaken. It must be regarded as a programmatic statement – merely the announcement of a new experimental research programme to complement that of Boyle and Hooke with the air-pump.[39] Petty believed that an experimental programme devised to test his principles would "solve all the Phaenomena of Elasticity, and as I think, of Hardness, Fixedness, Tenacity, Fluidity, Heat, Moisture,

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[35] Newton was subsequently to argue in a similar way. See J. E. McGuire, "Atoms and the 'Analogy of Nature': Newton's Third Rule of Philosophizing", *Studies in History and Philosophy of Science* 1 (1970): 3–58.

[36] Petty, *Discourse*, 33.

[37] Gilbert, *De Magnete*, 229; 328.

[38] Newton, *Opticks*, 401

[39] Robert G. Frank, *Harvey and the Oxford Physiologists: A Study of Scientific Ideas* (Berkeley, 1980), 278–87.

Fermentation, and the rest".[40] Unfortunately, he does not spell out in the few pages given over to his "New Hypothesis" just how elasticity, and these other phenomena, can be "solved". Besides, although both Oldenburg and Petty himself distributed a few copies to a number of their correspondents in England, Ireland and continental Europe, by the end of March 1675, Petty had not heard back from any of them. And when Petty finally wrote to his friend Dr. Robert Wood (1622–1685) complaining, Wood's only response to Petty was that "your atoms though very small are yet too big for me to swallow". This being so, we would never know about the second part of Petty's explanation about elasticity – he was too frustrated to deliver the promised second lecture in the Royal Society thereafter, merely complaining that he was censured for not being understood: "As for Mens Cencuring mee, for not understanding mee".[41]

However, in another letter written to Wood in April 1675, Petty rapturously suggested that the cohesion of matter could be explained without recourse to a supposed "Mortar" between the atoms provided we allow three points in every atom, the magnetic poles and the "byas" or centre of gravity.[42] At this point we should revisit the problem of Petty's *New Hypothesis* and action at a distance. If Petty was willing to explain cohesion on the grounds that "the Byas of one Atome may have a tendency towards the Byas of another near it", then it would seem to follow that he could explain elasticity or "free natural expansion" in terms of the repulsive forces between the poles of his atomic magnets.[43] That being so, such repulsive forces capable of acting at a distance could be demonstrated easily and very strikingly with two magnets. If such repulsive forces really did account for the ability of magnetic

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[40] Petty, *Discourse*, 134.
[41] Robert Wood to Petty, 30 March 1675, BL Ms. Add. 72850, fol. 218*r*; Petty to Wood, 10 April 1675, BL Ms. Add. 72858, fol. 211*r*; Wood to Petty, 18 April 1675, BL Ms. Add 72850, fol. 226*r*.
[42] Wood to Petty, 15 May 1675, ibid., fol. 228*r*. This comes from Wood's letter of 15 May which refers to and quotes from the letter from Petty dated 27 April.
[43] Ibid. See, Sharp, "Sir William Petty", 323–25.

particles of air to spread themselves apart through a vacuum, it would have to be shown how the atomic magnets which constitute the air could spontaneously align themselves so that like poles were confronting one another. “All Atoms by their Motion of Verticity or Polarity,” he wrote at one point, “would draw themselves, like Magnets, into a streight Line, by setting all their Axes in *directum* to each other…” There is no reason to suppose that Petty might not have been optimistic about the possibility of solving this problem experimentally. After all, one of Gilbert’s concerns was to account for the “fixed verticity” of the Earth, its ability to take “position in the universe according to the law of the whole”.[44] Petty might have believed that there must be some principles which dictate how his atom-sized magnets rotate, and might sometimes, therefore, spontaneously align themselves with like poles facing and repel one another, and at other times spontaneously align themselves with opposite poles facing one another and attract. But if Petty had been initially optimistic about the outcomes of such a research programme, he must soon have been disillusioned, as his correspondence with Wood suggests. Although his *New Hypothesis* was well received by the Royal Society its influence seems to have been minimal, and there was no subsequent programme of experimentation with magnets at the Society.[45]

In spite of this failure to introduce a new version of atomism into English natural philosophy, Sir William Petty’s *New Hypothesis* should still be considered an important part of the background from which Newton’s dynamic natural philosophy emerged. If nothing else, it shows that the new tradition of magnetic cosmology was seen by English natural philosophers to have such potential that it might be generalized to cover not just interplanetary phenomena, but also interparticulate phenomena. If Petty’s attempt to introduce this was under-developed and

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[44] Gilbert, *De Magnete*, 66, 68.

[45] On the reaction to Petty’s *Discourse*, see Sharp, “Sir William Petty”, 316–35; Lewis, *Petty*, 6–10.

consequently unsuccessful, the same could not be said of Newton's subsequent speculations about attractive and repulsive forces operating between atoms. Unlike the corpuscularism of the Cartesians, Petty's atomist speculations were based on the starting assumption that matter was not inert and passive as Descartes believed, but had in-built active principles by virtue of its magnetic nature – a clear affirmation that the existence of occult phenomena should not simply be summarily dismissed. Furthermore, Petty felt fully justified in these speculations because his matter theory was entirely in keeping with the English tradition of Baconian experimentalism which we considered in chapter 2. The significant thing to note about this experimental tradition in this context is that concepts of occult qualities, such as inherent motions, attractive and repulsive forces, magnetism, electricity, and other active principles, were not necessarily an embarrassment to English mechanical philosophers. The leading mechanical philosophers, such as Boyle, Hooke, and later Newton, were all committed to Baconian experimentalism, and therefore felt no need to outlaw vitalistic or occult notions from their matter theory. As long as their claims could be investigated experimentally, or as Petty put it, as long as their proposed explanations "may be represented in gross Tangible Bodies, and consequently may be made intelligible and examinable", they felt their assertions were justifiable.

While Petty's atomic magnetism was an example of a "full blooded" Gilbertian magnetic philosophy, his English contemporaries, in contrast, tended to subscribe to a non-Gilbertian account of magnetism. Influenced perhaps by an older occult tradition, and to some extent by Descartes's recently published account of magnetism, they focused on effluvial accounts of magnetism. The fellows of the Royal Society, such as Robert Boyle for instance, seemed to accept, with Descartes, the idea that magnets worked by emitting continually moving streams of effluvia, or extremely small particles. As we shall see, however, there were marked differences from the Cartesian account. In particular, where Descartes envisaged a circulating vortex of particles continually streaming out from, and returning to a magnet, the English natural philosophers spoke instead of "orbs of virtue", or "spheres of activity", and said almost nothing about effluvia returning back to the emitting body. In the next section, therefore, I will turn to the labyrinthine context of these notions, focusing on but not limiting myself to English thinkers writing after the revival of Ancient atomism. The aim here is to show that although such effluvial explanations conform to the precepts of Robert Boyle and other "mechanical" philosophers, and explain phenomena in terms of Boyle's "two great Catholick Principles, Matter and Motion", they take for granted an in-built activity in the emitting bodies, or in the particles of the effluvia themselves. There is no attempt among the English thinkers to explain the continual emissions of effluvia in terms of Cartesian transfer of motions, or continual circulation in vortices.

Magnetic Effluvia and Spheres of Activity: The Background before the 1650s

The focus in this section is upon two related notions, magnetic effluvia and spheres of activity, or orbs of virtue; that is to say, theories about magnetism which depend upon supposed emissions that are either material or immaterial, and the belief that these were confined to a sphere surrounding the magnet. Given that they were significant notions in sixteenth and seventeenth-century matter theory,[46] it is appropriate to survey the complex developments of this pair of concepts up to the use of effluvial explanations not just for magnetism, but for numerous other physical phenomena, which we can see in Walter Charleton, Robert Boyle, and others. Finally, we will consider Newton's use of this same tradition in his "An Hypothesis explaining the Properties of Light".[47]

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[46] Many philosophical traditions have been assumed to have shaped the conception of effluvia: the Stoic *pneuma*, the Platonist *anima mundi*, Galenic vital spirit, etc. See Gordon Keith Chalmers, "Effluvia, the History of a Metaphor," *PMLA* 52 (1937): 1031–1050; Gordon Keith Chalmers, "The Lodestone and the Understanding of Matter in Seventeenth Century England," *Philosophy of Science* 4 (1937): 75–95. Here I am only concerned with those developments which can be seen to be effluvial.

[47] Newton, "An Hypothesis explaining the Properties of Light" (1675) in Newton, *Papers & Letters*

Descartes's effluvial account of magnetism can be traced back to Epicurus, and it would have been familiar to Descartes's contemporaries through the *De rerum natura* of Lucretius. The ancient atomist account was less elaborate than that of Descartes, but like his account, it tried to deny that magnetism was an occult phenomenon. In Lucretius' account the atomic effluvia which were supposed to be streaming out from a magnet drove away the air surrounding the magnet. If there was a piece of iron, or another magnet nearby, the air pressure between them would be diminished, and the surrounding air would push (by the repeated collisions of its atoms against the magnet and iron) the magnet and iron together to close up the space where the air pressure was reduced.[48]

The atomist account perhaps raised more questions than it answered. Lucretius' attempt to explain why iron was affected in this way, but not any other kind of body was highly unconvincing (suggesting that the effluvia from the magnet passed through bodies that were less dense than iron, but forgetting that the effluvia were supposed to reduce air pressure).[49] Similarly, he offered no explanation as to how this effect still worked if there was a physical barrier between the magnet and the iron. Besides, atomism itself was generally rejected as unviable throughout the Middle Ages. Accordingly, the dominant explanations of magnetism from ancient times, through the Middle Ages and the Renaissance, until the atomist revival of the seventeenth century, tended to accept that magnetism was an occult phenomenon. It was often seen as an exemplar of action at a distance, and therefore that it must operate by non-material means. For scholastic natural philosophers it was a fundamental assumption that bodies could only act on other bodies by making contact with them; a body that was held to act at a distance, therefore, had to be

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on Natural Philosophy.

[48] Lucretius, *The Nature of Things*, trans. Alicia Stallings (London: Penguin, 2007), Book VI, lines 1002–41.

[49] Lucretius, *Nature of Things*, VI, lines 1042–47.

assumed to be acting by immaterial means. Aristotle's silence on magnetism meant that even scholastics accepted magnetism as an occult quality, which did not operate by means of any of the sensible qualities of heat, cold, dryness or wetness.[50] As the Aristotelian Sir Kenelm Digby admitted: "The Loadstone and Electrical bodies are produced for miraculous, and not understandable things; and in which it must be acknowledged, that they work by hidden qualities, that mans wit cannot reach unto."[51]

Before the atomist revival and the concomitant emphasis upon *material* effluvia (i.e. effluvia composed of invisibly small material particles), bodies that could affect their surroundings in some way—such as magnets, luminescent, or even fragrant bodies—were often assumed to operate by means of *immaterial* emissions. It was also assumed that such emissions were only capable of transmitting the power of the emitting body to a certain limited distance, and this distance defined an "orb of virtue" or "sphere of activity" surrounding the body.[52] As we saw in chapter 1, even as early as Al-Kindi's and Roger Bacon's works, rays were conceived as invisible, immaterial entities, whose action was similar to light. In the magical tradition, all bodies were considered to have the capacity to emit rays, transmitting whatever active and vital powers they might be supposed to have. It was also accepted that while the heavenly bodies could act at huge, cosmic distances, earthly bodies had a sphere of virtue of much more limited extent. Influences from bodies were always held to be emanated spherically, and the Renaissance magician Giambattista Della Porta, in his *Magia naturalis* (1589), compared the sphere of influence to the familiar

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[50] Chalmers, "Lodestone".
[51] Sir Kenelm Digby, *Two Treatises. In the One of Which the Nature of Bodies; in the Other the Nature of Mans Soule Is Looked into: In Way of Discovery of the Immortality of Reasonable Souls* (Paris, 1644), Preface, sig. B2*r*.
[52] Silvia Parigi, "Effluvia, Action at a Distance, and the Challenge of the Third Causal Model," *International Studies in the Philosophy of Science* 29 (2015): 351–68.

phenomenon of the light of "a candle spread[ing] everywhere".[53] Based on this comparison, Della Porta turned his attention to magnetism, and devoted 56 chapters to it in Book VII, "Of the Wonders of the Loadstone". In chapter 26, "The loadstone within the sphere of its vertue, sends it forth without touching", Della Porta insisted that a lodestone "will impart vertue to the iron, if it be but present", and not actually in contact.[54] Magnetic effluvia, in Della Porta's eyes, therefore, were similar to the light of a candle; light was held to be immaterial and acted without material contact, while magnets operate by "an effluxion of its forces", and there is no suggestion that the forces are material entities.[55]

Other accounts of magnetism avoided notions of effluvia all together. In his *On the Natural Faculties*, the influential ancient physician, Galen, suggested an animistic theory of the magnet.[56] This was taken up, for example, by Girolamo Cardano who first suggested in his *De subtilitate* (1560) that a magnet was attracted to iron because iron was its food, and subsequently suggested that a lodestone was male and iron female.[57] Similarly, William Gilbert dismissed all previous attempts to explain magnetism in materialist terms, including those of Epicurus and Lucretius, and developed a theory of magnetism which depended upon its immaterial magnetic soul.[58]

In spite of Gilbert's best efforts at rejecting materialist accounts of the magnet, the atomist revival increasingly led to the dominance of explanations of magnetism in terms of material effluvia. It is my contention, however, that hardly any of the effluvial accounts of magnetism developed by English thinkers can be seen to be as

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53 Della Porta, *Natural Magick*, 135.
54 Ibid., 203.
55 Ibid., 197.
56 Galen, *On the Natural Faculties*, trans. Arthur John Brock (Cambridge, MA, 1991), III, xv, 206.
57 Cardano, *De Subtilitate*, Book VII, 412, 420.
58 Gilbert, *De Magnete*, Book V, Chapter XII, 308–12. See also, Henry, "Animism and Empiricism."

mechanical as the Cartesian account. On the contrary, as I hope to show, they still showed significant traces of earlier occult ways of thinking, whether animistic, or involving ideas derived from theories of *immaterial* effluvia.

An important element in these lingering non-mechanistic ideas of magnetism is, of course, the influence of Gilbert on English thought. But, although this influence was undeniable, there was a strong tendency to introduce more corpuscularian accounts of magnetism into debate. With regard to the issue of effluvial accounts of magnetism, perhaps the legacy of non-mechanical effluvia derived from the prevarications of Francis Bacon. As we have seen in chapter 3, Bacon spoke of actions at a distance as a real possibility in his *Novum Organum*, and used magnetism to demonstrate his point.[59] In the *Sylva Sylvarum* (1627), Bacon introduced effluvia to explain magnetism, but they were clearly immaterial. In this work he defined magnetic virtue as the "emission of spirits, and immateriate powers and virtues, in those things which work by the universal configuration and sympathy of the world".[60]

Elsewhere, however, for example in his *Description of the Intellectual Globe* (1612), Bacon suggested that effluvia are invisibly small material particles given off by bodies. Addressing the problem as to whether there is "a collective vacuum in the interstellar spaces", Bacon insisted that "all the globes" "consist of solid and dense matter", and

> they are, however, immediately surrounded by some kind of bodies which are to some degree connatural with the globe itself, but nevertheless more imperfect, sluggish and attenuated, and which are nothing other than the effluvia and emanations of the globes themselves…[61]

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[59] For example, Bacon, *Novum Organum*, Book II, Aphorism 37. See also Chapter 3 above.
[60] Francis Bacon, *Sylva sylvarum*, in Bacon, Works, 2: 644.
[61] Francis Bacon, *A Description of the Intellectual Globe*, in Francis Bacon, *OFB VI: Philosophical Studies c.1611–c.1619*, ed. Graham Rees (Oxford, 1996), 125.

There is no vacuum, Bacon concluded, because the interstellar spaces are filled with an attenuated "kind of bodies… connatural with the globe[s]" of the stars and planets. Bacon's effluvia are now material.

The unresolved tensions in Bacon's writings on these matters may well derive from the fact that he was in two minds as to whether action at a distance was really possible. One way of avoiding action at a distance is simply to suppose that the effluvia usually brought in to explain these effects are *material* entities. Bacon was not committed to atomism, and so perhaps hesitated to embrace an effectively atomist way of accounting for certain phenomena, but his later English followers, thinkers such as Robert Boyle, Robert Hooke, and Isaac Newton, had no such anti-atomist qualms.[62] But, if they adopted the idea of material effluvia from Bacon, or from ancient atomism, their conception of these material effluvia was still partly shaped by earlier non-mechanical, and even non-material, theories of effluvia.

Before going on to establish this, it is perhaps worth pausing to note that even Descartes's own corpuscular matter theory has been seen as being dependent upon unacknowledged occult principles. While considering Descartes's three kinds of matter—his three "elements"—R. S. Westfall suggested that

> Descartes's himself did not realize how faithfully the three forms [of matter] repeated the characteristics of the Paracelsian *tria prima*, and in the case of his subtle matter, the most vehemently agitated particles, he cast the active principles of Hermetic philosophy into mechanistic form.[63]

Westfall is surely exaggerating, but there can be no denying that Descartes's "first element", composed of the smallest "scrapings" from larger parts of matter as they jostle one another and smooth one another into spheres seem to show signs of inherent activity. These tiny scrapings are held to fill the spaces that inevitably occur

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[62] On Bacon and atomism, see Graham Rees, "Atomism and 'Subtlety' in Francis Bacon's Philosophy", Annals of Science, 37 (1980): 549–71; Silvia Manzo, "Francis Bacon and Atomism: A Reappraisal", in Christoph Lüthy, John Murdoch and William Newman (eds.), *Late Medieval and Early Modern Corpuscular Matter Theories* (Leiden, 2001), 209–43.
[63] Westfall, "Newton and the Hermetic Tradition," 186.

when spherical particles are crowded together, thereby preventing formation of empty space. This is easy to imagine, but it is not so clear why they should be moving as rapidly as Descartes requires them to move. On the one hand he tells us that these tiny scrapings "have no motion which does not come from these [larger] parts", but on the other he says "they must however move much more quickly." Given that there are no new motions in the world, only transference of motion in accordance with Descartes's three laws of nature, it is not clear how the larger parts can impose faster movements on the particles of the first element. Indeed, this seems to run counter to Descartes's seven rules of collision.[64]

Similarly, even if we accept that the *Principia Philosophiae* gives a fairly serviceable account of why and how the Earth is a giant magnet, and even if we accept that a magnet is formed deep in the Earth by the same process of "scrapings" of Descartes's "first element" perpetually coursing through Earth's pores, it is impossible to understand what drives the effluvial particles in their perpetual circulation around a small piece of lodestone long after it has been dug out of a mine. It is impossible to understand this simply because Descartes does not say anything about it, and it is by no means easy to see how it follows from what Descartes does tell us about his system.[65] Even so, I do not intend to pursue this here. It is clear that Descartes believed he had established a mechanistic explanation of magnetism. Indeed, it is after completing his long account of magnetism that he announced that his readers should now be "easily persuaded that there are in rocks or plants, no forces so secret, no marvels of sympathy or antipathy so astounding", that they

[64] Descartes, *Principia Philosophiae*, Part III, § 51, 109. On Descartes's seven rules of collision, see Part II, §§ 45–52; and William R. Shea, *The Magic of Numbers and Motion: The Scientific Career of René Descartes* (Canton, MA, 1991), 295–300.

[65] Descartes's account of magnetism appears in *Principia Philosophiae*, Part IV, §§ 133–87; Descartes himself refers us back to Part III, § 87, and §§ 105–109 for essential background information about his system. On Descartes's plenist physics, see E. J. Aiton, *The Vortex Theory of Planetary Motions* (London, 1972); Shea, *Magic of Numbers and Motion*; Gaukroger, *Descartes' System*; Schuster, *Descartes-Agonistes*.

cannot be explained simply by "the figure, magnitude, situation, and motion of particles of matter".[66] Accordingly, we will take Descartes at his word and accept that his account is a mechanistic account. In what follows, however, I hope to show that the thought of English thinkers on effluvia did not come up even to the standard set by Descartes. If his was a mechanical account, theirs was not.

One easy way to see this is to consider the fact that English new philosophers did *not* think of effluvia in terms of them *circulating* outwards and back towards the emitting body—as was supposed in Descartes's theory of the magnet, and which was dictated by his plenist physics (movement in a completely full world could only take place by circulation). Rather, they seem to have thought of effluvia radiating outwards, but then effectively disappearing, as their power became exhausted—as in Della Porta's simile with light: the light of a candle can only illuminate a limited space but the light does not re-circulate back to its source.[67] Indeed, such effluvia were regarded as magical precisely because they were continually and perpetually emitted from their originating bodies, never to return, and yet the emitting bodies were never diminished.

This non-circulating view of effluvia in the magical tradition, somewhat remarkably, seems to have been the standard assumption adopted in the post-atomist revival in England, even though effluvia were now held to be material entities. As we shall see later, the late seventeenth century non-Cartesian effluvialists frequently wrote as though the material effluvia flow radially outwards from the emitting body, out to the final limits of the orb of virtue, and then the effluvia simply die away, or are exhausted, or consumed, in an unexplained way, so that there is no returning

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[66] Descartes, *Principia Philosophiae*, Part IV, § 187, 275.

[67] The only other image they might have had in mind was one of "ebbing and flowing", like the tides of the sea. This was the standard view of how blood flowed in the human body, derived from the opinions of Galen. There are little more than hints here and there that this idea might have been applied to effluvial flow.

flow—and certainly no discussion of effluvia circulating in a Cartesian vortex around the emitting body. At one point, Robert Boyle was even explicit in casting doubt on Descartes's circulation theory. In his *Essays of Effluviums* of 1673 he wrote:

> You will perhaps wonder, why I do not preferr to the Instances I make mention of in this Chapter, that which may be afforded by the Loadstone, that is acknowledge'd continually to emit multitudes of Magnetical Steams without decrement of weight. But though I have not thought fit to pass this wholly under silence; yet I forbear to lay so much stress on it, not only because my Ballances have not yet satisfied me about the *Effluvia* of Loadstones, (for I take them not all to be equally diffusive of their Particles;) but because I foresee it may be doubted, *whether* Loadstones, like odorous Bodies, do furnish afresh of their own, all the Corpuscles that from time to time issue from them? *Or*, whether they be not continually repaired, *partly* by the return of the Magnetical Particles to one Pole that sallied out of the other; and *partly* by the continued passage of Magnetical matter (supplied by the Earth or other Mundane Bodies)…[68]

It is clear from this, and from the rest of the text, that Boyle holds to the view that the lodestone continually emits effluvia "without decrement of weight". He does not stress this, however, because he anticipates that some may doubt this on the grounds that the substance of the magnet may be "continually repaired, *partly* by the return of the Magnetical Particles…" Clearly, this is the Cartesian view, but equally clearly, it seems, Boyle does not subscribe to it. Given that Boyle's approach represents the dominant view among English thinkers, it suggests the residual influence of the force of occult traditions. It is one thing to suppose an object can emit *immaterial* influence perpetually, without diminishing itself; but it is quite another to suppose that a body perpetually emits part of its *material* substance with no detectable diminishment.[69]

While accounting for how a magnet attracts a piece of iron, Descartes argued,

> the magnet attracts iron, or rather, a magnet and a piece of iron approach each other: for in fact there is no attraction there: rather, as soon as the iron is within the sphere of activity of the magnet, it borrows force from the magnet, and the grooved particles which emerge from both the magnet and the piece of iron

68 Boyle, *Works*, vii: 248.
69 This will be illustrated below, drawing upon the work of Robert Boyle. See also, Parigi, "Effluvia".

> expel the air between the two bodies: as a result, the two approach each other in the same way as two magnets do.[70]

Readers of Descartes's *Principia* have to assume that the "grooved particles" perpetually circulate around and through the magnet and the iron, and that this continues in a mechanistic way—that is to say, that it must have been initiated at the Creation and has somehow continued unabated to this day. A supposedly mechanistic account will not work, however, in the case of effects attributed to non-circulating effluvia, continually emitted radially from bodies, never to return.[71] In such cases, it has to be assumed that the emitting body has some in-built energy or power, enabling it to perpetually drive out its effluvia. English thinkers after the 1650s (unless they were followers of Descartes) all tended to subscribe to this radial version of effluvial action, rather than the Cartesian circulating version. As we shall see, there was little or no consternation about such an inherently occult view of effluvial action among English thinkers. Evidently, for Boyle and other Baconians, guided by experience rather than by elaborate theorizing, perpetually radiating effluvia were deemed to be preferable to Cartesian vortexes. If they ever thought about the fact that the emitting bodies must be inherently active, they did not stop to discuss the matter.

Active Effluvia in England after the Atomist Revival

The late 1640s saw the publication of Descartes's *Principia* (1644), Sir Kenelm Digby's *Two Treatises* (1644), and the major works of Pierre Gassendi on the philosophy of Epicurus (1647, 1649).[72] Increasingly, natural philosophers in England turned to atomist or corpuscularist systems of philosophy. One important outcome of this atomist revival was a general assumption that effluvia, which had

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70 Descartes, *Principles of Philosophy*, 265.

71 That being so, Descartes does not suppose any such effluvia. Indeed, effluvia do not appear in the *Principia Philosophiae*. His account of electrical phenomena depends upon the formation of "long ribbons" of Descartes's "first element" in the pores of the electric body, which can then emerge from the pores, but almost immediately must return again to the emitting body. Again, there is a circulation, not a continual emanation. See, Descartes, *Principia Philosophiae*, Part IV, § 185, 273–74.

72 Digby, *Two Treatises*; Pierre Gassendi, *De Vita, Moribus, et Doctrina Epicuri Libri Octo* (Lyon, 1647); Pierre Gassendi, *Syntagma Philosophiae Epicuri* (Lyon, 1649).

sometimes been held to be incorporeal, were material, and were simply streams of atoms or corpuscles, continually emitted from bodies. Many philosophical traditions have been assumed to have shaped earlier conceptions of effluvia[73], but there seems to be no denying that the influence of Lucretius' use of atomic effluvia in his poem *On the Nature of Things*, began to dominate. As Lucretius wrote:

> The question now before us – becomes easy to explain:
> Namely to make clear, extrapolating fact from fact,
> Why lodestone acts on iron with the power to attract.
> Firstly, there must be a quantity of seeds that flows
> Out from the stone, a streaming wave of seeds that, with its blows,
> Knocks away the particles of air that intervene
> Betwixt the iron and stone…[74]

Like Descartes, Sir Kenelm Digby did try to provide a mechanical account of magnetism in his *Two Treatises* (1644). Just as the heat of the Sun causes a circulation of air from the tropics to the poles, and from poles to tropics, so there is an analogous circulation of atoms in the body of the Earth, again driven by the heat of the Sun. These "steams", as Digby calls them, will eventually incorporate themselves into a "body of a convenient density". "It must come to passe", Digby writes, "that this body will become in a manner wholly of the nature of these steams". If such a body is dug out from the Earth, the north-south flow of atoms will continue in them; this is what a magnet is—a stone with a continual flow of streams of atoms moving north-south and south-north through it.[75] Digby's magnetic effluvia do circulate from pole to pole, and as long as we ignore the fact that the Sun drives the whole system, without its own perpetual heat being explained, it can pass as a

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[73] For example, the Stoic *pneuma*, the Platonist *spiritus mundi* and Galenic vital spirit, etc. See Monica Ugaglia, "The Science of Magnetism Before Gilbert: Leonardo Garzoni's Treatise on the Loadstone," *Annals of Science* 63, no. 1 (2006): 59–84; Chalmers, "Lodestone".

[74] Lucretius, *Nature of Things*, VI, ll. 999–1005. I have used Lucretius, *The Nature of Things*, trans. A. E. Stallings (London, 2007), 229. On the influence of Lucretius, see Catherine Wilson, *Epicureanism at the Origins of Modernity* (Oxford, 2008); Stephen Greenblatt, *The Swerve: How the World Became Modern* (London, 2011).

[75] Digby, *Two Treatises*, 218.

mechanical account of magnetism. Accordingly, Digby insists that magnetism "may be done by bodies, and consequently is not done by occult or secret qualities".[76]

The only other innovator in natural philosophy in England who developed a mechanical account of magnetism was Thomas Hobbes. His theory of magnetic attraction is essentially similar to that of Lucretius, and depends upon the movement of the parts of the magnet driving away the air between the magnet and a piece of iron, so that the iron is pushed towards the magnet by the pressure of the surrounding air. This account first appears in his *Decameron Physiologicum* of 1678, and is far from convincing. It is significant that Hobbes did not discuss magnetism at all in his major work of natural philosophy, *De corpore* (1655). Perhaps his attitude is summed up by his comment in *Seven Philosophical Problems* (1682), as to whether the Earth is a giant magnet, that "For my part I am content to be ignorant."[77]

Although all the other English new philosophers use material effluvia in their accounts of magnetism and how it worked, they all seem to favour a *radial* theory of emission, rather than a circulation theory, and none of them take the trouble to explain how or why magnets continually emit material effluvia. By this omission, they were effectively introducing active principles into their matter theory; i.e. to simply say a body emits effluvia is to attribute unexplained activity to that body—which is to attribute an occult quality to it. To put it another way, active principles in matter gave rise to unexplained motions of the particles. Furthermore, these writers did not confine their effluvial speculations to magnetism alone. This again suggests some lingering influence from more occult traditions. While Descartes and Digby resorted to effluvia to explain magnetism, they did not go on to adopt effluvia as a major aspect of their philosophical systems (although Digby also

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[76] Ibid., 230.
[77] Thomas Hobbes, *Decameron Physiologicum* (London, 1678), chap. 9; Thomas Hobbes, *Seven Philosophical Problems* (London, 1682), chap. 7.

used effluvia to explain the workings of the weapon salve—another highly occult phenomenon).[78] If we consider Walter Charleton, Henry Power, and Robert Boyle, and even Newton himself, however, we shall see that all of them did. A natural philosophy in which all things, not just magnets, are continually emitting radially-disseminated streams of invisible and otherwise insensible effluvia, seems to be reminiscent of the natural philosophy of Al-Kindi's *De radiis stellarum*, in which all things are held to issue rays of influence—the major difference being that Al-Kindi's rays are immaterial, but the radial effluvia are material.[79] This new vogue for effluvial explanations was summed up by Sir Thomas Browne in his *Pseudodoxia Epidemica* (1646):

> And truly the doctrine of effluxions, their penetrating natures, their invisible paths, and insuspected effects, are very considerable; for, besides this magnetical one of the earth, several effusions there may be from divers other bodies, which invisibly act their parts at any time, and, perhaps, through any medium; a part of Philosophy but yet in discovery, and will, I fear, prove the last leaf to be turned over in the booke of Nature.[80]

As if taking their cue from Browne, other English natural philosophers tried to turn over that last page in the book of nature.

A typical example can be found in Walter Charleton's exposition of the "weapon salve" in his loose translation of three short works by J. B. van Helmont, under the title, *A Ternary of Paradoxes* (1650). According to Paraselsus and J. B. van Helmont, the "weapon salve", or "powder of sympathy", acting at a distance would cure a person's wound in an occult way.[81] Assuming this was overly magical, Charleton

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[78] Sir Kenelm Digby, *A Late Discourse Made in a Solemne Assembly of Nobles and Learned Men* (London, 1658). See Betty Jo Dobbs, "Studies in the Natural Philosophy of Sir Kenelm Digby Part III. Digby's Experimental Alchemy—The Book of Secrets", *Ambix* 21 (1974): 1–28; Elizabeth Hedrick, "Romancing the Salve: Sir Kenelm Digby and the Powder of Sympathy", *British Journal for the History of Science* 41 (2008): 161–85.

[79] On Al-Kindi's *De radiis stellarum*, also known as *Theoria magicarum*, see Chapter 1 above. See also, Adamson, *Al-Kindī*; Pinella Travaglia, *Magic, Causality, and Intentionality: The Doctrine of Rays in Al-Kindī* (Florence: SISMEL, 1999).

[80] Thomas Browne, *Sir Thomas Browne's Pseudodoxia Epidemica*, ed. Robin Robbins (Oxford, 1981), Book II, Chapter 2, 88. See also, Gordon Keith Chalmers, "Three Terms of the Corpuscularian Philosophy," *Modern Philology* 33 (1936): 243–60.

[81] Allen G. Debus, *The Chemical Philosophy: Paracelsian Science and Medicine in the Sixteenth and*

explained its action in terms of streams of effluvia flowing from the salve to the wound, and he called this process a "magnetic cure". Before coming to his conclusion, he denies that the magnetic cure takes place by the aid of the Devil, and insists it was the "Work of Nature" (i.e. it operates by natural means). Indeed, throughout this early work, Charleton persistently sees the "powder of sympathy" (or weapon salve), and maybe the occult notion of sympathy in general, as being magnetic phenomena—perhaps for no other reason than the fact that he attributed these phenomena to the action of effluvia.[82] He then stressed that it was not acting at a distance, because the cure depends on the "Balsam of the blood, flowing to the part wounded", which it does as an "Evaporation" or "Aporrhoea" (i.e. emanation, or effluvium in the ambient air). The "magnetic cure", "powder of sympathy", or "weapon salve", as Charleton argued, was analogous to the way in which the stars transmitting their influence by "imperceptible Emissions streaming, in a semi-immaterial thread of Atomes".[83] While this is consistent with an atomic theory, it is not clear why Charleton named the atoms "semi-immaterial" here, but it seems obvious enough in the rest of the passage that he was thinking of streams of atoms as streams of material bodies. As he wrote,

> when the powder thereof is applied to the blood, effused out of a wound, the Balsamical Faculty of it is not confined to a meer Topical Operation but … by a Congenerous Magnetism, holdeth a certain sympathy with that Fountain, from whence it was derived… in a stream of subtiliated Atomes…[84]

It should be noticed that Charleton does not have a view of effluvia as passively knocked out of bodies, by the external heating or cooling of the atmosphere (as Digby does) or anything else. Instead, the effluvia are simply sent out by the active bodies themselves:

> every mixt Body, of an unctuous Composition, doth uncessantly vent, or expire a circumferential steam of invisible Atomes, homogeneous and consimilar, that

Seventeenth Centuries (New York: Science History Publications, 1977), 103–5.

[82] Jean Baptiste van Helmont, *A Ternary of Paradoxes: The Magnetick Cure of Wounds. Nativity of Tartar in Wine. Image of God in Man*, trans. Walter Charleton (London, 1650), sig. E*r*–E*v*.sig. E*r*–E*v*.

[83] Ibid., sig. D*v*–D*2r*.

[84] Ibid., sig. D*4v*.

> is of the same identical nature with it self; and for that reason, efficaciously operative to the same Finality...[85]

In these two quotations Charleton provided his clear understanding of the occult nature of the effluvia. Indeed, throughout his explanation of the weapon salve, he never explains why the effluvia keep flowing from the salve and how they find their way along the trails to the wound. It might be supposed that these views would be superseded by more mechanistic theories in his later more comprehensive work, the *Physiologia Epicuro-Gassendo-Charletoniana* (1654). But, although this was written in a much less occult style, he still offered no explanation of why loadstones and iron continually emit effluvia. If Charleton now saw himself as conforming more closely to the mechanical philosophy, he would not have satisfied a real follower of Descartes. Here again, he simply claims that "both from the Loadstone and Iron there perpetually issue forth continued streams of insensible particles, or bodies".[86]

Charleton repeatedly shows that he did not believe in a circulation of effluvia around the magnet. At one point he insists that "the Virtue of the Loadstone is diffused in round, or spherically, and upon consequence", he said, its effluvia,

> are so much the more rare, by how much the farther they are transmitted from their source or original; and so being less united, become less vigorous in their attraction, and at large distance, i.e. such as exceeds the sphere of their Energy, are languid and of no force at all: so doth the Terrestrial Globe diffuse its Attractive Virtue in round…[87]

There is no suggestion that the transmitted particles return to their source.

It is in this supposedly more "modern" work, also, that Charelton extends the notion of effluvia from magnets to all bodies. We can see this, for example, when he defends the notion of void space. If vacuum does not exist, he wrote, "there would be no room to entertain the continual Effluviums, expiring from all bodies passing their

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[85] Ibid.
[86] Charleton, *Physiologia Epicuro-Gassendo-Charltoniana*, Book III, Chapter, XVI, 385.
[87] Ibid., Book III, Chapter XI, 283.

natural vicissitudes and degenerations".[88] Effluvia are now supposed to be ubiquitous, precisely because they are expired by "all bodies". "If there be any validity in what we have so plainly asserted", he wrote,

> that most, if not All Bodies are… *Perspirable* and *Conspirable, i. e.* that they continually emit insensible Effluvia's from themselves to others: We say, if there be any weight in all this, men cannot think it unreasonable in us to conceive, that those Admired Effects, which they commonly ascribe to Hidden Sympathies and Antipathies, are brought about by the same ways and means, which Nature and Art use in the Causation of the like Ordinary and Sensible Effects…[89]

Charleton's rhetoric makes it look as though he is rejecting occult notions such as "Hidden Sympathies and Antipathies", but the idea that all bodies continually "perspire" streams of effluxes would hardly count as mechanical explanations in the eyes of Continental Cartesians. It is obvious that the key point of his conclusion here does not depend on mechanical principles, but is based on occult ideas.

Even Henry Power (1626–1668), who has been regarded by historians of science simply as an English Cartesian,[90] seems to have believed that all bodies emitted effluvia. Clearly, the undeniable elements of Cartesianism in his *Experimental philosophy, in three books containing new experiments microscopical, mercurial, magnetical* (1664) were tempered by an emphasis upon Baconian experimentalism and by an approach that owes much to the influence of Robert Boyle. Even so, he did choose to follow Descartes on the issue of void space, developing a plenist physics contrary to that of Boyle.[91] Similarly, he accepted the Cartesian account of the magnet, holding it to work by means of "Corporeal effluviums" which "wheel about,

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88 Ibid., Book I, Chapter IV, 30.
89 Ibid., Book III, Chapter XV, 344–5.
90 Charles Webster, "Henry Power's Experimental Philosophy," *Ambix* 14 (1967): 150–178. Webster says on 155 that Cartesianism "became a dominant influence in his natural philosophy", and on 158 calls him "a convinced Cartesian"; see also 167, 168, 169. See also Marie Boas Hall, "Introduction," in *Henry Power, Experimental Philosophy* (New York: Johnson Reprint Corp., 1966).
91 Henry Power, *Experimental Philosophy: In Three Books: Containing New Experiments Microscopical, Mercurial, Magnetical. With Some Deductions, and Probable Hypotheses, Raised from Them, in Avouchment and Illustration of the Now Famous Atomical Hypothesis* (London, 1664), 95–103.

and, by a Vortical Motion, do make their return unto the Loadstone again, as *Des-Cartes* hath excellently declared."[92] Power seems to be unique among English thinkers in accepting the Cartesian account of magnetism.

It should be noted, however, that one of his major arguments against the existence of void space was that the so-called Torricellian vacuum was filled not only with light (which he took to be material, "Solary atoms"), but also with "magnetical and coelestial particles, besides the halituous effluviums of all Bodies whatsoever."[93] Where Charleton argued that a void was necessary to allow room for the incessant effluvia given off by bodies, Power argued that a vacuum was impossible because a void space would always be filled by the effluvia from bodies. Power argued that the air-pump could not remove all of the air, because

> By Atmosphaerical Air, I understand such as we constantly breathe and live in, and is a mixt Body of Luminous and Magnetical Effluviums, powdred with the influential Atoms of Heaven from above, and the halituous Effluxions and Aporrhoea's of this terraqueous Globe below.[94]

A little later, he wrote of "all these Luminous and Opace Bodies (I mean the Starrs and Planets) with their Luminous and Vaporous Sphaeres (continually effluviating from them)".[95]

So, although Power agreed with Descartes's account of the magnet, he did not otherwise exclude effluvia from his physics, as Descartes did. There is no suggestion anywhere in Descartes's *Principia Philosophiae* that any other bodies operated by emitting effluvia. Even electrical phenomena are attributed to the motions of Descartes's "first element" (the finest particles which completely fill up all the gaps and spaces between the successively larger particles of the second and third

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[92] Ibid., 156.
[93] Ibid., 99.
[94] Ibid.
[95] Ibid., 103.

elements)[96] coursing through the pores of electrical bodies; there is no suggestion that the electrical bodies themselves emit effluvia.[97] Indeed, effluvia are simply not possible in Descartes's physics; the very concept of effluvia is excluded from Cartesianism. As Silvia Parigi has correctly pointed out when comparing Gassendi's atoms and Descartes's corpuscles:

> Gassendi's atoms are different from Cartesian corpuscles. The former are always parts of a determinate substance, keeping the physical characteristics and chemical properties of the substance they derive from; whereas the latter do not belong to single bodies, but to three elements (earth, air, aether), differing from one another only in their quantitative characteristics. Gassendi's atoms may transmit their properties and powers within a limited extension… Gassendian corpuscles may be said (and in fact they will be said) to be friendly or unfriendly, luminous and coloured, fiery or terrestrial, rarified or viscous, odorous or venomous… Cartesian corpuscles do not tolerate any qualitative specification.[98]

According to Parigi, Boyle clearly grasped this difference, and favoured the "qualitative corpuscularianism" of Gassendi, rather than the austerity of Descartes's three-element theory.[99] Whether Power, who was clearly more sympathetic to Descartes, saw this distinction quite as clearly is doubtful, but it is very clear that Power introduced "qualitative corpuscles" into his experimental philosophy, and believed that all bodies emitted "halituous effluviums". Furthermore, he contrasts these with magnetical effluvia because, unlike the "Vortical Motion" of magnetic effluvia, these do not return to the bodies that emit them:

> all Effluxions that come from all other Bodies, besides Magnetical, as Electrical, Odoriferous, *&c*.... all Bodies that effluviate intrinsecally from themselves, their exspirations flye quite away into the open Ayr, and never make any return again to the Body from whence they proceeded…[100]

It seems clear that, although Power was persuaded that the Cartesian account of magnetism was essentially correct, this did not prevent him from also accepting that

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96 Gaukroger, *Descartes' System*; William B. Ashworth, "Christianity and the Mechanistic Universe," in *When Science & Christianity Meet*, ed. David C. Lindberg and Ronald L. Numbers (Chicago, 2003), 61–84.
97 Descartes, *Principia Philosophiae*, Part IV, § 185, 273.
98 Parigi, "Effluvia", 360. Parigi uses "earth, air, aether" loosely to refer to Descartes first, second, and third elements; see works cited in previous note.
99 Ibid. Parigi cites Boyle's *Experiments and Notes about the Mechanical Origin or Production of Electricity* of 1675. See Boyle, *Works*, viii: 512.
100 Power, *Experimental Philosophy*, 159.

bodies had in-built principles of activity which enabled them to “effluviate intrinsecally from themselves”.

Power differs from Descartes also when he considers “the Speculation of Motion, and its Origin, being, as I conceive, one of the obscurest things in Nature.” Where Descartes’s particles are completely passive and only move inertially, Power’s atoms are said to possess motion as inseparably as they are said to possess extension:

> Now as Matter may be great or little, yet never shrink by subdivision into nothing; so, is it not probable, that Motion also may be indefinitely swift or slow, and yet never come to a quiescency? and so consequently there can be no rest in Nature, more than a Vacuity in Matter.

He goes on to suggest that “the Minute particles of most (if not all) Bodies are constantly in some kind of motion, and that motion may be both invisibly and unintelligibly slow, as well as swift, and probably is as unseparable an attribute to Bodies, as well as Extension is.”[101] Emphasizing the point a little later, Power asks: “Is it not, I say, more than probable, that rest and quiescency is a meer Peripatetical Notion, and that the supreme Being (who is Activity it self) never made any thing inactive or utterly devoid of Motion?”[102] For Power, as for the majority of his English contemporaries (the only notable exception being Thomas Hobbes), matter was held to be inherently active.

Judging from the work of the leading Epicurean philosopher in England, Walter Charleton, and the work of the thinker who came closest to being a follower of Descartes, Henry Power, we can see that after the atomist revival there was a clear shift from earlier speculations about immaterial effluvia to material effluvia. At this time, English thinkers were conscious of the Cartesian boast of having dismissed incomprehensible occult phenomena from natural philosophy. English thinkers did not embrace Cartesianism without question, and seemed for the most part to regard

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[101] Power, *Experimental Philosophy*, The Preface, sig. b3*v*.
[102] Ibid., The Preface, sig. c*r*.

Descartes's claims about what completely passive and inert matter was capable of doing as unpersuasive and indeed unworkable. Nevertheless, they followed Cartesian fashion to the extent of trying to exclude the use of overtly magical or occult assumptions in their natural philosophies. Immaterial influence from matter suggested matter could operate at a distance, and so English thinkers simply substituted incessant streams of material particles emanating from bodies for earlier ideas of immaterial rays. Although this new effluvial physics looked much more compatible with the mechanical philosophy, it would hardly have satisfied a strict Cartesian. If bodies were held to send forth effluvia incessantly, without any suggestion of re-circulation, then those bodies had to be inherently active. But Descartes himself had introduced God into his system to account for the motions of bodies and the transference of motions in collisions, so it was an easy matter for English thinkers to follow suit and to justify their inherently active matter on the grounds that "the supreme Being (who is Activity it self) never made any thing inactive or utterly devoid of Motion", or similar metaphysical claims.

Even so, the difference between the Cartesian mechanical philosophy and English experimental philosophies was very marked. Descartes only resorted to an effluvial account in the extremely difficult case of magnetism—a phenomenon which seemed so undeniably occult that Descartes had to develop a special (and complicated) explanation to remove it from the realm of the occult. Accordingly, he spent 51 numbered sections in Part IV of the *Principia* dealing with this one topic; no other single topic required such a detailed and extended treatment.[103] By contrast, English thinkers, who generally accepted the Baconian premise that occult phenomena could be readily accepted provided that they could be demonstrated by experiment, had no difficulty extending the concept of active effluvia from magnets to many other, or

[103] Descartes, *Principia Philosophiae*, Part IV, §§ 133–87, 242–72.

even all, bodies. These effluvia were *active*, as opposed to being merely passive transmitters of mechanical pulses, because they were held to carry with them the qualities of the bodies from which they are emitted—they have the physical and chemical characteristics, and other qualities, of the emitting bodies, and can do what the bodies themselves can do. Furthermore, English thinkers all wrote of effluvia as constantly moving streams of particles, without offering any explanation about what processes emitted them, or kept them moving. On both counts, their qualities and their unexplained motions, they were far from conforming to Cartesian principles.

In case it is objected that we have so far only been considering second-rank thinkers, to make this claim, we will now show that the claims made here are substantiated even more clearly if we consider one of the leading natural philosophers in England, Robert Boyle.

Robert Boyle and Effluvia

Although once regarded as the leading mechanical philosopher in England, Robert Boyle has recently been re-assessed as the leading experimental philosopher, in the Baconian mould, and therefore as one who frequently accepted non-mechanical, and even occult phenomena and processes.[104] John Henry has shown that Boyle's "cosmical qualities" are not mechanical; while Antonio Clericuzio and Joel Shackelford have pointed to the prevalence of "seminal principles" in Boyle's matter theory.[105] This non-mechanistic Boyle is revealed also in his extensive thinking about effluvia. Essentially, for Boyle, magnetic effluvia are simply one prominent example of the kinds of effluvia that are supposed to be emitted radially by most, if not all, bodies. In what follows, we will begin with Boyle's various discussions of

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[104] On Boyle as a mechanical philosopher, see Marie Boas Hall, *Robert Boyle and Seventeenth Century Chemistry* (Cambridge, 1958).

[105] John Henry, "Boyle and Cosmical Qualities," in *Robert Boyle Reconsidered*, ed. Michael Hunter (Cambridge, 1994), 119–38; Clericuzio, "A Redefinition"; Shackelford, "Seeds with a Mechanical Purpose".

magnetism, before going on to show that Boyle made such claims fairly general, and introduced effluvial explanations into many aspects of his natural philosophy. As he wrote in the Advertisement to his *Essays of Effluviums* of 1673, he regarded the doctrines "of *Effluvia*, of *Pores* and *Figures*, and of *Unheeded Motions*, as the three principal Keys to the Philosophy of Occult Qualities."[106]

We can see Boyle calling upon magnets as prime examples of bodies that operate by means of effluvia in his essay "Of the Great Efficacy of Effluviums". Here, the loadstone provides "an eminent Example of the great power of a multitude of invisible Effluviums". Boyle points out that,

> incomparably little Magnetical Effluxions proceeding from vigorous Loadstones, will be able to take up considerable quantities of so ponderous a Body as Iron; in so much that I have seen a Loadstone not very great, that would keep suspended a weight of Iron, that I could hardly lift up to it with one Arm; and I have seen a little one, with which I could take up above eighty times its weight. And these *Effluvia* do not only for a moment fasten the Iron to the Stone, but keep the Metal suspended as long as one pleases.[107]

In the essay "Of the Strange Subtilty of Effluviums", Boyle seeks to show that bodies can give off effluvia incessantly "without decrement of weight". As we saw earlier, he explained to his readers that he had deliberately refrained from using the example of the magnet precisely because the Cartesians have claimed it does not emit effluvia radially, but only by means of re-circulation of the same particles.[108] If the Cartesian account is correct, then it is hardly surprising that magnets do not lose weight.

Clearly Boyle thought the example of the magnet was likely to mislead readers into assuming he agreed with the Cartesian view. The fact that magnets do not lose any measurable weight suggests there here must be a continual vortex-like return of the particles. Although Boyle does not commit himself to a particular account of how the

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[106] Boyle, *Works*, vii: 229.
[107] Ibid, 266–67.
[108] Ibid, 248.

loadstone works, he certainly does not favour the Cartesian view. Indeed, Boyle seems to be more in favour of the non-mechanical suggestion that the Earth replenishes the lodestone with its own (the Earth's) "Magnetical matter". Before mentioning the Cartesian account, he talks about his own attempts to weigh lodestones, which have not "satisfied [him]". And he also throws in an undeveloped comment about lodestones not all being "equally diffusive of their Particles"—these distract the reader from the Cartesian account, which is only acknowledged as a partial explanation. Boyle avoids giving the impression that he favours the Cartesian account, and certainly does not endorse it.

When Boyle *does* use magnetism as an example of effluvial activity he is careful not to mention the Cartesian account:

> I shall only add here that most remarkable Proof, That some Emanations, even of solid Bodies, may be subtil enough to get through the pores, even of the closest Bodies; which is afforded us by the Effluvia of the Loadstone, which are by Magnetical Writers said to penetrate without resistance all kind of Bodies.[109]

In his "Of the Cause of Attraction by Suction", published in his *Tracts* of 1674, Boyle tried to claim that all cases of attraction are really accomplished by "pulsions". However, he admitted that magnets and electricals present a challenge to this claim. Even here, however, he does not simply resort to the Cartesian account. Pointing out that the Cartesians "have recourse on this occasion either to screwed Particles and other Magnetical Emissions", Boyle acknowledges that "according to such Hypotheses, one may say, that many of these Magnetical and Electrical Effluvia come behind some parts of the attracted Bodies", and therefore are pushing them from behind, rather than attracting them.[110] Continuing to be sceptical of Descartes's hypotheses, Boyle prefers to accept that magnets and electricals might actually attract by occult means:

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[109] Ibid, 244.
[110] Boyle, *Works*, viii: 204–05. Boyle means that the "screwed Particles" circulate around to the back of a nearby piece of iron and push it towards the magnet as they circulate back to it.

> But if there were none of these [screwed particles], nor any other subtil Agents that cause this Motion by a real, though unperceived, Pulsion; I should make a distinction betwixt other Attractions and these, which I should then stile *Attraction by Invisibles*. But, whether there be really any such in Nature, and why I scruple to admit things so hard to be conceived, may be elsewhere consider'd.[111]

When it comes to magnetic and electrical attraction, therefore, Boyle no longer seeks to explain it away as "pulsion", but calls it "Attraction by Invisibles".

It is clear in everything that Boyle writes about magnets that he considers them only to be special kinds of bodies that act on their surroundings by means of effluvia. In "Of the Determinate Nature of Effluviums", another essay in the *Essays of Effluviums* (1673), Boyle simply tells us "there are very many mixt Bodies, that emit Effluviums",

> which make, as it were, little Atmospheres about divers of them, it will be congruous to our Doctrine and Design, to add in this place, That … the Steams of Bodies may be almost as various as the Bodies themselves that emit them; and that therefore we ought not to look upon them barely under the general and confused notion of Smoak or Vapours, but may probably conceive them to have their distinct and determinate Natures, oftentimes (though not always) suitable to that of the Bodies from whence they proceed."[112]

In "Of the Strange Subtilty of Effluviums", Boyle proposed to handle the doctrine of effluviums "more largely", proposing to offer "some Considerations and experimental Collections about the Nature and power of Effluviums". It is clear from this that, just like other English thinkers, Boyle believed all bodies, including the hardest and solidest ones, could and did emit effluvia. In arguing for this, he provided some "remarkable Proof[s]".[113] Boyle contended that many phenomena, including especially occult phenomena, could be explained by the actions of (subtle material) effluvia, and that these effluvial explanations were far superior to Aristotelian or Cartesian explanations of the same phenomena. The effluvia, as conceived by Boyle, provided clear evidence of "the Minuteness of the Parts of Solid

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[111] Ibid, 205.
[112] Boyle, *Works*, vii: 275-6.
[113] Ibid, 244.

Bodies".[114] Boyle demonstrated this with two dramatic examples: ambergris, a substance found in the heads of sperm-whales, and used in perfumes, and asafoetida, a strong-smelling substance used in medicines. A piece of ambergris or asafoetida, Boyle pointed out to his readers, can emit a strong smell, filling a whole room, for several days, and yet neither the ambergris nor the asafoetida lose any appreciable weight (at least not a weight that can be detected using scales). Boyle argues that therefore the effluvial particles must be inconceivably tiny—since the source body emits them in large quantities to fill the room, and does so continually for days, and yet added all together, they make no appreciable weight.[115]

Boyle considers two sorts of objections to his argument here: from more magical thinkers on the one hand, and from mechanical philosophers on the other. An obvious heckle from more magical thinkers is that the constant weight of the ambergris or asafoetida shows it must work by *immaterial* means rather than material. Boyle had certainly been anticipating these questions from those "Chymists and Physicians". In his next step, accordingly, he hammered home that the effects he was talking about were by no means done by immaterial entities, and could not be used as evidence for the existence of immaterial entities. He resolutely insisted that the effects were done by extremely tiny and subtle material corpuscles. Interestingly, however, Boyle does not make his case by providing evidence, but simply by denying that the "Chymists" have any positive proof. Boyle simply insists that he would not believe in immaterial influence until "competent Relators" show by repeated trials that it could not be otherwise.[116]

When Boyle provides his own opinion as to how materials such as ambergris and asafoetida work, it is equally clear that he is not providing a Cartesian account.

[114] Ibid, 236.
[115] Ibid, 248.
[116] Ibid, 247.

Rejecting the claim that effluvia, like magnetical particles, always return to the magnet, Boyle writes:

> I doubt not but it will make it more probable, that a small Quantity of matter being scatter'd into invisible *Effluvia* may be exceedingly rarified and expanded, if it can be made appear, that this little portion of matter shall, for a considerable time, emit multitudes of visible parts …

The phrase "exceedingly rarified and expanded" suggests spreading out in a surrounding sphere of influence; this is not a Cartesian account. But, nor was it a magical account—at least not in Boyle's view as to what constituted magic. The operation of such materials is not by immaterial means, but by "substantial effluxion", and so is not magical, according to Boyle. And yet, Boyle does not ask how it is that the effluvia he discusses are, as he says, "endow'd with a stream-like motion".[117] The fact is, Boyle, unlike Descartes, simply accepted that matter could be, indeed was, inherently active. In the "Advertisment to the Reader" of the *Essays of Effluviums*, Boyle wrote of "the Affinity betwixt the preceding Doctrine about *Effluviums* in general, and Experiments that shew in particular the Subtilty and the Efficacy of those of Fire and Flame."[118] Clearly, Boyle wanted to imply that effluvia were as inherently active as fire was held to be in the Aristotelian system.

Based on these inherent motions of effluvia, Boyle thinks one body could then act upon another, and give rise to several phenomena. As he told us thereafter, "there are *at least* six ways, by which the Effluviums of a Body may notably operate upon another", for example, by "their penetrating and pervading nature", by "the motions of one part upon another, that they excite or occasion in the Body they work upon according to its Structure", or, by "the Fitness and Power they have to make themselves be assisted, in their Working, by the more Catholick Agents of the Universe."[119]

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[117] Ibid., 248.
[118] Ibid., 230.
[119] Ibid., 258. On the last point, expounded more fully 270–71, see Henry, "Boyle and Cosmical Qualities."

Given that Boyle has declared effluvia to be one of the "principal Keys to the Philosophy of Occult Qualities", it is hardly surprising that he should call upon effluvia to explain the effects of classical occult creatures, the torpedo and the tarantula, and the rapid effects of epidemic plagues, which spread so quickly that it cannot operate as most diseases do, by corrupting the blood.[120] Similarly, "Amulets, and other solid substances applied by Physicians outwardly to our Bodies" are said to work by "subtle Emanations, that pass thorow the Pores of the Skin to the inward parts of the Body."[121] Boyle even wrote a work with the revealing title, *Notes &c. About the Atmospheres of Consistent Bodies (here below.) Shewing, That even Hard and Solid Bodies (and some such as one would scarce suspect) are capable of emitting Effluvia*… (1669), in which he wrote:

> there may be divers other ways… of discovering the *Effluvia* of solid Bodies, and consequently of shewing, that tis not safe to conclude, that because their Operation is not constant or manifest, such Bodies do never emit any *Effluvia* at all… And this I the rather desire that you would take notice of, because my chief (though not onely) design in these Notes is (you know) to illustrate the Doctrine of *occult Qualities*…[122]

Perhaps the best evidence for the lingering "occult" nature of Boyle's thinking about effluvia is to be found in his *Suspicions about Some Hidden Qualities of the Air* of 1674. Here we learn that these hidden (had he been writing some decades earlier, he might have written "occult") qualities derive from the fact that the air is made up of effluvia from many different bodies:

> I have often suspected, that there may be in the Air some yet more latent Qualities or Powers… principally due to the Substantial Parts or Ingredients, whereof it consists. And to this conjecture I have been led, partly… by considering the Constitution of that Air we live and breathe in… For this is not,

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[120] Boyle, *Works*, vii: 244, 251, 260. See, Brian P. Copenhaver, "A Tale of Two Fishes: Magical Objects in Natural History from Antiquity through the Scientific Revolution", *Journal of the History of Ideas* 52 (1991): 373–398; Copenhaver, *Magic in Western Culture*. On the supposed occult nature of pestilential diseases, see Henry and Forrester, *Jean Fernel's* On the Hidden Causes of Things.

[121] Boyle, *The Works of Robert Boyle*, vii: 271; see also vi: 178.

[122] This work was published with *A Continuation of New Experiments Physico-Mechanical Touching the Spring and Weight of the Air, and their Effects*, in 1669. Boyle, *Works*, vi: 177.

> as many imagine, a Simple and Elementary Body, but a confus'd Aggregate of Effluviums from such differing Bodies…[123]

Some of these effluviums are assumed to be "emitted from the Subterraneal parts of the Terrestrial Globe", and this allows Boyle to speculate about "fossils" even more mysterious than the loadstone:

> Now among this multitude and variety of Bodies, that lye buried out of our sight, who can tell but that there may be some… of a nature very differing from those we are hitherto familiarly acquainted with; and that, as divers wonderful and peculiar operations of the *Loadstone*… so there may be other Subterraneous Bodies, that are indowed with considerable powers, which to us are yet unknown, and would, if they were known, be found very differing from those of the *Fossiles* we are wont to deal with?[124]

Another source of effluvia may be the heavenly bodies:

> I also further consider, that… the Sun and Planets (to say nothing of the Fixt Stars) may have influences here below distinct from their Heat and Light. On which Supposition it seems not absurd to me to suspect, that the Subtil, but Corporeal, Emanations even of these Bodies may… reach to our Air, and mingle with those of our globe in that great receptacle or rendevouz of Celestial and Terrestrial Effluviums, the *Atmosphere.*

After all, Boyle points out, we are as ignorant of what minerals might be found on the planets and stars as we are of what might lie beneath the Earth:

> this great imperfection, I say, of our knowledge may keep it from being unreasonable to imagine, that some, if not many, of those Bodies and their effluxions may be of a nature quite differing from those we take notice of here about us, and consequently may operate after a very differing and peculiar manner.[125]

Imaginative speculations of this kind clearly show that Boyle was completely unaffected by Cartesian claims that all phenomena could be explained just in terms of the behaviour of matter, differentiated only by the size and shape of the particles into which it was formed, moving inertially. Clearly, Boyle allowed for bodies having unknown natures, and "consequently" operating in different and peculiar ways.

Boyle takes these speculations even further:

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123 Boyle, *Works*, viii: 121.
124 Ibid.
125 Ibid.

> we may be allow'd to consider, whether among the bodies we are acquainted with here below, there may not be found some, that may be *Receptacles*, if not also *Attractives*, of the Sydereal, and other exotic Effluviums that rove up and down in our Air.

He explains what he has in mind by referring again to magnetism, but also to the Philosophers' Stone:

> Some of the Mysterious Writers about the Philosophers-stone, speak great things of the excellency of what they call their Philosophical Magnet, which… attracts … the Universal Spirit, or (as some speak) the Spirit of the World.[126]

It is clear that Boyle is sympathetic to the claims of these "Mysterious Writers", and like them has no objection to the idea that some bodies may attract celestial influences and effluvia. It should be remembered that for a Baconian thinker such as Boyle, such speculations did not deviate from what was legitimate in natural philosophy. Provided we can test, or investigate, by experiment whether such influences exist, then

> one may discourse like a Naturalist about Magnets of Celestial and other Emanations, that appear not to have been consider'd, not to say, thought of, either by the Scholastic, or even the Mechanical, Philosophers.[127]

Boyle subscribed to the Baconian view that occult qualities were acceptable provided their existence and operations could be established experimentally. Indeed, Boyle was so committed to this view that he even used it to justify an open-minded approach to the possibility of new discoveries:

> Whether, as I think it no impossible thing, that Nature should make, so I think it no unpracticable or hopeless thing, that Men should find, or Art should prepare, useful Magnets of the exotic Effluviums of the lower region of the Earth, or the upper of the World …

Boyle seems to express here an optimism that we might discover the kind of "Philosophical Magnets" spoken of by "Mysterious Writers", and went on: "and therefore I would not discourage any curious or industrious Man from attempting to satisfie himself by Experiments, because even a seemingly slight discovery in a thing of this nature may be of no small use in the investigation of the nature of the Air."[128]

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[126] Ibid, 135–36.
[127] Ibid, 136.
[128] Ibid, 137. See also Ibid, 179: "it is not unlikely that there may be more and more Bodies (even of those that are solid and hard) found to emit *Effluvia*, as more and more wayes of discovering that they

Where Descartes wanted to dismissively exclude all occult effects, Boyle clearly accepted that there might be occult influences at work, and to discover what they are, even if they are only very slight effects, might prove to be useful. Boyle's experimentalism, just like Bacon's, was linked to a belief in occult influences.

From Magnetism to Newton's Effluvial Aether

We have seen that the phenomenon of magnetism, always accepted as the most striking example of occult influence, played an important role in seventeenth-century English natural philosophy by demonstrating, contrary to what Descartes took as his starting point, that matter could be, and in some cases certainly was, inherently active. We have seen that magnets, and their seemingly occult ability to act at a distance, either attracting or repelling other magnets, led Sir William Petty to develop a natural philosophy based on the assumption that the particles of bodies "either are impelled towards one another and cohere, or repel each other and fly apart." The quotation, of course, is from a draft of the Preface which Newton wrote for his *Principia* (1687), over a decade after Petty's *Hypothesis of Elastique Motions* (1674).[129] The ingenuity of Petty's *Hypothesis*, and its potential for producing a new kind of dynamic physics, is easily recognised from our post-Newtonian perspective, but this could not be seen when it first appeared in print. Some years before, Petty himself had dismissed Descartes's system as "figments" based on "Imaginary principles", so that it was nothing more than a "phantasmaticall seeming philosophy".[130] Perhaps Petty's own *Hypothesis* was dismissed in the same way by his contemporaries, in spite of Petty's claims that its principles could be established experimentally. Nevertheless, it should be seen, alongside the development of ideas on gravity which we looked at in Chapter 3, as further testimony to the richness and power of English magnetic

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do so, shall either by chance or industry be brought to light…"

[129] Isaac Newton, "Partial Draft of the Preface, MS. Add. 3965, fol. 620", in Newton, *Unpublished Scientific Papers*, 305. See also, Newton, *Principia*, 382–3; Petty, *Discourse*.

[130] William Petty, letter to Henry More, March 1648/9, reprinted in Webster, "Henry More and Descartes," 368.

philosophy. Furthermore, Newton owned a copy of Petty's *Discourse made before the Royal Society*, and so might well have used it in developing his own ideas about attractive and repulsive forces operating between atoms. Unfortunately, Newton's copy is now lost, and so we cannot know whether he read it avidly, or not.[131]

If Petty's magnetic atomism led nowhere, magnetism featured more generally in other thinkers' attempts to develop new natural philosophies. In particular the study of magnetism was bound up with wider thinking about the role of effluvia in the new systems of philosophy. Material effluvia were seen as a way of avoiding the actions at a distance, which were prevalent in Renaissance attempts to develop alternatives to scholastic Aristotelianism, and which tended to rely on immaterial influences. Although effluvia were presented by English thinkers as a way of avoiding recourse to action at a distance, the idea that all bodies, like magnets, were continually and incessantly "exhaling" streams of material particles was entirely dependent on the assumption that matter must be inherently active. Using the magnet as an example of a body that was generally believed to operate by means of effluvia, Boyle pointed out that magnets were hard and compact bodies, not volatile bodies like wines or perfumes.[132] Similarly, Boyle uses diamonds as another example: "though Diamonds be confest to be the hardest Bodies that are yet known in the world, yet frequent Experience has assur'd me, that even These, whether raw or polish'd, are very manifestly… Electrical." And, for "all the Corpuscularians… all Electrical Bodies, which, as I have already noted, must according to their Doctrine be acknowledged to operate by substantial Emanations", and so diamonds must emit effluvia.[133] If loadstones and diamonds could emit effluvia, then all bodies might be capable of emitting effluvia, and this was the line that Boyle, Charleton, Power, and others took. Browne was right to declare the powerfulness of the new "doctrine of

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[131] John Harrison, *The Library of Isaac Newton* (Cambridge, 1978), Item 1292, 215.
[132] Boyle, *Works*, vii: 244.
[133] Ibid, 172–73; and "Of the Atmospheres of Consistent Bodies", in *Works*, vi: 172.

effluxions, their penetrating natures, their invisible paths, and insuspected effects, … which invisibly act their parts at any time, and, perhaps, through any medium."[134]

We have seen that Boyle, in his *Suspicions about Some Hidden Qualities of the Air*, of 1674, wrote of atmospheric air as largely made up of various effluvia. The "Air we live and breathe in", he wrote, "is not, as many imagine, a Simple and Elementary Body, but a confus'd Aggregate of Effluviums from such differing Bodies…"[135] The following year, Newton sent "An Hypothesis explaining the Properties of Light, discoursed of in my several Papers" to Henry Oldenburg, so that it could be read out at a meeting of the Royal Society.[136] Here, we can see that Newton was also influenced by the new "doctrine of effluxions". At this early stage in his career, Newton evidently looked to an all pervasive aether to explain many of the phenomena of nature, but this aether was itself closely related to the air; it was, he wrote, "much of the same constitution with air". He went on:

> But it is not to be supposed that this medium [the aether] is one uniform matter, but compounded, partly of the main phlegmatic body of the aether, partly of other various aetherial spirits, much after the manner that air is compounded of the phlegmatic body of air intermixed with various vapours and exhalations: for the electric and magnetic effluvia, and gravitating principle, seem to argue such variety. Perhaps the whole frame of nature may be nothing but various contextures of some certain aethereal spirits, or vapours, condensed as it were by precipitation, much after the manner, that vapours are condensed into water, or exhalations into grosser substances, though not so easily condensable; and after condensation wrought into various forms…. Thus may all things be originated from aether…[137]

We will come back to this paragraph later. But it is important to point out here that in the "Vegetation of Metals" of 1672, Newton clearly held the idea that the aether is "just a homogeneous body". By the time he came to write the "Hypothesis… of Light" of 1675, however, he seems to have changed his mind, and then insisted that

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[134] Browne, *Pseudodoxia Epidemica*, Book II, Chapter 2, 88.
[135] Boyle, *Works*, viii: 121.
[136] Newton, "An Hypothesis explaining the Properties of Light" (1675), reprinted in Newton, *Papers & Letters on Natural Philosophy*, which is cited in following notes.
[137] Newton, "Hypothesis… of Light", 179–80.

the aether "is not just a homogeneous body". It is my contention that Newton's aether in the "Hypothesis" of 1675 might have partially derived from his readings in Boyle's research into effluvia during 1673 to 1674 – a possible non-alchemical origin for the concept of aether as it was presented in the "Hypothesis… of Light".

Let us start from Newton's alchemical aether of 1672 (as scholars have dubbed this, to distinguish it from the force aether, developed much later in the *Opticks*).[138] In the "Vegetation of Metals", the whole of nature was described by Newton as a kingdom of vegetables and metals, a circulating and animistic system. This earth, according to Newton, therefore, "resembles a great animall or rather inanimate vegetable, draws in aethereall breath for its dayly refreshment & vitall ferment & transpires again with gross exhalations". It is important to note, moreover, that these exhalations seem to pre-exist the bodies they are subsequently associated with. The *homogeneous* aether exists first, and is then condensed into "grosser substances".

> And according to the condition of all other things living ought to have its times of beginning youth old age & perishing. This is the subtil spirit which searches the most hiden recesses of all grosser matter which enters their smallest pores & divides them more subtly then any other materiall power what ever. (not after the way of common menstruums by rending them violently assunder etc) this is Natures universall agent, her secret fire, the onely ferment & principle of all vegetation.[139]

Having said this, Newton continued that the "materiall soule of all matter which being constantly inspired from above pervades & concretes with it into one form", could be activated or "incited" by a gentle heat, so was probably composed of or the same as light. "A great part if not all the moles [i.e. mass] of sensible matter is nothing but", he said,

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[138] See Ernan McMullin, *Newton on Matter and Activity*; Richard Westfall, *Force in Newton's Physics*; McGuire, "Force, Active Principles, and Newton's Invisible Realm"; Newman, *Newton the Alchemist*, chapters 7 and 8.

[139] Newton, "Of Natures obvious laws & processes in vegetation". An edited text is now available at the *Chymistry of Isaac Newton* website: http://webapp1.dlib.indiana.edu/newton/mss/dipl/ALCH00081/. See, fol. 3*v*.

> Aether congealed & interwoven into various textures whose life depends on that part of it which is in a middl state, not wholy distinct & lose from it like the Aether in which it swims as in a fluid nor wholly joyned & compacted together with it under one forme but in som degree condensed united to it & yet remaining of a much more rare tender & subtile disposition & so this seems to bee the principle of its acting to resolve the body & bee mutually condensed by it & so mix under one form being of one root & grow together till the compositum attain the same state which the body had before solution.[140]

And then Newton provided his understanding of aether thereafter that "the aether is but a vehicle to some more active spirit", and this spirit [aether] is perhaps the body of light, because firstly both light and aether "have a prodigious active principle both are perpetuall workers"; secondly "all things may be made to emit light by heat", and thirdly "the same cause (heat) banishes also the vitall principle". In short, the aether as a vehicle is a pure spirit.

As we have shown, it is not difficult to conclude that for Newton the alchemical aether is clearly an active substance or "one uniform matter", which is held to constitute the "more grosser" matter, and then the "whole frame of nature" – at least there is no evidence to show that it was not a uniform matter. Moreover, since it is "a prodigious active principle", and is a "perpetuall worker", it is evident that Newton held it to be inherently active.

Now let us come back to the paragraph on the aether from the "Hypothesis… of Light", which we have already quoted above.[141] Newton starts off talking about this later aether, saying it is like the air and is not just a homogeneous body, but is intermixed with other things, and indeed is a thoroughly heterogeneous body. So, both the proposed aether and the air are said to include "various vapours and exhalations", and Newton explicitly gives examples of electrical and magnetic

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140 Ibid, ff. 3*v*–4*r*.
141 Quoted at note 137 above.

effluvia. So here he was not simply repeating what he had said three years before in the "Vegetation of Metals", but he was bringing in effluvia as part of the constitution of the aether. Furthermore, Newton does not stop here to explain where these exhalations come from. He is obviously taking for granted that the fellows of the Royal Society will be familiar with earlier work in which the existence of effluvia has already been established: things spontaneously give off effluvia, and these are always mixed in with the air, or with the aether. It is important to note, moreover, that these vapours and exhalations seem to pre-exist the bodies they are subsequently associated with. This time the *heterogeneous* aether (rather than a *homogeneous* one) exists first, and is then condensed into "grosser substances". Newton's scheme seems to suggest, therefore, that when bodies are condensed out of the aether, they maintain a tendency to return back to aether, and continually give off the vapours or exhalations that originally went into their making. This picture is a long way from Cartesian mechanicism, but it is rather close to Boyle's, Charleton's, and Power's, accounts of all bodies continually emitting out of themselves incessant and always active effluvia. Evidently Newton believes that effluvia are so common in nature that they constitute a significant part of the air and of the aether, and he seems to associate them with activity in matter. As he writes at the beginning of the following paragraph: "at least, the elastic effluvia seem to instruct us, that there is something of an aethereal nature condensed in bodies."[142]

It is interesting to note that in the following paragraph Newton described an experiment to demonstrate effluvial attraction, but subsequently several fellows of the Royal Society failed to reproduce the results however hard they tried. The experiment was simple. Newton kept rubbing a circular piece of glass set in a brass ring, until tiny bits of paper left under the glass "began to be attracted and move

[142] Newton, "Hypothesis", 180.

nimbly to and fro". And "the papers would continue a pretty while in various motions; sometimes leaping up to the glass and resting there a while; then leaping down and resting there", even after Newton had stopped the rubbing. Apparently, "these odd motions", Newton wrote, were caused by some "subtle matter" constituting "aethereal wind" in the glass. Newton might have taken this from Boyle's research into effluvia as well. When Boyle mentioned in *Tracts ... by the Honourable Robert Boyle* (1674) that he has "in certain cases been able to make some bodies, not all of them Electrical, attract (as they speak) without being excited by rubbing, &c. far less light bodies, than the Effluviums we are speaking of", he was referring to experiments he did as early as 1669 in *Notes &c. about the Atmospheres of Consistent Bodies*, in which he had just started research into effluvia and hoped to prove "that Glass does attract light Bodies", even without rubbing the glass. It is possible that Newton's experiment might have been inspired by Boyle's attempts to show electrical activity without rubbing.[143]

It seems, therefore, that this important aspect of Newton's early natural philosophizing derived in part from the earlier speculations of writers who were known to be major influences on his thought (he knew Charleton's and Boyle's work well). Later in his career, however, as we shall see, Newton moved away from the notion that distant effects were brought about by invisible but material effluvia, and directly embraced a belief in action at a distance. His later philosophy, from the *Principia* onwards, was closer to that adumbrated (admittedly only vaguely) by Sir William Petty, in his *Hypothesis of Elastique Motions*. As R. S. Westfall pointed out in his biography of Newton, by 1686–87, "Newton applied action at a distance to virtually all the phenomena of nature."[144] After that switch in his thinking, therefore,

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[143] See Sir David Brewster, *Memoirs of the Life, Writings, and Discoveries of Sir Isaac Newton*, 2 vols (Edinburgh: Constable, 1855), 393.
[144] Westfall, *Never at Rest*, 388.

we would not expect to see any accounts in Newton's work based on active effluvia. As we shall see in the next chapter, this does indeed seem to be the case.[145]

Conclusion

Continuing with the focus on magnetism, this chapter looked first of all at a remarkable variation on the theme of magnetic cosmology, the speculative system of atomic magnetism only briefly developed by Sir William Petty. Petty's "New Hypothesis of Springing or Elastique Motions" ingeniously suggested that many problems of corpuscular philosophy could be solved by assuming that the corpuscles were tiny spherical magnets. Petty wrote explicitly of the spontaneous "Copernican" movements which his magnetic atoms were capable of, but remained silent about their ability to act at a distance, but as this chapter has suggested, this ability must have been assumed by Petty, and was defended on empiricist grounds. Unfortunately, Petty's "Hypothesis" seems to have had little impact, although it was owned by Newton, and may well have entered Newton's consciousness. But another aspect of magnetic speculation seems to have been taken up much more widely. This was the view, inspired partly by earlier theories and reinforced by Cartesian speculations that magnets operated by means of effluvia—streams of invisibly small particles continually emitted by the magnet and interacting with surrounding magnets or pieces of iron. This in turn led to more extensive theorising in which it was assumed that all bodies emitted effluvia of different kinds, and that it was by means of effluvia that bodies interacted with one another (this can be seen as a materialist equivalent of Lindberg's view (chapter 1) "that every creature in the universe is a source of radiation and the universe a vast network of forces"—but what radiates are material particles and they create a vast network of effluvia rather than of immaterial

[145] There are a few mentions of effluvia in the *Opticks:* Newton, *Opticks*, Book II, Part III, 267; Book III, Part I, Query 8, 341; Book III, Part I, Query 22, 353. But these are merely routine mentions of magnetic and electrical effluvia.

forces.[146] Another important aim of this part of the chapter was to show that although effluvial accounts explain all things in terms of "matter in motion", they do not conform to the mechanical philosophy because no explanation is given for how bodies continually emit effluvia.

The first section "Sir William Petty's Atomic Magnetism" introduced the reader to Petty's hypothesis about atom-sized magnets, and its links to Gilbert's and Bacon's earlier theories, and how he intended it to solve all the problems of elasticity, hardness and softness, fluidity, fermentation, and so forth. The following section, "Petty's 'Elastique Motion' and Baconian Experimentalism" looked more closely at the phenomenon of "elasticity"—what was meant by it, why it was seen as so problematic, and how Petty hoped to solve it. Given that elasticity involved what Sir Matthew Hale called "a free natural expansion of itself [i.e. of the air]", it seemed to involve repulsive forces capable of acting at a distance. Although Petty did not explicitly mention actions at a distance, he did take the trouble to offer a defence of such occult notions in his "Hypothesis" based on Baconian principles. Petty, like Bacon, refused to offer causal explanations, but insisted that his claims could nevertheless be tested upon empirical grounds, in just the same way that Gilbert demonstrated his claims about magnets by empirical means. Petty suggested that experiments on hand-sized spherical magnets could be used to test his claims about the behaviour of his atomic magnets—even though in neither case could causes be offered, since magnetism was thoroughly occult.

The following section then switched to an account of magnetism based on pre-Gilbertian assumptions—involving the belief that magnets continually sent forth effluvia: streams of particles. Although the theories of Descartes were included in

[146] Lindberg, "Genesis", 13.

this survey (beginning with Lucretius), the section brought out an important difference between effluvial theories as they were developed in early modern England and Cartesian theory. Descartes emphasised the circulatory nature of magnetic effluvia—leaving one pole of the magnet and returning at the other pole—in conformity with his vortex theories. It was pointed out here, however, that English thinkers did not talk in terms of circulation but merely of continually radiating outward streams of effluvia. This was inherently more occult than the Cartesian explanation because no mechanical account was provided as to why or how particles are continually emitted from magnets. Using the examples of Charleton and Henry Power (chosen because he was the closest to a Cartesian sympathiser in England) the next section, "Active Effluvia in England after the Atomist Revival", substantiated the claim made in the previous section that English thinkers thought of continually radiating effluvia, not circulating effluvia. This section also showed that these two thinkers, standing representative of others, extended their theory of magnetic effluvia and claimed that all bodies emitted effluvia. Again, this was completely incompatible with Cartesian views, as was also shown in this section.

In case it is objected that Charleton and Power were minor thinkers, and not very significant historically, the following section then examined Boyle's views in detail. Again it was shown that Boyle's effluvial theory of magnetism provided no mechanical account of how and why magnets emit particles. Furthermore, it was also shown that Boyle too developed the idea that not just magnets but *all* bodies give off their own characteristic effluvia, by which they interact with other bodies. The section showed that Boyle's speculations were highly occult and do not in the least conform to Cartesian mechanistic principles.

The similarities between Petty's magnetic atoms and Newton's assumption in the *Principia* that all phenomena might be explained by particles capable of attracting or repelling other particles was brought out here. Similarly, Boyle's speculations, published in 1674, about the atmosphere being made up of a mixture of various effluvia from the Earth and lesser bodies were shown to be similar to Newton's speculation in his "Hypothesis… of Light" that there is an all-pervasive aether made up of various "vapours and exhalations", including "electric and magnetic effluvia". This early aether theory of Newton's has long been recognised to be markedly occult and has been linked to his alchemy, but it was here shown that the aether presented in the "Hypothesis… of Light" was significantly different from the aether presented just a few years before in Newton's alchemical essay known to scholars as the "Vegetation of Metals". It was concluded, therefore, that Newton's theory of the aether as presented in the "Hypothesis… of Light" was influenced by Boyle's speculations, published the previous year, about the composite nature of the atmosphere. As we will see in Chapter 5, this aether of 1675 would not survive into Newton's mature philosophy, but would be replaced by an aether in which the particles of the aether repelled each other, and repelled particles of other matter. It can be seen, however, that both aethers were essentially occult. The aether of 1675, derived, at least in part, from earlier speculations about material effluvia, emitted by all bodies, which grew out of attempts to explain the occult behaviour of magnets.

Part III: Matter

We have seen that the magnetic philosophy, and other studies of magnetism in seventeenth-century England, led to speculations that matter might be inherently active. This marked out English matter theory (with the exception of the matter theory developed by Thomas Hobbes) as distinctly different from the matter theory developed by René Descartes which was dominant in the rest of Europe. For Descartes, matter was completely passive and inert, and could not be said to have virtues, or powers, and the only forces allowed to bodies were forces of impact—resulting from their motions. The only activity allowed to matter, or to bodies, was motion. Bodies were movable, and if put into motion were incapable (because of their inert nature) of changing their own movements, and would therefore continue to move in the same way until something changed their direction, or speed, or simply stopped them. The only things that could make these changes to a moving body, were other bodies, themselves either moving or stationary. As we shall see in the two chapters in this section, such an austere view of bodies was never accepted by the major natural philosophers in England. Instead, the leading English natural philosophers speculated about various kinds of activity in bodies, and in the matter that constituted those bodies.

In the first chapter, we show that the emission of effluvia from bodies that we looked at in the last chapter, was not the only kind of activity in matter. After considering active matter in general and how it appeared in English natural philosophy, we focus in particular on the idea that matter can be incessantly vibrating. This in turn leads us to consider the related notion of a vibrating material aether; how it first appeared in English philosophy, and how it was taken up by Isaac Newton.

In the second chapter, we focus on the interrelated phenomena of condensation and rarefaction, and show how these too led to speculations about activity in matter. Beginning with a survey showing that condensation and rarefaction were problematic even from Ancient times, we show that it was particularly problematic for the mechanical philosophy, and in England at least, led to speculations about matter that could not be incorporated into Cartesian mechanical philosophy, but were implicitly occult. Again, we will show how these speculations reached their culmination in the work of Isaac Newton.

Chapter 5: From Active Matter to Active Aethers: Boyle, Hooke, and Newton

Introduction

This chapter is intended to reveal two important aspects of the natural philosophical speculations which provided the English background to Newton's own emerging natural philosophy. In the last chapter we saw that in seventeenth-century English natural philosophy bodies were more often than not regarded as perpetual sources of streams of material effluvia, and by reason of these effluvia all bodies could be said to be at the centre of their own spheres of activity. In this chapter the aim is to show, firstly, that the emission of effluvia was not the only activity attributed to bodies by English thinkers at this time. Although it would be possible to demonstrate this by surveying the writings of several natural philosophers, we will focus here simply on the two leading natural philosophers in England before Newton burst on to the scene, Robert Boyle and Robert Hooke.[1] We will begin by looking at various ways in which active matter appears in Boyle's writing, before focussing on a particular kind of activity in matter—incessant vibration. Having shown that this is an important aspect of Boyle's attempts to explain various natural phenomena, we will then turn to Robert Hooke, for whom vibrating matter seems to have been seen as a particularly fruitful way of considering problems in natural philosophy.

A second aim of this chapter is to show how the concept of vibrating matter led, first of all in Hooke's work and subsequently in the thought of Isaac Newton, to a concept of an all pervasive vibrating aether. It will be shown that Hooke's concept of a vibrating aether played a crucial role in the speculations about an aether which appeared briefly in Newton's work. Firstly, at the beginning of Newton's career, in the "Hypothesis of Light" of 1675, and also briefly towards the end of his career,

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1 For indications of active matter in a wider sample of English natural philosophers, see Henry, "Occult Qualities".

when he introduced the so-called "Aether Queries" into the 1717 edition of the *Opticks*.

For most of his career, there was no such thing as a Newtonian aether. By the second half of the seventeenth century the idea of an aether had become associated with the plenist natural philosophy and vortex physics of Descartes. Newton's *Principia* was devoted to establishing an alternative physics based on the assumption of an absolute void space and the operation of forces acting at a distance between bodies scattered through that space. In pursuit of this, Newton demonstrated in the *Principia* that, far from carrying the planets around in their orbits, a dense aether of the kind supposed by Descartes could not sustain its own circulatory motions and would act merely as a drag on the planetary motions.[2] There is no Newtonian aether, therefore, in the *Principia*, or in the first edition of the *Opticks* (1704), and the *Optice* (1706). Remarkably, however, Newton introduced an aether into his physics in a set of eight new queries, often referred to by scholars as the "Aether Queries", which he added to the second English edition of the *Opticks* in 1717. But his speculations here were not entirely new. The aether queries drew upon earlier ideas about an aether which he had developed in his "Hypothesis explaining the Properties of Light", which was read at meetings of the Royal Society in 1675.

The "Hypothesis" was never published and was known only to the fellows of the Society who were present when it was read, or who took the trouble to read it in the Society's archives. Indeed, Newton himself wrote in 1716, when drafting what soon appeared in the aether queries, that "Above forty years ago I sent the following Observation to Mr. Oldenburg & have now transcribed it out of one of the Books of the Royal Society".[3] Accordingly, the aether queries in the 1717 *Opticks* mark the

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2 I. Bernard Cohen, "A Guide to Newton's *Principia*," in *The Principia: Mathematical Principles of Natural Philosophy*, trans. I. Bernard Cohen, and Anne Whitman (Berkeley, 1999), 187–88.

3 Cambridge University Library, Add. 3970, No. 9, fol. 626*v*. Available online from the University of

first appearance in print of a Newtonian aether. Given that my interest here is in showing the occult, unexplained, or non-mechanical, background to Newton's work, it is important for me to consider the aether as it appears in the *Opticks*, because this has often been seen as a purely *mechanical* aether, and therefore a feature of Newton's philosophy which supposedly restores his credentials as a good mechanical philosopher.[4]

By contrast, I would have no difficulty in establishing the occult nature of the earlier aether, as proposed in the "Hypothesis… of Light". As has been shown by R. S. Westfall, Betty Jo Dobbs, and others, the "Hypothesis" owes much to one of the few alchemical works actually composed by Newton, and known by its incipit as "Of Natures obvious laws & processes in vegetation" (*c*. 1672).[5] This is an occult active aether if ever there was one:

> And thus perhaps a great part if not all the moles [*i.e.* mass] of sensible matter is nothing but Aether congealed & interwoven into various textures whose life depends on that part of it which is in a middl state…

And reappears a few years later in the "Hypothesis":

> Perhaps the whole frame of nature may be nothing but various contextures of some certain aetherial spirits, or vapours, condensed as it were by precipitation,… and after condensation wrought into various forms…[6]

This occult "alchemical aether" was nowhere to be found in Newton's mature natural philosophy from the *Principia* onwards. Although the aether that did finally appear

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Cambridge Digital Library, http://cudl.lib.cam.ac.uk/view/MS-ADD-03970/1272

4 For example, Edmund Taylor Whittaker, *A History of the Theories of Aether and Electricity: The Classical Theories* (London, 1951); I. Bernard Cohen, *Franklin and Newton: An Inquiry into Speculative Newtonian Experimental Science and Franklin's Work in Electricity as an Example Thereof.* (Philadelphia, 1956), especially the section headed "Newton's Grand Hypothesis on the Aether," 166-172; Hall and Knight, *Isaac Newton*, 255–6; Andrew Janiak, *Newton as Philosopher* (Cambridge, 2008), 78–9.

5 Sometimes referred to by scholars as "The Vegetation of Metals", an edited text is now available at the *Chymistry of Isaac Newton* website: http://webapp1.dlib.indiana.edu/newton/mss/dipl/ALCH00081/. See, Westfall, "Newton and the Hermetic Tradition"; Dobbs, *The Janus Faces of Genius*.

6 The Dibner Library of the History of Science and Technology, Smithsonian Institution Libraries, Smithsonian Institution, Dibner Collection MS. 1031 B, fol. 3*v* [online at http://webapp1.dlib.indiana.edu/newton/mss/norm/ALCH00081/]; Newton, *Papers and Letters*, 180.

in 1717 drew on the "Hypothesis" of 1675, as we will see, the source of these aspects of the earlier aether was not alchemy, but the supposedly mechanical philosophy of Robert Hooke. But to properly understand Hooke's aether, and to be able to assess whether it really should count as "mechanical", or whether it in fact incorporates many unexplained principles of activity, we need to look first at the related work of his mentor, Robert Boyle.

Robert Boyle on the Activity Inherent in Matter

Robert Boyle used to be presented in the early historiography of science as the leading mechanical philosopher in England. His *Origin of Forms and Qualities* (1666), with its distinction between primary and secondary qualities, and its easy reliance on atomist explanations, at least did seem to support the view of him as a "modern" battling against hidebound Aristotelians. His *Sceptical Chymist* (1661), however, could only be presented as a modern rejection of *Paracelsian* and other alchemical ideas, as indeed it was presented, by emphasising Boyle's scepticism and ignoring his own alternative chymistry, which was every bit as alchemical as the Paraclesians and Helmontians he rebuked.[7] More recent assessments of Boyle's work, however, have dismissed these presentist approaches by showing that Boyle was in fact one of the leading alchemical philosophers in early modern England, and that as a result he embraced many chymical and related occult ideas.[8]

The main focus of these more historicist approaches to Boyle and his context has been on his alchemy, or chymistry, and the case has been made so well that it is

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[7] Robert Boyle, *The Origin of Forms and Qualities* (London, 1666); Robert Boyle, *The Sceptical Chymist* (London, 1661). From now on references to Boyle's works will be given from Boyle, *Works*. For Boyle as a thoroughly mechanical philosopher, see Hall, *Robert Boyle and Seventeenth Century Chemistry*; Marie Boas Hall, *The Mechanical Philosophy* (New York, 1981).

[8] Piyo Rattansi and Antonio Clericuzio, eds., *Alchemy and Chemistry in the 16th and 17th Centuries* (Dordrecht, 1994); Principe, *The Aspiring Adept*; Newman, *Atoms and Alchemy*. See also Michael Hunter, *Boyle: Between God and Science* (New Haven, 2009); Hiro Hirai and Hideyuki Yoshimoto, "Anatomizing the Sceptical Chymist: Robert Boyle and the Secret of His Early Sources on the Growth of Metals," *Early Science and Medicine* 10 (2005): 453–77.

hardly necessary to repeat it here. What I want to do in this chapter, therefore, is to focus on aspects of Boyle's work which should be categorised as natural philosophy, rather than the chemical work which would have been less familiar to most of his readers.[9] By looking at Boyle's natural philosophy, and showing that it too should not be regarded as strictly mechanical—the *Origin of Forms and Qualities* and other works notwithstanding—it is hoped that current non-mechanical assessments of Boyle will be reinforced. Furthermore, in keeping with our main theme, we hope to show that the non-mechanical and even occult aspects of Boyle's natural philosophy was another significant factor in making it possible for Newton to confidently propose the non-mechanical natural philosophy which he developed in his *Principia*, and in his *Opticks*.

We have already seen (Chapter 4) that Boyle developed a matter theory in which many, if not all, bodies continually emit effluvia; and that these effluvia were called upon by Boyle to explain various phenomena associated with those bodies—phenomena which Boyle held to be inexplicable without assuming the existence of active effluvia. Furthermore, we indicated that Boyle was far from consistent in explaining why or how bodies emitted effluvia, and why or how the effluvial bodies themselves continued to move. In the absence of an elaborate mechanical system of the kind developed by Descartes, Boyle only occasionally suggested that effluvia were knocked out of their emitting bodies by heat, light, or some other means. More often than not, bodies were simply held to be capable of spontaneously emitting effluvia, and the effluvia were regarded as inherently active and self-motive. Boyle's speculations on bodies as emitters of active effluvia were closer, therefore, to occult notions of the behaviour of bodies than to anything that

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9 Alchemy or chymistry was not an official part of the university curriculum and so would not have been known in any detail by Boyle's readers, but natural philosophy would be well understood by all university-educated men. See Phyllis Allen, "Scientific Studies in the English Universities of the Seventeenth Century", *Journal of the History of Ideas*, 10 (1949): 219–53.

might be considered acceptable in strictly mechanical philosophies. In this section I want to take things further, and show that active effluvia are not the whole story. Boyle also supposed—again to explain what he took to be otherwise mysterious or problematic effects—that even seemingly passive and inert bodies had in-built principles of motion and were either continually active, or perpetually ready to become active in the right physical circumstances.

We can see this, for example, in Boyle's *History of Fluidity* (1661). It was a standard assumption in the atomist, or corpuscularian philosophy that fluids, or liquids, differed so obviously from solids because their constituent particles were capable of moving freely relative to one another, while the particles of a solid were locked in their places. As Boyle wrote, "it conduces to the making of a Body fluid, that its smal parts be actually mov'd".[10] Any Cartesian would have thoroughly agreed with this, but we can see straight away that Boyle was not simply subscribing to the Cartesian account of fluidity. Boyle wants to know *why* the particles of a fluid are in motion—what makes the behaviour of the particles of a fluid so different from the behaviour of the particles of a solid? The full answer to this problem, Boyle writes, would involve him in "two or three of the difficultest as well as the importantest controversies belonging to natural philosophy", for example:

> whether motion, or a propensity to it, be an inherent quality belonging to atoms in general, and not losable by them; or whether all motion is communicated by impulse from one body to another.[11]

The Cartesians were committed, of course, to the latter explanation: there are no new motions in the Cartesian universe, so the motions of the particles of a fluid must be communicated to them by colliding with other moving particles. It is pretty clear, however, that Boyle does not want to commit himself to this mechanist view here. Similarly, he is not convinced by the view which he attributes to "most men"—that

[10] Boyle, *Works*, ii: 135.
[11] Ibid.

is to say to educated laymen—that "the motion produced in the parts of the fluid bodies there mentioned" is due "to the action of the fire"[12]. Boyle shows his lack of commitment to either of these two accounts by adding: "what it is, that puts the parts of fluid bodies in general into the motion requisite to make them such, is a question, of which the true resolution indeed were very desirable."[13]

A few pages later, Boyle describes an experiment on a seemingly quiescent liquor; that is to say, a liquor which does not seem to be subject to the kind of ebullition one might expect if Cartesian accounts of impulse from other particles was true, and which has not been subject to heat. The point of this experiment, he tells his readers, is "to shew by an ocular example, that there may be a quick and intestine motion in some parts of a liquor, notwithstanding that the unassisted eye can discern no such matter."[14] These "quick and intestine" motions seem to suggest that Boyle favours the view that the motions of the particles of a fluid demonstrate that the motions are, as he wrote earlier, "an inherent Quality belonging to Atoms in general, and not losable by them".[15] We can see similar suggestions about the incessant intestine motions within seemingly quiescent fluids in the *History of Firmness* (1661). In this treatise Boyle tries to explain the change from the solid to the fluid state, but clearly does not attribute it in all cases to the effect of heat. At one point, for example, he argues that the change of state could be illustrated,

> by shewing what the intestine motion of the parts, even without the assistance of adventitious heat, may do, to make a body change its consistence, according to the previous disposition of the matter, and become of firm, fluid;[16]

Boyle takes it for granted here that even a solid body has internal parts which are in motion; and he suggests that these "intestine motions" can break down the solid body

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[12] Ibid.
[13] Ibid.
[14] Boyle, *Works*, ii: 142.
[15] Ibid, 135.
[16] Ibid, 183.

into a liquid, and that we do not have to suppose this is caused by increased heat. Boyle makes the same claims some years later in his *Of Absolute Rest in Bodies* (1669), where he writes that "when Water and several other Liquors seem to be continued Masses of Matter, and to be as much at rest, as the very Glasses that contain them; their constituent Corpuscles are in an actual and various though slow and unperceived Motion."[17]

In his "Excursion about the Relative Nature of Physical Qualities" in *The Origin of Forms and Qualities*, Boyle writes of the motions of corpuscles altering the bodies they constitute: "if many or most of them [insensible Corpuscles] be put into Motion, from what cause soever the Motion proceeds, That it self may produce great Changes, and new Qualities in the Body they compose".[18] Boyle seems to identify the inherent motions (the intestine motions) here as simply an aspect of a body's nature. At one point, he simply declares motion to be one of the primary agents in making a body what it is:

> Local Motion hath, of all other affections of Matter, the greatest Interest in the Altering and Modifying of it, since it is not onely the Grand Agent or Efficient among Second Causes, but is also oftentimes one of the principal things that constitutes the Forme of Bodies.[19]

In fact, Boyle goes even further than this. In order to reinforce the view that all particles of bodies including "some of those Bodies which we think to have their parts most at Rest, are not exempted from having Intestine Motions in them"[20], he includes in his *Of Absolute Rest in Bodies* of 1669 "An Essay of the Intestine Motions of the Particles of Quiescent Solids Where the Absolute Rest of Bodies is called in Question".[21] Here Boyle reminds readers that, in the popular sense of the word, "rest" just means at rest as far as the senses can tell. Accordingly, some very firm bodies,

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17 Boyle, *Works*, vi: 196
18 Boyle, *Works*, v: 326.
19 Ibid, 327.
20 Boyle, *Works*, vi: 194.
21 Ibid, 191.

such as diamonds, etc., can owe their firmness to the extreme slowness of the inward motions of the particles. Boyle is taking for granted here that there are such inward motions within firm bodies, but he then promises to establish the truth of this by experiments in the following sections. He proposed, while making comparison to fluids, that "there may be likewise such a Motion in the minute parts of Silver and Iron themselves". His evidence for this is the fact that a piece of iron can be easily magnetised by passing a loadstone by it.[22]

Boyle also finds support for the intestine motions of solid bodies from Epicurean atomism:

> For the Epicureans supposing this World to be produced by the casual concourse of Atoms, and ascribing to every particular Atom an innate, and unlooseable mobility, or rather, an actual motion, or a restless endeavour after it; 'tis consonant to think, that though in Concretions, they so entangle one another… yet they do incessantly strive to disentangle themselves and get away: by which means there is always in the Atoms even of Solid Bodies, actual endeavours of each of the distinct Atoms to extricate it self from the rest… and in the mean while these perpetual and contrary endeavours produce intestine Commotions in the internal parts of the Body wherein these Atoms were imprison'd.[23]

Having said all this, Boyle ought to feel confident to conclude that "there is no such thing as absolute Rest in Nature".[24] This is too dogmatic for the mitigated scepticism of Boyle, however, and he finishes his essay on "Absolute Rest" in a typically doubtful way:

> I shall conclude as I began, and without resolutely denying that there can be any such thing *in rerum naturâ*, as absolute Rest, I shall content my self to say, That 'tis not either absurd to doubt whether there be or no; nor improbable to think that there is not, since we have not found it in those very Bodies, where with the greatest likelihood it might have been expected.[25]

In spite of Boyle's doubts, it is clear that he did indeed entertain the idea that the particles of even quiescent or unmoving bodies might be perpetually in motion; and

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[22] Ibid, 195, 196.
[23] Ibid, 194–95.
[24] Ibid, 210.
[25] Ibid, 210–11. On Boyle's "mitigated scepticism", see Henry G. Leeuwen, *The Problem of Certainty in English Thought 1630–1690* (Dordrecht, 1963); Richard Popkin, *The History of Scepticism : From Savonarola to Bayle* (Oxford, 2003).

that these motions were not assumed to be caused by "adventitious heat" or any other external impulse from other bodies.[26] What remains to be discussed, however, is the nature of these intestine motions. What kinds of motion did Boyle have in mind? We have seen him just above talking of "intestine Commotions" but elsewhere, he seems to have a more specific kind of motion in mind. There is a hint of this in Boyle's *An Examen of Mr T. Hobbes his Dialogus Physicus De Natura Aeris* (1662). At one point Boyle criticises Hobbes's explanation of fluidity and firmness, objecting to Hobbes's suggestion that the internal particles of a hard body might be free to move in exactly the same way that the particles of a fluid body are free to move. For Boyle the ability of the particles to move freely seems to be characteristic of liquids, while in solids the particles seem to be more constrained. However, he suggests here that the particles of a hard body at rest may be *vibrating* around a fixed point:

> For indeed the implicated parts of a firm body may be made to tremble, or a little vibrate as it were to and fro, as those of a sounding Bell do, or as in a Hedge the branches and twigs may be shaken by the wind, whilest the trees and bushes themselves continue rooted in the ground.[27]

The notion of vibrating matter will appear again in a significant way in the work of Boyle's erstwhile assistant, Robert Hooke, and will appear again in the later physics of Isaac Newton. It is important, therefore, to consider this aspect of Boyle's speculations more thoroughly.

Robert Boyle and Vibrating Matter

There are plenty of cases where Boyle discusses mechanical vibrations—usually the "vibrations" of pendulums (sometimes used for timing in experiments), or the vibrations of mercury or other fluids in U-tubes, or in barometers, when the mercury or fluid has been disturbed. These are not relevant here. Our concern is with supposed vibrations of the invisibly small corpuscles which were, according to Boyle,

[26] We saw earlier that intestine motions could change the state of a body from solid to liquid, "even without the assistance of adventitious heat". See at note 16 above (Boyle, *Works*, ii: 183).

[27] Boyle, *Works*, iii: 171–72.

the constituents of all bodies, that is to say with vibrations as a special kind of "intestine motions". Furthermore, if we wish to claim that these kinds of corpuscular vibrations establish our claim that Boyle believed in active matter, we must show that Boyle did not always conceive of such vibrations as merely initiated by physical impact or some other mechanical means.

We shall start by looking at "a Difficulty" Boyle confronted, in "An essay… Where the Absolute Rest of Bodies is Called in Question". The "Difficulty" Boyle mentioned originated from an experiment on the supposed intestine motions of Metallic Bodies. Long after a bell has been struck by its clapper, and its visible vibrations seem to have ceased, "it causes in the Air an odd kind of ringing, or if I may so call it, undulating Sound or Motion, which will sometimes last a considerable while", and "'twil not be without a shrilness". Boyle infers, therefore, that

> whilst to the Eye the Bell seems to be at Rest, yet the minute parts of it continue in a very brisk motion, without which they could not strike the air strongly and fast enough to make it produce so shrill a noise in the Ear.[28]

Regarding this as presenting a "perhaps more difficult" problem than he has faced so far, Boyle has a ready answer: perhaps the intestine motions he is talking about might not be directly *caused* by external agents (such as air or fire, or even the clapper of the bell) acting as efficient causes, but are merely "excited" by them:

> these Intestine Motions of the Corpuscles of hard Bodies, need not be solely, nor perhaps principally ascribed to those obvious external Agents, to which we are wont to refer them, since these may but excite or assist the more principal or internal Causes of the Motions we speak of…[29]

The external agents merely excite the corpuscles, which are then moved by *internal* causes.

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[28] Boyle, *Works*, vi: 196.

[29] Ibid, 196, 197. I take Boyle to be using the word "excite" here with its second meaning in the *OED*: "To rouse, awaken", especially meaning 2.c.: "To call forth or quicken (a faculty, feeling, etc.) from potential into actual existence; to rouse up, awaken (what is dormant, sluggish, or latent)." So, we are not talking of a mechanical transfer of motion, but a process of inciting a body to stir itself, or set itself in motion.

Boyle reconsidered the same question several years later in *An Essay of the Great Effects of Even Languid and Unheeded Motion* (1685). This time he describes how it is only necessary to "gently pass the point of a pin for a little way along the brim" of a hemisphere of Bell-metal, and that as a result "it [the hemisphere] would sensibly resound, and that (to a very attentive ear) so long". More importantly, as Boyle maintains,

> the parts, immediately touched (and not so much as scratched) by the point of a pin, were not onely put into *a vibrating motion themselves*, but were *enabled to communicate it to those that were next them*, and they to those that were contiguous to them, and so the tremulous motion was propagated quite round the bell, and made divers successive Circulations before it quite ceased to be audible.[30]

Boyle infers from this that

> we must grant in our Instances a wonderfull propagableness of motion, even when 'tis not violent, in Solid bodies themselves; since the point of a pin, gently striking a part, no bigger than it self, of a mass of very solid metal, could thereby communicate a sensible motion, and that several times circulated, to millions of parts equall to it in bulk, and much exceeding it in hardness.[31]

In other words, a small amount of motion applied externally only briefly, is sufficient to set the bell vibrating for a significant period of time. It is apparent that the implication here is not that Cartesian transference of motion is taking place, in which the in-put of motion must be equal with the out-put, but rather that the initial motion stimulates the particles of the bell to move themselves, *i.e.* to set themselves vibrating.

To strengthen his case in *Of Absolute Rest in Bodies*, Boyle later turns to diamonds. Given that these are generally believed to be the hardest material, and therefore to have the "closest and firmest Texture" of any body, Boyle suggests that "if we could shew an intestine motion even in the parts of these; fitter Instances for our purpose could not in reason be desired." Again, Boyle has a ready answer, based on experience:

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[30] Ibid, x: 268–69.
[31] Ibid, 269.

> In the first place then, to remove that prejudice that may be entertain'd from the incomparable hardness of Diamonds… as if Bodies so hard and solid could not have their parts put into motion but by some extraordinary, not to say, prodigious force; I shall only repeat here what I have elsewhere shewn, that Diamonds are Bodies that easily enough become actually Electrical, and that some Diamonds… will by rubbing upon a cloath be brought to shine in the dark… it may be thence argued, that a very moderate force may suffice to beget an internal motion in the inward Particles of Diamonds themselves.[32]

If Cartesian transference of motion were required to set the parts of such a hard body vibrating, we might expect it to involve "prodigious force". The fact that it can evidently be done by a few passes with a soft cloth, suggests that the external motion merely "begets" motion in the "inward Particles" themselves.[33]

In his *Languid and Unheeded Motion*, Boyle noted at one point that although we tend to think of cause and effect in terms of "one whole Body" driving away another, "or at least knock[ing] visibly against it", "many effects proceed from the intestine motions produced by the external Agent, in, and among, the parts of the same body." He offers as "proof" of this the familiar experience of setting a glass of water vibrating by rubbing a finger on the rim.[34] A little later Boyle displays a reluctance to attribute such vibrations in the corpuscles of bodies to "meer heat":

> I think it worth inquiry, whether in this case the whole work be performed by meer Heat, and whether there intervene not a peculiar kind of motion, into which some bodies are disposed to be put by a peculiar kind of friction, which seems fitted to produce in manifestly springy bodies, and perhaps in some others… such a vibrating or reciprocal motion, as may have some notable effects, that are not wont to be produced by moderate Heats, nor always by intense ones themselves.

Here we have a "peculiar kind of friction" which is "fitted to produce" peculiar kinds of motion, namely, "vibrating or reciprocal motion." Whatever this peculiar kind of friction might be, it does not seem to work by generating heat. Although Boyle does not develop the idea here, it seems likely that he was thinking once again in terms of

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32 Ibid, vi: 202–3.

33 Boyle's use of the concept of "begetting" here supports my earlier claim (see note 31 above) that Boyle's talk of "exciting" a body to motion should not be read in a mechanical way. To beget is to procreate—to give life to a new creature.

34 Boyle, *Works*, x: 287.

a friction which *excited* the "springy bodies" into self-sustained vibrating motions.[35] As he goes on to say: "That there may be a considerable Commotion produced among the internal parts of bodies, by rubbing them even against soft bodies, I have divers times observed."[36]

If Boyle's speculations about such phenomena are very different from Descartes's, they are not so far removed from those of Francis Bacon. Indeed, Boyle's belief in insensible vibrations in bodies seems very close to similar speculations by Bacon. In his *Historia Densi et Rari*, for example, Bacon suggests that iron and glass when heated, are not only dilated by a supposed "enclosed spirit", but they are also set vibrating. "We distinctly detect in them a certain invisible swelling or pulsation of the parts, although this is held back by their close compaction." He went on:

> For if you take a very hot glass and put it on a stone table or some such other hard body (the table or hard body having been well heated so that cold cannot be taken for the cause), the glass will in fact break because of the hardness of the table resisting this occult swelling of the glass."[37]

In a second example of insensible vibrations, Bacon says that after cannon balls have been fired and they have come to rest, "such that to all appearances they are totally motionless, we find that for a long time after they have a commotion or pulsation in their smallest parts". Similarly, in *Sylva Sylvarum*, Bacon suggests that a bell or a string when struck do not only visibly vibrate, but there is also "a trepidation wrought in the minutest parts". Accordingly,

> you must distinguish that there are two trepidations: the one manifest and local; as of the bell when it is pensile: the other secret, of the minute parts… But it is true, that the local helpeth the secret greatly.[38]

According to Guido Giglioni, "the motion of trepidation epitomizes the universal condition of material bodies" for Bacon, and ensures that matter is "always restless", and continually pulsating.[39]

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[35] Ibid, 289.
[36] Ibid, 290.
[37] Francis Bacon, *OFB XIII: The Instauratio Magna: Last Writings* (Oxford, 2000), 95.
[38] Francis Bacon, *Works*, ed. James Spedding, R. L. Ellis, and D. D. Heath (London: Longman, 1857-74), ii: 415–16.

Returning to Robert Boyle, we can see that he used similar speculations about inherently active matter in another work which received its "imprimatur" from the Royal Society in the same year (1669, although in fact the work was not published until 1671). In the Appendix, "Cosmical Suspicions", to his *Tracts about the Cosmical Qualities of Things*, Boyle speculated that "there may be… peculiar sorts of corpuscles that have yet no distinct name, which may discover peculiar faculties and ways of working."[40] The reference is vague and obscure, and yet it seems safe to say that whatever Boyle had in mind here would not come under any of the usual headings in the mechanical philosophy. Similarly, whatever Boyle had in mind when he wrote of a "peculiar kind of friction" capable of generating "a peculiar kind of motion", it could not have been merely mechanical.

It seems, then, that Boyle considered the possibility that the corpuscles of matter might achieve some of their physical effects by their vibrations—vibrations seen either as an aspect of their "innate and unlooseable mobility", or a "peculiar kind of motion" capable of being excited, even in the hardest bodies, by "peculiar" means. This does not look like the passive matter that is supposed in Cartesian philosophy. Furthermore, he entertained these ideas from the 1660s through to 1685. In the light of this it is perhaps worth reconsidering his early work, *New Experiments Physico-Mechanical, Touching the Spring of the Air and its Effects* (1660). This is usually seen as a clear example of Boyle working as a mechanical philosopher, as even the title seems to imply. Moreover, the "spring" of the air has usually appeared in the historiography as being concerned with "modern" ideas such as atmospheric pressure, and the discovery that air has weight (unlike in the scholastic view, where air has "levity" and naturally flies upwards). There is a case to be made, however, for

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[39] Giglioni, "Lists of Motions", 76.
[40] Ibid, 303. For a discussion of Boyle's cosmical qualities, see Henry, "Boyle and Cosmical Qualities."

the claim that Boyle's real concern is the fact that air particles have an "Elastic power", and that, accordingly, they continually try to separate themselves from whatever surrounds them, and to spread themselves out. Consider, for example, the fact that he writes of a "Spring, or Elastical power in the Air", which is manifested when particles of air, released from pressure, "stretch… out themselves".[41] It is easy, of course, to put an entirely mechanical gloss on this. Especially in view of the fact that he goes on to liken the air to a "Fleece of Wooll" or a sponge, and writes of each particle of air as "like a little Spring, …easily bent or rouled up; but will also, like a Spring, be still endeavouring to stretch it self out again".[42] But in the same paragraph he also refers to a "Power of self Dilatation", and there are other grounds for considering a non-mechanical interpretation.

A non-mechanical reading seems justified, for example, when Boyle admits that he is "not willing to declare peremptorily" for either an analogy with springs or the Cartesian plenist account of the dilatation of air under reduced pressure. He then goes on to indicate that he is not satisfied with either of the alternatives, or with any mechanical account:

> And indeed, though I have in another Treatise endeavoured to make it probable, that the returning of Elastical Bodies (if I may so call them) forcibly bent, to their former position, may be Mechanically explicated: Yet I must confess, that to determine whether the motion of Restitution in Bodies, proceed from this… seems to me a matter of more difficulty, then at first sight one would easily imagine it. Wherefore I shall decline medling with a subject, which is much more hard to be explicated, then necessary to be so, by him, whose business it is not, in this Letter, to assign the adequate cause of the Spring of the Air, but onely to manifest, That the Air has a Spring, and to relate some of its effects.[43]

We noted in the last chapter that Boyle's refusal to commit himself to a causal explanation of the spring of the air can be seen as an example of his Baconian experimental method, which we have presented as a way of allowing occult qualities and principles into natural philosophy, as long as the phenomena attributed to these

41 Boyle, *Works*, i: 165.
42 Ibid.
43 Ibid.

occult principles can be established experimentally. In the passage above Boyle expresses his doubts about two prominent mechanical explanations (the Cartesian, and the cruder one involving spring-like particles), but he is in no doubt that air has a "Power of self-Dilatation". The fact that Boyle declares at this point that his aim is merely "to manifest, That the Air has a Spring" strongly suggests that he regarded spring as an essentially occult phenomenon, which seemed to defy mechanical explanations. He was not the only one who thought so. Newton drew upon Boyle's work with the air-pump to conclude that it was "unintelligible" to explain the spring of the air "by feigning the Particles of Air to be springy and ramous, or rolled up like hoops."[44] Newton, as is well known, developed an explanation which assumed repulsive forces operating across the distance between particles (which we will return to in the next chapter). Boyle did not develop such an overtly occult account, but it seems fair to say that his beliefs about the self-Dilatation of the air were not as mechanical as the title, or a superficial reading, of his *New Experiments Physico-Mechanical* might suggest.

Robert Hooke and Vibrating Matter

In the early part of his career, Boyle worked closely with his "assistant" Robert Hooke. This proved a fruitful relationship until Hooke was appointed as Curator of Experiments for the Royal Society in 1661. It is now known, for example, that Boyle did not understand Descartes's physics until Hooke explained it to him.[45] Accordingly, it is not easy to separate Boyle's speculations from Hooke's, or to establish who was the first to develop any of the ideas common to both men. It does seem, however, that where Boyle was simply ready to allow non-mechanical and even occult features into his natural philosophy, Hooke tried much harder to present his philosophy as conforming to the demands of the mechanical philosophy. In spite

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[44] Newton, *Opticks*, 396, 367.
[45] Edward B. Davis, "'Parcere Nominibus': Boyle, Hooke and the Rhetorical Interpretation of Descartes," in *Robert Boyle Reconsidered*, ed. Michael Hunter (Cambridge, 1994), 157–75.

of these efforts, however, Hooke has been seen as an "incongruous mechanist", whose speculations frequently led him to introduce non-mechanical phenomena into his philosophy.[46] Certainly, as with Boyle, there are places in Hooke's writings where he seems to accept innately active matter. Consider his early response to the criticisms of Francis Linus against Boyle's account of the spring of the air. In his "Explication of Rarefaction", included in Boyle's *Defence of the Doctrine Touching the Spring and Weight of the Air* (1662), Hooke develops a speculative theory that particles of air may be

> of the form of a piece of Riband, that is, to be very long, slender, thin and flexible *laminæ*, coyled or wound up together as a Cable, piece of Riband, Spring of a Watch, Hoop, or the like, are: we will suppose these to have all of them the same length, but some to have a stronger, others a weaker Spring: we will further suppose each of these so coyled up to have such an innate circular motion, as that thereby they may describe a Sphere equal in Diameter to their own, much after the manner that a Meridian turn'd about the Poles of a Globe will describe by its revolution a Sphere of the same Diameter with its own in the Air

So, a hoop rotating on its axis describes a sphere in space. But notice that Hooke simply supposes that a hoop of this kind will have "such an innate circular motion." It is possible Hooke is deriving this notion of "circular motion" from the earlier work of Galileo, or Thomas Hobbes, both of whom develop a physics based on what might be called "circular inertia"—that is to say, a supposition that once a body is set moving in a circle, it will continue to move in a circle until something interferes with it. In the case of Galileo and Hobbes, however, the body has to be set moving in a mechanical way; Hooke simply declares that the circular motion he envisages is "innate".[47] Elsewhere, Hooke writes of matter and motion as "two single Powers". Matter is "a Power in itself wholly unactive, until it be, as it were, impregnated by the second Principle [Motion]". According to this speculation, then, motion is, as John Henry has suggested, "not just an active principle but even a seminal

[46] Henry, "Robert Hooke".

[47] Robert Hooke, "Explication of Rarefaction", in Robert Boyle, *A Defence of the Doctrine Touching the Spring and Weight of the Air* (London, 1662); Boyle, *Works*, 3:84. On Galileo's and Hobbes's ideas about circular motion, see Henry, "Simple Circular Motions".

principle."[48] So, active matter is certainly a recurring feature in Hooke's speculations. He is simply not averse to accepting the Epicurean view: "So then, by granting *Epicurus* his Principles, that the Atoms or Particles of bodies have an innate motion… all the *Phænomena* of Rarefaction and Condensation, of Light, Sound, Heat, &c. will naturally and necessarily follow".[49] In what follows we will concentrate on the kind of activity in matter which is most persistent, and most prominent, throughout Hooke's career, namely, vibrating matter.

Vibrating matter was important for Hooke in providing a supposedly mechanical explanation of phenomena which he attributed to what he called congruity and incongruity. Whether vibrating matter really qualifies as a *mechanical* account of congruity seems to me to be questionable, and we shall examine this closely in what follows. To begin with, it is worth noting that the very first time congruity appears in Hooke's writings, he defends it in the same terms as we have just seen Boyle defending the idea of the spring of the air, and in the same terms that Newton was later to defend his "occult" concept of gravity. That is to say, by insisting that the aim is simply to establish the fact, even though a cause of that fact cannot be established.

In his *An Attempt for the Explication of the Phenomena*, of 1661, Hooke introduces the notions of congruity and incongruity and declares congruity

> to be a property of a fluid Body, whereby any part of it is readily united or intermingled with any other part, either of it self, or of any other Homogeneal or Similar, fluid, or firm and solid body: And unconformity or incongruity to be a property of a fluid, by which it is kept off and hindred from uniting or mingling with any heterogeneous or dissimilar, fluid or solid Body.[50]

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[48] Hooke, "Discourse of the Nature of Comets" (1682), in idem, *Posthumous Works*, 174. See Henry, "Robert Hooke", 151.
[49] Robert Hooke, *An Attempt for the Explication of the Phaenomena, Observable in an Experiment Published by the Honourable Robert Boyle* (London, 1661), 85–6.
[50] Ibid., 8.

Hooke defends the latter on experiential grounds—pointing out, for example, the familiarity of oil and water refusing to mix. But when it comes to explaining the cause he suggests that it is simply enough to show that congruity and incongruity exist, even if their causes remain unknown:

> Now from what cause this congruity or Incongruity of bodies one to another, does proceed, whether from the Figure of their constituent Particles, or interspersed pores, or from the differing motions of the parts of the one and the other, as whether circular, undulating, progressive, &c. whether I say from one, or more, or none of these enumerated causes, I shall not here determine;… knowing it likewise sufficient for this enquiry to shew, that there is such a property, from what cause soever it proceeds.[51]

By the time Hooke came to write his *Micrographia*, however, in 1665, he was able to suggest that congruity and incongruity, for all their similarity to the old occult principles of sympathy and antipathy ("*Congruity* seems nothing else but a *Sympathy*, and *Incongruity* an *Antipathy* of bodies"),[52] can be explained on the assumption that matter is continually vibrating. True to form, Hooke illustrates his theorizing by a simple experiment. If we mix in a dish "*several kinds* of sands, some of *bigger*, others of *less* and finer bulks", he writes, and then set the dish briskly vibrating (either by placing it on a rapidly rotating millstone, or a nimbly beaten drumhead),

> we shall find that by the agitation the *fine sand* will *eject* and *throw out* of it self all those *bigger* bulks of small *stones* and the like, and those will be *gathered* together all into *one* place; and if there be *other* bodies in it of other natures, those also will be *separated* into a place by themselves, and *united* or *tumbled* up together.

Hooke noticed this phenomenon while experimenting with glass plates covered with flour and sand, and then set vibrating (by using a violin bow) in order to display standing waves. He goes on to compare congruity with "*equal musical strings equally strecht*" and the harmony or unison which results, and incongruity with untuned strings whose vibrations "cannot agree".[53]

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[51] Ibid., 10.
[52] Hooke, *Micrographia*, 16.
[53] Ibid., 15. For more on Hooke and music, see Penelope Gouk, "The Role of Acoustics and Music Theory in the Scientific Work of Robert Hooke," *Annals of Science* 37 (1980): 573–605.

The question immediately arises, however, as to why fluids are perpetually vibrating? Although, it is worth noting, that even before Hooke addresses this question, he admits that vibrations “do not come up to the *highest property* of *Congruity*, which is a *Cohaesion* of the parts of the fluid together, or a kind of *attraction* and *tenacity*, yet this does as 'twere *shadow* it out, and somewhat resemble it.”[54] This is not a single unrepeated comment; subsequently we are told of “the tenacity or attractive virtue of Congruity”, that congruity is an “attractive or retentive faculty”, and that there is a “Sphere of the attractive activity of congruity.”[55] If Hooke seems unperturbed by the fact that he has hereby undermined his own efforts to claim that the seemingly occult congruity is really explained by mechanical vibrations, it is perhaps because at this early stage in his career he still has not fully committed to mechanistic explanations. Consider, for example, his answer to the question as to why the parts of bodies are vibrating:

> Now that the *parts* of all *bodies*, though never so *solid*, do yet *vibrate*, I think we need go no further for proof, then that *all* bodies have some *degrees* of *heat* in them, and that there has not been yet found any thing *perfectly cold*: Nor can I believe indeed that there is any such thing in Nature, as a body whose particles are at *rest*, or *lazy* and *unactive* in the great *Theatre* of the *World*, it being quite *contrary* to the grand *Oeconomy* of the Universe.[56]

It is important to note that heat is only invoked here as an *indicator* that the parts of all bodies have what Boyle would call “intestine motions”—Hooke does not suggest the heat is what sets the parts vibrating. He has already made plain that “Heat being nothing else but a very *brisk* and *vehement agitation* of the parts of a body”, we do not need to suppose “heat to be any thing else, besides such a motion”.[57] Our sensation of heat is the *effect* of vibratory motion, not its cause.

When Hooke revisited the concepts of congruity and incongruity, in his *Potentia Restitutiva, or Spring* (1679), he did try to put a more Cartesian gloss on the idea of

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[54] Hooke, *Micrographia*, 15.
[55] Ibid, 32.
[56] Ibid, 16.
[57] Ibid, 12-3.

vibrating matter: "This Vibrative motion I do not suppose inherent or inseparable from the Particles of body, but communicated by Impulses given from other bodies in the Universe."[58] This seems to be a new idea, however, contradicting earlier suggestions that the vibrations were innate. Furthermore, it is bound up with a remarkable new and original theory of the nature of bodies.

Hooke's theory of body in the *Potentia restitutiva* has hardly attracted any scholarly attention, but it shows the importance to Hooke of his concept of vibrating matter. The discussion begins when Hooke makes the supposition that the sensible universe consists only of body and motion. He continues:

> I do further suppose then that all things in the Universe that become the objects of our senses are compounded of these two (which we will for the present suppose distinct essences, though possibly they may be found hereafter to be only differing conceptions of one and the same essence) namely, *Body,* and *Motion.* And that there is no one sensible Particle of matter but owes the greatest part of its sensible Extension to Motion whatever part thereof it ows [*sic*] to Body according to the common notion thereof…[59]

The common notion of body, according to Hooke, is that it fills a specific three-dimensional space in such a way that it excludes all other bodies from the same dimensions. Consequently, "I do therefore define a sensible Body to be a determinate Space or Extension defended from being penetrated by another, by a power from within."[60]

It is at this point that Hooke introduces his own theory of body, "which differs from the common notion of Body". He illustrates his theory by supposing a very thin iron plate, a foot square,

> moved with a Vibrative motion forwards and backwards the flat ways the length of a foot with so swift a motion as not to permit any other body to enter into that space within which it Vibrates, this will compose such an essence as I call in my sense a Cubick foot of sensible Body…[61]

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58 Robert Hooke, *Lectures de Potentia Restitutiva* (London, 1678), 8.
59 Ibid.
60 Ibid.
61 Ibid.

Such a vibrating square plate would defend from penetration a cubic foot of space, and would therefore be indistinguishable from a solid cubic foot of iron. Hooke makes it clear that he considers his theory to reflect the way things really are: "The Particles therefore that compose all bodies I do suppose to owe the greatest part of their sensible or potential Extension to a Vibrative motion."[62]

It is at this point that Hooke says the vibrations are not inherent or inseparable from the particles of body but are communicated by impulse. The details as to how this might work are by no means fully developed, but Hooke clearly introduces the phenomenon of sympathetic resonance into his speculations:

> This only I suppose, that the Magnitude or bulk of the body doth make it receptive of this or that peculiar motion that is communicated, and not of any other. That is, every Particle of matter according to its determinate or present Magnitude is receptive of this or that peculiar motion and no other…

He illustrates this with a scenario in which two sets of musical strings sympathetically resonate, or do not, with one another.[63] Although sympathetic resonance had previously been regarded as a highly occult phenomenon, Hooke's emphasis upon the "determinate or present Magnitude" of the resonating bodies shows that he regards it as a phenomenon that can be easily absorbed into mechanical philosophies. It is important to note, however, that this claim is supported by evidence derived from experiment, or everyday experience. There is no attempt on Hooke's part to provide a theoretical account as to why a "determinate or present Magnitude is receptive of this or that peculiar motion and no other". Indeed, as Hooke makes clear, this is merely a supposition: "This only I suppose".

Whether Hooke's account of sympathetic resonance should be considered mechanical or not, he goes on to present an image of a universe in which the constituent particles of all bodies are incessantly vibrating:

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62 Ibid.

63 Ibid, 8, 9.

> According to this Notion I suppose the whole Universe and all the particles thereof to be in a continued motion, and every one to take its share of space or room in the same, according to the bulk of its body, or according to the particular power it hath to receive, and continue this or that peculiar motion.[64]

Again suggesting a mechanistic picture of how this works, he seems to imply that the vibrations are maintained in perpetual collisions:

> All bulky and sensible bodies whatsoever I suppose to be made up or composed of such particles which have their peculiar and appropriate motions which are kept together by the differing or dissonant Vibrations of the ambient bodies or fluid.[65]

It is by no means clear how the vibrations of an adjacent body could mechanically maintain the vibrations of a body if their vibrations were mutually "differing or dissonant" (they ought to have a strong tendency to cancel each other out, and to lose their vibrations). Indeed, later he inconsistently suggests this:

> All solid Bodies retain their solidity till by other extraordinary motions their natural or proper motions become intermixed with other differing motions, and so they become a bulk of compounded motions, which weaken each others Vibrative motions.[66]

But we need not pursue this here, because he also introduces at this point the notion of a fluid menstruum which is also held to be responsible for maintaining the vibrations:

> I do further suppose, A subtil matter that incompasseth and pervades all other bodies, which is the Menstruum in which they swim which maintains and continues all such bodies in their motion, and which is the medium that conveys all Homogenious or Harmonical motions from body to body.[67]

Hooke now appropriates the old idea of an all-pervasive aether and puts it to a new use—communicating the vibrations of one body to another.

Robert Hooke: From Vibrating Matter to a Vibrating Aether

It is easy to see how an ambient aether could convey the motions of one body to another—this conforms to what has always been one of the main reasons for supposing the existence of an aether, namely, to avoid any suggestion of action at a distance. What is not clear, however, is what Hooke means when he writes that this

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64 Ibid, 9.
65 Ibid.
66 Ibid, 12.
67 Ibid, 9.

hypothesized subtle menstruum “maintains and continues” vibrating particles in their motions. The suggestion now is that the aether plays a role in keeping particles vibrating. It is easier to understand his meaning, perhaps, when he invokes the aether in his account of the differences between the solid and fluid states:

> Fluid bulks differ from solids only in this, that all fluids consist of two sorts of particles, the one this common Menstruum near the Earth, which is interspersed between the Vibrating particles appropriated to that bulk, and so participating of the motions and Vibrations thereof: And the other, by excluding wholly, or not participating of that motion…

So, the particles of fluids are interspersed with aether, and the particles of the fluid and of the aether share each others’ motions. The particles of solids by contrast, as he adds a little later, “do by their Vibrative motions exclude this fluid [the aether] from coming between them.” [68] The vibrating particles of solids defend from penetration the space across which they vibrate, and so aether cannot intermingle with the particles of a solid. The vibrating particles of fluids must be less vigorous, however, because vibrating particles of aether *can* intermingle with them. Although it is easy to imagine that an intermingled aether might maintain the vibrations of the particles with which it is interspersed, it is not so easy to imagine how a solid body, whose vibrating parts are beating off a surrounding aether, can have its vibrations perpetuated by that same aether. Clearly, the precise role of Hooke’s vibrating aether has not been fully worked out. Be that as it may, his theorizing on aether is summed up like this:

> All bodies neer the Earth are incompassed with a fluid subtil matter by the differing Velocity of whose parts all solid bodies are kept together in the peculiar shapes, they were left in when they were last fluid. And all fluid bodies whatsoever are mixed with this fluid, and which is not extruded from them till they become solid.

So, what we have here is an all-surrounding aether, which is itself fluid, and whose parts have differing velocities. This fluid aether, by surrounding solid bodies, prevents the dissipation of their vibrating particles. As he says, “All bodies whatsoever would be fluid were it not for the external Heterogeneous motion of the

[68] Ibid., 10.

Ambient." Moreover, "all fluid bodies whatsoever would be unbounded, and have their parts fly from each other were it not for some prevailing Heterogeneous motion from without them that drives them more powerfully together."[69] The importance of the heterogeneity of the aether will emerge later, but given what was said above about the fact that "differing motions" (i.e. inharmonious or discordant motions) in bodies "weaken each others Vibrative motions", then a heterogeneous aether (where the heterogeneity is defined in terms of differing motions) ought to weaken the vibrations of other bodies, but it is suggested that the surrounding aether maintains things as they are.[70]

It is clear, anyway, that Hooke's aether is playing an active role in the system of natural philosophy he is trying to develop in the *Potentia Restitutiva*. It has its own motions, deriving from the fact that its parts have "differing Velocities". It does not simply communicate the motions of one body to another, but it "maintains and continues all such bodies in their motion", while also preventing the break-up of solids and the dissipation of fluids. Given that Hooke has already insisted that the particles of all bodies, whether solid or fluid, are incessantly vibrating ("I suppose the whole Universe and all the particles thereof to be in a continued [vibrating] motion"[71]), it seems likely that he held the parts of the aether itself to be vibrating. Indeed, there is a clear implication that the parts of the aether should be more active than the parts of less subtle bodies:

> According to the bigness of the bodies the motions are, but in reciprocal proportion: That is, the bigger or more powerful the body is, the slower is its motion with which it compounds the particles; and the less the body is, the swifter is its motion… The smaller the particles of bodies are, the nearer do they approach to the nature of the general fluid [i.e. the aether] and the more easily do they mix and participate of its motion.[72]

69 Ibid., 12.
70 Ibid.
71 Ibid., 9.
72 Ibid., 10–11.

The general fluid—the all-pervasive aether—has its own motion, which is faster than the motions of larger particles; only bodies with smaller particles can vibrate at similar speeds to the vibrations of the aether.

Unfortunately, the *Potentia Restitutiva* breaks off shortly after this and the promised "next place", where he intends to say more never seems to have been written. But there are a few hints about Hooke's active vibrating aether elsewhere. In the "Discourse on Gravity or Gravitation" (which Richard Waller, in his edition of Hooke's *Posthumous Works*, annexed to Hooke's "Discourse of Comets" of 1680), Hooke tried to explain the cause of gravity. He did so by supposing what he called a "globular motion" in the Earth, "whereby all the parts thereof have a vibration towards and fromwards the Center… and that this vibrative Motion is very short and very quick, as it is in all very hard and very compact bodies."[73] Although Hooke is about to invoke the aether as a mechanical means of transmitting this globular motion of the Earth, he does not offer a mechanical account of why or how the Earth has such a globular motion:

> The Gravity of the Earth may be caused by some internal Motion of the internal or central Parts of the Earth; which internal and central Motion may be caused, generated and maintained by the Motion of the external and all the intermediate Parts of its Body: So that the whole Globe of the Earth may contribute to this Motion.[74]

There is no mention of any external mover setting the parts of the Earth moving. A little later, he defends this supposition simply by insisting "that there is some such Motion in those Parts [of the Earth]" and hinting that he will prove this when he comes to talk of the Earth's magnetism. Meanwhile, he borrows from Boyle and invokes the case of diamonds being made to shine and electrically attract other bodies merely by rubbing.[75] The implication is that if something as hard as a diamond can be so easily excited into internal motions, then so might the Earth be

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[73] Hooke, *Posthumous Works*, 184.
[74] Ibid.
[75] Ibid., 185.

excited in this way. But if the globular motion of the Earth is not mechanical, the motion of the surrounding aether evidently is. The supposed globular motion of the Earth causes the surrounding aether "to vibrate every way in Orbem" thereby creating what Hooke calls a "radiating Vibration of this exceeding Fluid".[76]

Hooke's ingenuity enables him not only to explain how such vibrations in an aether could account for gravitational attraction towards the Earth, but also to suggest that the attraction would diminish "reciprocal" to the "duplicate of the Distance", and that the observed acceleration of bodies subject to this attraction would conform to Galileo's rule, falling one unit in the first second, three in the second, five in the third, and so on.[77] It is not clear when this "Discourse on Gravity or Gravitation" was written, but it suggests that although Hooke had developed a theory of gravity as early as 1666 which seemed to accept actions at a distance (see Chapter 3), he was also making serious efforts to avoid actions at a distance and to develop a mechanical account of gravity, by assuming an aether.[78] Although, perhaps we should describe it as an attempt to develop *as mechanical an account as possible*. Hooke's account was based on a supposed globular motion in the gravitating bodies, which was not mechanically explained. The account only becomes mechanical at the point where the aether is introduced. There was a similar, not-fully-mechanical account of gravity in Hooke's earlier *Micrographia*.

Speculating in the *Micrographia* about the "multitudes of… uses" which could be accounted for by the principles of congruity and incongruity, Hooke proposed that an aether which was heterogeneous to "the Globe of the Earth, Water and Air" might provide a plausible account of gravity. Assuming that this heterogeneous aether completely surrounds everything in the world, then it would "endeavour to detrude

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[76] Ibid., 184.
[77] Ibid., 185. On Galileo's discovery of the "odd-number rule", see Drake, *Galileo at Work*, 98–100.
[78] For a detailed account of Hooke's early action-at-a-distance theory of gravity, see Nauenberg, "Seminal Contribution"; Gal, *Meanest Foundations*.

all earthly bodies as far from it as it can", by virtue of the fact that it is heterogeneous to all earthly bodies, and this would have the effect of pushing earthly bodies towards the centre of the Earth.[79] The account is not fully developed, but it is very similar to the account which Newton later introduces into the "Queries" at the end of the second English edition of the *Opticks* (1717). It is known that Newton was aware of Hooke's speculative explanation of gravity because he commented on it in his "Out of Mr Hooks Micrographia", notes written before 1672. In a note on the contents of page 21 of *Micrographia*, Newton writes:

> & of gravity, ye Aether (its motion being incongruous to all other bodys) forcing bodys to retire from those places where it is in greatest plenty, towards the Earth where it is in least plenty.[80]

Interestingly, Newton says that it is the *motion* of Hooke's aether which is incongruous to all other bodies. Newton is remembering Hooke's earlier claims that incongruity is the result of vibrations which are inharmonious, or out of tune, with the motions of the bodies to which they are incongruous. But Hooke himself does not mention the motions of the aether here; he simply supposes "the *Globe* of Earth, Water, and Air to be included with a *fluid*, heterogeneous to all and each of them". This all surrounding fluid's heterogeneity or incongruousness is simply presupposed, and Hooke's account hardly counts as mechanical. Even if, like Newton, we fill in the blank left by Hooke, and assume the heterogeneity is the result of its discordant vibrations, it is impossible to attribute those vibrations to the impact of some external mover.

Newton's later version of this, in the 1717 edition of the *Opticks*, is much more clearly expounded, but it is undeniably based on Hooke's explanation. Newton does not need to introduce a notion of incongruity because he has committed himself, since the *Principia* of 1687, to the idea that all physical phenomena may be

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79 Hooke, *Micrographia*, 22.
80 Newton, *Unpublished Scientific Papers*, 401.

explained by attractive and repulsive forces operating between particles.[81] Consequently, repulsive force takes the place of incongruity in Newton's account: the particles of the aether repel the particles of other bodies, and so aether becomes rarer in the vicinity of other bodies. The result is a density gradient in the repelling aether which forces bodies together in the least dense parts of the aether. Where the aether is rarer, bodies in the aether are repelled less forcefully, conversely bodies are pushed by denser parts of the aether to places where there are already other bodies (and the aether is rarer)—thus giving the appearance of gravitational attraction.

> Is not this Medium much rarer within the dense Bodies of the Sun, Stars, Planets and Comets, [Newton wrote,] than in the empty celestial Spaces between them? And in passing from them to great distances, doth it not grow denser and denser perpetually, and thereby cause the gravity of those great Bodies towards one another, and of their parts towards the Bodies; every Body endeavouring to go from the denser parts of the Medium towards the rarer?[82]

This appears in one of the so-called "Aether Queries" which Newton added to the second English edition of the *Opticks*, in 1717.[83] It has been frequently seized upon by scholars seeking to claim that Newton really intended to provide a mechanical explanation for gravity (and, by their implication, that Newton always believed there must be such an explanation), in spite of his choosing not to offer a mechanical account in the *Principia*.[84] These scholarly efforts not only overlook the fact that Newton's aether depends upon repulsive forces operating between its particles, but they also give the false impression that the aether queries were added by Newton in order to provide an explanation for gravity. In fact, the chief purpose of the eight aether queries was to address an important technical issue in Newton's optics which had been left unresolved in the main text of the *Opticks*. Furthermore, as we shall see,

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[81] Newton, *Principia*, 382–83: "For many things lead me to have a suspicion that all phenomena may depend on certain forces by which the particles of bodies by causes not yet known, either are impelled toward one another and cohere… or are repelled from one another and recede."

[82] Newton, *Opticks*, 350.

[83] On the "Aether Queries", see A Rupert Hall, *All Was Light: An Introduction to Newton's Opticks* (Oxford, 1995), 145–62.

[84] For example, Cohen, *Franklin and Newton*, the section headed "Newton's Grand Hypothesis on the Aether," 166-72; Whittaker, *A History*, 17; Philip E. B. Jourdain, "Newton's Hypotheses of Ether and of Gravitation from 1672 to 1679," *The Monist* 25 (1915): 79–106. And more recently, Janiak, *Newton as Philosopher*.

it is clear that these other additional queries were also borrowed from, or at least based upon, ideas that had been expressed long before in Hooke's *Micrographia*.

Newton's Vibrating Aether

Hooke's speculation on gravity being caused by density gradients in a universally incongruous (and therefore effectively repelling) aether was the *second* of the "multitudes of other uses" for congruity and incongruity which Hooke put forward in the *Micrographia*. The *first*, however, was an explanation as to why light rays were sometimes refracted, and sometimes reflected, within the media through which they travelled.

> Upon the consideration of the *congruity* and *incongruity* of Bodies, as to *touch*, I found also the like *congruity* and *incongruity* (if I may so speak) as to the *Transmitting* of the *Raies* of Light: For as in this regard, *water* (not now to mention other Liquors) seems nearer of affinity to *Glass* then *Air*, and *Air* then *Quicksilver*: whence an *oblique Ray* out of *Glass*, will pass into *water* with very little *refraction* from the *perpendicular*, but none out of *Glass* into *Air*, excepting a *direct*, will pass without a very great refraction from the perpendicular, nay any oblique Ray under thirty degrees, will not be admitted into the Air at all. And *Quicksilver* will neither admit oblique or direct, but reflects all; seeming, as to the transmitting of the Raies of Light, to be of a quite differing constitution, from that of *Air, Water, Glass, &c.*[85]

The ingenious Hooke does not linger over these speculations and develop them properly. But, it is Hooke's undeveloped speculation on "*Transmitting* of the *Raies* of Light" which is developed, for the first time in published form, in Newton's aether queries. With regard to the transmission of light, however, as opposed to the speculation on the cause of gravity, Newton had already developed Hooke's idea in his "Hypothesis explaining the Properties of Light", which was read at a meeting of the Royal Society in 1675.[86] Newton tells us there that aether "is a vibrating medium" and uses this to explain why light rays are "refracted by some superficies, and

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[85] Hooke, *Micrographia*, 21.

[86] Newton, *Papers & Letters on Natural Philosophy*, 178–99. As we will see, there are clear similarities between Newton's views on light and Hooke's admittedly less developed views. Hooke's theory of the cause of gravity, however, does not appear in Newton's work until the *Opticks* of 1717. In the "Hypothesis" of 1675, Newton speculates that gravity is caused "by the continual condensation… of something… of an unctuous or gummy, tenacious, and springy nature…". See Newton, *Papers and Letters on Natural Philosophy*, 181.

reflected by others". But he then goes on to use the vibrating aether to explain "how rays alike incident on the same superficies (suppose of crystal, glass, or water) may be at the same time some refracted, others reflected."[87] Newton is confronting various effects which are now (and were then) attributed to the wave-like properties of light, but which Newton had to explain differently, since he held light to consist of moving particles, not waves.[88]

It is important to acknowledge a major difference between Hooke's and Newton's theories. Hooke believed that *the vibrations in the aether constituted light*, but Newton believed that moving light particles struck the aether and set it vibrating. We have seen above that Hooke suggested that phenomena in which light was sometimes refracted and sometimes reflected at the boundaries between the media through which it travelled could be explained by assuming different congruities and incongruities between the aether and the media. Given that congruities and incongruities were determined by the harmonic or discordant vibrations of the media and the aether, the account could be reduced to one involving vibrations (and remaining silent about congruity and incongruity). This is what Newton did:

> Supposing that light , impinging on a refracting or reflecting aetherial superficies, puts it into a vibrating motion, that physical superficies being by the perpetual appulse of rays always kept in a vibrating motion, and the aether therein continually expanded and compressed by turns; if a ray of light impinge upon it, while it is much compressed, I suppose it is then too dense and stiff to let the ray pass through, and so reflects it; but the rays, that impinge on it at other times, when it is either expanded by the interval of two vibrations, or not too much compressed and condensed, go through and are refracted.[89]

In some cases, however, light rays could be seen to be alternately transmitted and reflected in a periodic way. As Newton wrote at one point in the *Opticks*, when discussing light passing through thin transparent plates: "this action or disposition, in

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[87] Newton, *Papers and Letters on Natural Philosophy*, 188.

[88] Alan E. Shapiro, *Fits, Passions and Paroxysms: Physics, Method and Chemistry and Newton's Theories of Colored Bodies and Fits of Easy Reflection* (Cambridge, 1993), 72–89.

[89] Newton, *Papers and Letters on Natural Philosophy*, 188–89.

its propagation, intermits and returns by equal Intervals".[90] This kind of periodicity was also evident in the phenomenon now known as Newton's rings—rings of alternate brighter and darker illumination that appear when a plano-convex lens is placed on a plane glass surface.[91] But, here again, Hooke's speculations already provided just what Newton needed, because Hooke himself had introduced musical harmonies (and discordances) into his attempts to explain various phenomena. Consider, for example this passage from the *Micrographia*:

> particles that are all *similar*, will, like so many *equal musical strings equally strecht*, vibrate together in a kind of *Harmony* or *unison*; whereas others that are *dissimilar*, upon what account soever, unless the disproportion be otherwise counter-ballanc'd, will, like so many *strings out of tunne* to those unisons, though they have the same agitating *pulse*, yet make quite *differing* kinds of *vibrations* and *repercussions*, so that though they may be both mov'd, yet are their *vibrations* so *different*, and so *untun'd*, as 'twere to each other, that they *cross* and *jar* against each other, and consequently, *cannot agree* together, but *fly back* from each other to their similar particles.[92]

Newton adopted this aspect of Hooke's theorising too, and took it even further. As is well known, Newton drew a precise analogy between the "bignesses" of the vibrations light caused in the aether by striking it, and the "aereal vibrations of several bignesses to generate sounds of divers tones." After all, Newton went on to explain, "the analogy of nature is to be observed."[93] Newton went on to claim that he had been able to experimentally verify that the centres of the colours in the spectrum could be "divided in about the same proportion that a string is, between the end and the middle, to sound the tones in the eighth."[94] Putting it simply, Newton believed that the spectrum was divided into seven colours, just as the musical scale was divided into seven notes. Newton repeated this "notorious assertion", as A. R.

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[90] Newton, *Opticks*, 279.

[91] Newton, *Papers and Letters on Natural Philosophy*, 193–7. For a detailed study, which brings out the importance for Newton of achieving an explanation for the obvious periodic aspects of Newton's rings and other diffraction phenomena, see Shapiro, *Fits, Passions, and Paroxysms*, especially: 72–89. See also, Richard S. Westfall, "Isaac Newton's Coloured Circles Twixt Two Contiguous Glasses," *Archive for History of Exact Sciences* 2 (1965): 181–96.

[92] Hooke, *Micrographia*, 15.

[93] Newton, *Papers and Letters*, 192. On Newton's ideas on the "analogy of nature", see McGuire, "'Analogy of Nature.'"

[94] Newton, *Papers and Letters*, 192.

Hall called it, in the *Opticks*. For Hall it was "not otherwise justified in the *Opticks*", which is to say, it is by no means obvious why it appears there. The assertion is, as he says, "mysterious to physicists, though less so to those who would number Newton among the Platonists, alchemists, and magicians."[95] It is possible Newton was inspired by notions of Pythagorean cosmic harmonies, but it is at least arguable that he was inspired by Hooke's analogy between his vibrating aether and musical strings, either in unison, or "untun'd, as 'twere", which then allowed him to suggest that the (musically) vibrating aether could account for the seemingly periodic alternations of light from reflection to transmission.[96]

Newton refused to allow Oldenburg to publish his "Hypothesis" in *Philosophical Transactions* and his speculations involving a vibrating aether remained largely unknown, until Newton returned to them, and published them, in the second set of additions to the Queries at the end of the *Opticks*.[97] It is evident from the first of the aether queries, Query 17, that Newton's intention was to offer a conjectural explanation for the alternating "Fits of easy Reflexion and easy Transmission" which he had introduced into the *Opticks* in Book II, Proposition XII. Although he hinted in Proposition XII that these "fits" might be explained by vibrations in the medium excited by the percussion of light particles, he concluded by insisting that he does not consider here whether this hypothesis is true or not.[98] So things stood until 1717, when he returned to this hypothesis. Query 18 offers experimental evidence that such a vibrating aether might exist, while Query 19 explains more fully how the vibrations might cause the alternating "fits" of easy reflection and easy transmission. Query 20 introduces the idea that the aether grows successively denser as it retreats from

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95 Hall, *All Was Light*, 112. Newton, *Opticks*, Book I, Part II, Proposition III, 125–28.
96 There is no denying Newton was also interested in Pythagorean harmonies, which featured in the so-called "Classical Scholia". See, J. E. McGuire and P. M. Rattansi, "Newton and the 'Pipes of Pan,'" *Notes and Records of the Royal Society of London* 21 (1966): 108–43.
97 The first edition, 1704, concluded with 16 queries. Newton added seven more to the Latin edition of 1706, and added the eight "Aether Queries" in 1717. See Hall, *All Was Light*, 127–62, and 238.
98 Newton, *Opticks*, 278–81.

"other compact and dense Bodies"—here it is used to account for the nature of refraction and for diffraction effects that occur when light passes by "the edges of dense Bodies".[99]

Query 21, which uses the repelling aether to suggest an explanation for gravity, appears as something of a digression, therefore. Having introduced the notion of a density gradient in the aether in Query 20, Newton shows how this could also be used to offer a tentative explanation of gravity. This seems less out of place if we remember that Hooke also introduced his density-gradient explanation of gravity in *Micrographia* just after discussing how different vibrations could account for differences in "*Transmitting* of the *Raies* of Light".[100] Given that Newton's *Principia* drew much of its force from demonstrating that a dense plenist Cartesian aether could not exist, Newton also had to digress here to ensure no readers mistook him to be introducing a Cartesian-like aether into his physics. Accordingly, he took pains to establish the extreme tenuity of this newly proposed aether. The following query, 22, reinforces this point by arguing that an aether of such extreme rarity would not slow down the planets by friction, or drag—an issue that told against the Cartesian aether.[101] The final two aether queries (23 and 24) are concerned with the role of this newly proposed aether in vision and in animal muscular motion and do not concern us here.[102]

I have now established that the material included in the aether queries was remarkably close to the earlier work of Robert Hooke, and derived either from Newton's "Hypothesis… of Light", which in itself owed much to Hooke's speculations about a vibrating aether in *Micrographia*, or it derived directly from the

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[99] Ibid, 348–50.
[100] Hooke, *Micrographia*, 21–22.
[101] Newton, *Opticks*, 350–3. On Newton's opposition to the Cartesian aether, see Newton, *Principia*, Book II, Section 9, 779–90; and "General Scholium", 939; and Cohen, "A Guide to Newton's *Principia*", 187–8.
[102] Newton, *Opticks*, 353–54.

Micrographia itself (as in the case of the aetherial density gradient theory of gravity). If this is correct, it suggests that an earlier theory about the origins of these newly added “Aether Queries” is misconceived. It has been suggested that the aether queries were inspired by the electrical experiments of Francis Hauksbee, the Curator of Experiments for the Royal Society under Newton’s Presidency. It seems clear that Newton was excited about the initial results of these experiments, because he added a paragraph right at the end of the “General Scholium”, in the second edition of the *Principia* of 1713, about “a certain very subtle spirit pervading gross bodies and lying hidden in them”; although not explicit, it is clear that this spirit is electricity, or is responsible for electrical effects. It has been suggested by Henry Guerlac, and reiterated by A. R. Hall, that this electrical spirit of 1713 inspired the aether queries of 1717.[103]

It is important to note, however, that there is no mention whatsoever of electricity, electrical phenomena, or an electrical spirit in any of the aether queries. Furthermore, the arguments in favour of identifying the aether of the 1717 additional queries with the 1713 electrical spirit are hardly persuasive. They hinge upon a draft for a proposed Part II of Book III written in 1716 in which Newton wrote that “gross bodies contain within them a subtile Aether or Aetherial Spirit w^{ch} by friction they can emit to a considerable distance… as is manifest by the following Phaenomena shewed to the R. Society by Mr Hawksby.” Hall concludes:

> The elastic spirit is therefore also electric, and we have clear proof that this whole revival of Newton’s interest in the attribution of all forces to a single universal “active Principle” was occasioned by Hauksbee’s experiments.[104]

It should be noted, however, that while some of the drafts written for this abandoned Part II of Book III found their way into the Queries, this comment did not. Certainly,

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103 Henry Guerlac, “Newton’s Optical Aether: His Draft of a Proposed Addition to His *Optiks*,” *Notes and Records of the Royal Society of London* 22 (1967): 45–57. See also Hall, *All Was Light*, 154–5.

104 Hall, *All Was Light*, 154. See also Ibid., 48. Cambridge University Library, Add. 3970, No. 9, fol. 626*r* [available online through University of Cambridge Digital Library: http://webapp1.dlib.indiana.edu/newton/mss/norm/ALCH00081;jsessionid=5C35F5DC087C352293AD057C168B1A7F].

new references to Hauksbee's experiments were added to the Queries in 1717 (for example, in Query 8), but there is no hint of anything electrical in any of the aether queries.[105] In the end, Guerlac's argument is based on nothing more than his first conjecture, which he admits was "based upon the concordance in time between Newton's resurrection of the aether and his association with Hauksbee".[106]

The question remains, however, as to why Newton interpolated these queries when he did. Why in 1717, and not in the first edition or in the Latin *Optice*? Given the fact that the ideas expressed in the aether queries were so similar to the speculations of Robert Hooke; and given that Hooke's comment that Newton's "Hypothesis… of Light" was similar to his own was the beginning of Newton's subsequent enmity towards Hooke, it seems that we need look no further. It was recorded in the minutes of the Society in 1675 that "After reading this discourse [Newton's "Hypothesis"], Mr Hooke said, that the main of it was contained in his *Micrographia*, which Mr Newton had only carried farther in some particulars."[107] This was one reason why Newton withdrew his "Hypothesis" from publication in the *Philosophical Transactions*. It is also well known that Newton finally began to prepare the *Opticks* for the press in 1703, when he knew Hooke was on his deathbed.[108] It must have struck Newton that to incorporate material from his "Hypothesis" in 1704, just after Hooke's death, might have led others to see the similarity with the *Micrographia*. Similarly, the *Optice* appeared the year after Waller's edition of Hooke's *Posthumous Works*. Once again, Newton might have thought that his contemporaries would perhaps be thinking once again about Hooke's ingenious speculations, and might recognise the similarity to Newton's aether queries. By 1717, however, he

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105 Newton, *Opticks*, 341.
106 Henry Guerlac, "Newton's Optical Aether", 46.
107 Newton, *Letters and Papers*, 199. For an indication of just how single-minded Newton was in his implacable opposition to those who he felt had wronged him, see Iliffe, *Priest of Nature,* especially Chapter 10, and on this accusation by Hooke in particular, see 324–27.
108 Hall, *All Was Light*, 3–4, and 92.

might have been more confident that any similarity would not be noticed; and indeed, as far as we can tell, nobody at the time did remark upon any similarity between the aether queries and Hooke's speculations in *Micrographia* or his later works. Newton delayed publishing his *Opticks* from the late 1670s to 1704, largely due to his resentment of Hooke; he was certainly capable, therefore, of delaying from 1704 to 1717 the addition of a series of queries that drew heavily on Hooke's speculations.

One final point seems to reinforce the importance of Hooke's influence upon the aether queries. Newton's "Hypothesis explaining the Properties of Light" was by no means all drawn from Hooke, and the aether which plays a major role in this work clearly owes a great deal on the one hand to Boyle's speculations about atmospheric air being composed of various effluvia (as we saw in the last chapter), and on the other to earlier work of Newton's on alchemy.[109] When Newton wrote in the "Hypothesis" that perhaps "the whole frame of nature may be nothing but various contextures of some certain aetherial spirits, or vapours, condensed as it were by precipitation", and that, therefore, "all things [may] be originated from aether", he was drawing upon alchemical notions, and in particular upon ideas that he had developed in "Of Natures obvious laws & processes in vegetation".[110] But there is no hint of this alchemical aether in the queries added in 1717. Newton had evidently rejected his earlier belief in an aether by the time he came to write the *Principia*, and much of his great work is devoted to demonstrating that the Cartesian aether cannot exist. Furthermore, the only discussions of aether in the pre-1717 versions of the *Opticks*, are in Book II, Part II, and in Queries 21 and 23 of the *Optice*, where its existence is dismissed all three times.[111]

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[109] Newman, "Preliminary Reassessment of Newton's Alchemy".
[110] Newton, *Letters and Papers*, 180. "Of Natures obvious laws & processes in vegetation" is now available online at the *Chymistry of Isaac Newton* website: http://webapp1.dlib.indiana.edu/newton/mss/dipl/ALCH00081/ See also, Newman, "Preliminary Reassessment".
[111] Newton, *Optice*, 315, and 337; see *Opticks*, 242, 363–64. The critical passage in Quaestione 23 of the *Optice* (337), was omitted from the 1717 *Opticks*. See Hall, *All Was Light*, 145.

The introduction of the aether queries in 1717 did not signify a complete change of heart and mind on Newton's part. He was not newly convinced that, after all, his natural philosophy needed an all-pervasive aether. He was still committed to a belief in attractive and repulsive forces between the particles of bodies, and the belief, as expressed in the Preface to the *Principia*, that "all phenomena" may be explained by the operation of these interparticulate forces.[112] The aether was introduced merely as a possible means of explaining the continual, and periodically regular, switching of light between fits of easy reflection and fits of easy transmission that his theorizing, earlier in the book, required. And that aether, characterized by its vibrating nature, and by its supposed incongruity to other bodies, could be, and was, borrowed from Hooke with a few changes dictated by their different starting positions (Hooke believing that light *was* the vibrating of the aether, while Newton believed that the vibrations of the aether were caused by the impact of light particles upon it).

The digression into an explanation for gravity, introduced in Query 21, was also borrowed from Hooke, but was there for a different reason. Contrary to what a number of scholars have supposed, it was not introduced because Newton wished to provide a *mechanical* account of gravity; it was introduced, as Newton himself tells us, to avoid charges that he was committed to a concept of gravity as an essential property of bodies. As Newton indicated in "Advertisement II", added to the 1717 *Opticks*, Query 21 suggested that gravity might be explicable by some force external to the gravitating bodies, and so he should not be charged with holding gravity to be innate in bodies.[113] But he also made it clear in the Advertisement that he was by no means committed to this alternative account either:

[112] Newton, *Principia*, 382–83.
[113] Careful readers might have noticed, however, that Query 21 assumed repulsive forces operating between the particles of aether, and between the aether particles and the particles of all other bodies. If gravity was not innate, the supposed repulsive forces might be said to have been innate. Perhaps this is why Newton never returned to this theory of gravity in anything he wrote later.

> to shew that I do not take Gravity for an essential Property of Bodies, I have added one Question concerning its Cause, chusing to propose it by way of a Question, because I am not yet satisfied about it for want of Experiments.[114]

Rather than reverting to his alchemical aether Newton was simply reviving the active vibrating aether that he had developed earlier as a revised version of Hooke's aether. Newton was clearly trying to conform more to the precepts of the mechanical philosophy than he had been in his "Hypothesis… of Light", but his new aether still depended upon repulsive forces operating at a distance between its particles, and therefore could be said to incorporate occult forces. But for Newton, this was good enough. As he wrote in the Preface to the *Principia* at the point where he suggested that all phenomena could be explained by attractive and repulsive forces: "If only we could derive the other phenomena of nature from *mechanical* principles by the same kind of reasoning!"[115] We have already seen (Chapter 3) how Newton came to incorporate attractive forces acting at a distance into his physics (and how Hooke played an important part there too); in the next chapter, we will see how he came to believe in interparticulate repulsive forces.

Conclusion

It has been shown throughout the thesis so far that active matter was generally accepted by English natural philosophers—from John Dee's perpetually radiating bodies, to Bacon's nineteen kinds of activity in matter, and from the magnetic cosmologists' belief in attracting bodies, to Petty's magnetic atoms and Charleton's, Power's and Boyle's bodies which perpetually emitted endless streams of effluvia. In the last two chapters, the focus is directly on theories of matter and on further evidence that the dominant view in English natural philosophy was that matter was inherently active. This chapter has extended the analysis of active matter beyond the issue of perpetually emitting effluvia and has considered other aspects of the activity

[114] Newton, *Opticks*, cxxiii.
[115] Newton, *Principia*, 382. My emphasis.

of matter. It has looked at advanced aspects of matter theory and accordingly focused on the work of the two leading thinkers in English natural philosophy before Newton, Robert Boyle and Robert Hooke. It showed that Boyle's speculations about the undetectable motions that he believes must be taking place even in bodies which seem to be completely still and stationary, led him to suppose there must be vibrations occurring in bodies even though we are unaware of them. Robert Hooke seems to have accepted the same conclusion, but his speculations about incessantly vibrating matter led him to take the idea further and to suppose that there must be an all-pervasive constantly vibrating aether. Hooke's ideas have been shown to have been under-developed and not fully coherent. Nevertheless, it can be clearly seen that Newton took up some of Hooke's ideas on a vibrating aether and used them for his own purposes.

The chapter began with a section which exposed Boyle's speculations on motions that natural philosophers are unaware of, or at least not sufficiently aware of. What Boyle had in mind were what he called "intestine motions", that is to say motions of the particles which make up a body. These motions were assumed to be taking place all the time even though they are not sensible to the casual on-looker, and they include extremely slow motions, which Boyle referred to as "languid and unheeded", and more rapid but very restricted motions such as vibrations. It was only by assuming that there are such motions, Boyle believed, that certain phenomena could be explained. Boyle saw these intestine motions at work in cases of magnetism, electricity, changes of state from solid to liquid, and various chemical phenomena.

The second section focused on vibrating matter in Boyle's speculations. It was shown here that Boyle does not regard all cases of vibrations in matter as being caused by simple mechanical percussion. Boyle introduced a much more occult series of speculations. The theory Boyle developed is that bodies are ready to set themselves vibrating, and all that is required is an initial stimulus. The initial stimulus does not act as a mechanical impulse, but simply "excite[s] or assist[s] the more principal or internal Causes of the Motions we speak of…"[116] The vibrations are set off by "internal Causes" which are merely "excited" by the external stimulus. The occult or non-mechanical aspects of Boyle's speculations were brought out here, and included a fresh look at his claims about the "spring" of the air, which far from being a mechanical concept is held to be the result of an internal "Elastic power" or "Power of self-Dilatation".

Hooke also supposed that vibrations in matter could explain certain phenomena. Vibrations first appeared in *Micrographia* as a way to explain phenomena which Hooke attributed to congruity and incongruity. Hooke's observation that different sizes of sand grains can spontaneously separate from one another if they are simply set vibrating seems to have been the starting point for these speculations. At this point (1665) he did not provide a mechanical explanation for these vibrations—they were simply held to be "intestine motions" which Hooke, like Boyle, assumed must be present in bodies. In the later *Lectures de potentia restitutiva* (1679), however, Hooke tried to suggest that the vibrations in matter are "communicated by Impulses given from other bodies in the Universe". Hooke went on to develop a theory of bodies in which all bodies are held to be composed of particles in incessant vibrating motions.

Still seeking to avoid suggestions that the vibrations in matter were innate and unexplained, Hooke turned to the age-old idea of an all-pervasive aether "which

[116] Boyle, *Works*, vi: 197.

maintains and continues all such bodies in their motion".[117] The next section, therefore. expounded Hooke's claims in *De potentia restitutiva* about the aether and critically assessed their plausibility. It was shown that Hooke's aether was not simply a passive means of transmitting vibrations from one body to another but must have had its own vibrations. Hooke argued that the surrounding aether maintains bodies in their incessant vibrations, and to do so it must be vibrating itself. In spite of the earlier claim that vibrations are "communicated by Impulses… from other bodies in the Universe", it is not clear how the aether is set vibrating. Clearly, the aether cannot be set vibrating by the vibrations in the bodies it surrounds, since its purpose is to maintain the vibrations of bodies. Hooke's vibrating aether seems to have been inherently active. At this point the section returned to earlier speculations by Hooke about an active aether. In the *Micrographia* Hooke supposed an aether that was incongruous, or heterogeneous, to all earthly bodies. He then used this to show that such an aether would have the effect of pushing bodies towards the Earth—that is to say, would explain gravity. This speculative explanation of gravity was shown to have been taken up by Newton in Query 21 of the 1717 edition of the *Opticks*. Substituting repulsive forces between the particles of aether and the particles of bodies for Hooke's incongruous aether, the result would be the same, namely, density gradients in the aether caused by the presence of bodies. Because of incongruity (or repulsion) bodies would move from a dense part of the aether to a rarer part. The aether was held to be rarer where bodies were already present, and so an observer would see bodies moving towards each other, as if by attraction. It is interesting to note that Hooke's principles of congruity and incongruity, which he used to explain many phenomena in *Micrographia*, were similar to Newton's later idea that many phenomena could be explained by attractive and repulsive forces.

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117 Hooke, *Lectures de Potentia Restitutiva*, 9.

Finally, it was shown that Newton had already borrowed Hooke's idea of a vibrating aether in his "Hypothesis… of Light", and returned to this idea in 1717 in the so-called "Aether Queries" added to the *Opticks* at that time. The Aether Queries offered an explanation for periodic aspects of the behaviour of light (attributed by Huygens and Hooke to the wave-like nature of light), which Newton needed because he held light to consist of streams of particles (not periodic waves). Newton added Hooke's density gradient theory of gravity in response to critics who accused Newton of holding gravity to be "an essential Property of Bodies". The final section rejected earlier suggestions on the one hand that Query 21 was added to show that Newton did not believe in action at a distance, and on the other that it was added as a result of the experimental revelations (about electricity) of Francis Hauksbee. It also pointed out that there was no continuity between the aether of the "Hypothesis… of Light" and the aether introduced into the *Opticks* in 1717. Newton had clearly abandoned his earlier speculations about an alchemical aether by the time he came to write the *Principia*. Aethers played no role in his physics until the 1717 *Opticks*, but the vibrating aether introduced into the *Opticks* in 1717 was borrowed directly from Hooke, not from alchemy.

Chapter 6: Rarefactions & Condensations and the Origins of Newtonian Repulsive Force

Introduction

Rarefactions and condensations, in their simplest form, are those phenomena in which material substances vary in their densities, becoming more fine or tenuous on the one hand, or coarser or thicker on the other, such as water turning to steam or vice versa. Although they might seem unproblematic concepts to modern readers, in fact they were extremely problematic from ancient times, and this is shown by the complex history of rarity and density in natural philosophy. For a significant number of those thinkers who engaged with this topic, the phenomena of rarefactions and condensations seemed to suggest, inescapably, that matter must have in-built principles of activity. Essentially, the result is a belief that matter can determine its own dimensions in some way: either by spreading itself out, or contracting itself inwards, or, in the case of atomist or corpuscularist theories, by moving its constituent particles closer together or further apart. And this kind of self-determination or self-movement was, for these thinkers, either occult, or fundamental and unexplained. That being so, it was inevitable that other thinkers, most notably the influential Aristotle, should try to counter such views with an account that avoided occult or metaphysical assumptions about the variable density of bodies. As with so many other issues, the Aristotelian solution to the problem of condensation and rarefaction seemed persuasive in the natural philosophy of the Latin West until the early modern period.

In the seventeenth century, however, rarefaction and condensation once again came to be seen by philosophers as deeply problematic, and the Aristotelian solution to be just one more example of the unintelligibility of scholastic natural philosophy. Hence, this chapter seeks to reveal the occult aspects of pre-Newtonian theories of rarefactions and condensations. It will also show that the phenomena of condensation and rarefaction have been unduly neglected in previous historiography of science. The importance of these interlocked concepts can be seen not only from their appearance in a prominent way in Ancient Greek natural philosophy, but also from the fact that they formed the background to Newton's eventual acceptance, in his mature philosophy, of actions at a distance between particles. Although Newton's *Principia mathematica* (1687) was chiefly concerned with the action at a distance of gravity on a cosmic scale, his suggestion in the Preface that "all phenomena may depend on certain forces by which the particles of bodies… either are impelled toward one another… or are repelled from one another" derives, as I hope to show in what follows, from his thinking about condensation and rarefaction.[1] And, as a result of the extraordinary influence of his speculations in the Queries added to the end of the *Opticks* (1717), this suggestion went on to shape the physics of the Enlightenment and beyond.[2] It seems hard to deny that the persistent problem posed to natural philosophers by the phenomena of condensation and rarefaction was far more significant in the history of natural philosophy than current historiography would suggest.

In what follows, I will first of all try to indicate the problematic nature of the variable density of bodies from ancient times, through to the Renaissance. I will then focus on developments in English natural philosophy from Francis Bacon through to Isaac Newton.

The Pre-Modern Background: Problematizing Condensation and Rarefaction

The importance of the concepts of condensation and rarefaction can be seen from the fact that one of the very earliest of the Pre-Socratic natural philosophers, Anaximenes of Miletus (BC. 585–528), considered them as fundamental to physics

[1] Newton, *Principia*, 382.

[2] See Robert E. Schofield, *Mechanism and Materialism: British Natural Philosophy in an Age of Reason* (Princeton, 1970).

and ultimately responsible for all physical change. Seeking to reduce the complexity of the material world to one fundamental substance, Anaximenes fixed on air as the "originative substance and basic form of matter,"[3] but it was only through condensation that air could manifest itself as liquid or solid and only through rarefaction that it could return again to air or by further rarefaction manifest itself as fire.

> It [air] is always in motion: for things that change do not change unless there be movement. Through becoming denser or finer it has different appearances; for when it is dissolved into what is finer it becomes fire, while winds, again, are air that is becoming condensed, and cloud is produced from air by felting…when it is condensed still more, water is produced, with a further degree of condensation earth is produced, and when condensed as far as possible, stones…[4]

What is not clear is how these changes of state were brought about. Anaximenes simply seems to suggest that air can condense or rarefy of its own accord, as though it works by its own power, an explanation which might be characterized as occult. The crucial thing is that condensation and rarefaction were presented by Anaximenes as devices to explain all the diversity of the world, even though all was originally air. The fundamental nature of condensation and rarefaction for Anaximenes can be seen in the fact that he explained other phenomena in terms of them. Noting that steam is hotter than water, and that fire is hotter than air, Anaximenes suggested that rarefaction resulted in the generation of heat. Similarly, the coldness of ice suggested that condensation from water to ice (the fact that ice is less dense than water was unknown to the Ancients) generated cold.[5]

Heraclitus and Plato, who both recognized the fundamental nature of change in the physical world, essentially embraced Anaximenes' view. As Plato wrote: "we see

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[3] G. S. Kirk, J. E Raven, and Malcolm Schofield, *The Presocratic Philosophers: A Critical History with a Selection of Texts*, 2nd ed. (Cambridge, 1983), 144.
[4] Ibid., 145. The quotation is from Hippolytus, *Refutatio*. The use of the word "felting" suggests that air can be matted together more compactly to form clouds, analogous to fibres of wool being compacted to form felt.
[5] Ibid., 148.

that what we just now called water, by condensation, I suppose, becomes stone and earth; and this same element, when melted and dispersed, passes into vapour and air."[6] For Heraclitus fire seems to have been the archetypal form of matter and successive condensations of fire gave rise to other bodies.[7] For Aristotle, however, change was not something to be merely accepted but had to be explained. Seeking to reduce physical change to the behaviour of his four elements and their qualities, he insisted that condensation and rarefaction were passive reactions of matter to what Aristotle saw as the "manifest" qualities of heat and cold. It was heat which caused rarefaction, not the other way around; and it was cold which resulted in bodies contracting. Even so, Aristotle did at least acknowledge that

> the principle of all changes of quality is condensation and rarefaction, for heavy and light, soft and hard, hot and cold are taken to be different manifestations of condensation and rarefaction, and condensation and rarefaction, again, to be identical with the combination and resolution by which the genesis and evanishment of things are supposed to come about.[8]

These examples reveal that right from the very origins of natural philosophy, condensation and rarefaction were seen to defy easy explanation, and were therefore taken to be fundamental aspects of the natural world.

Approximately one and a half centuries after Anaximenes, the ancient atomistic explanation of rarity and density came to be seen by subsequent generations of Greek thinkers to be equally problematic. Democritus and Leucippus explained rarefactions and condensations in terms of atoms either receding from or approaching toward one another. The ancient atomists never actually gave any further explanation as to how atoms could recede from or approach each other. Given their belief that there were only atoms and the void, the atoms of a rarefied substance ought to be considered as

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6 Plato, *Timaeus*, 49 in Plato, *Dialogues of Plato: Translated into English, with Analyses and Introduction*, ed. Benjamin Jowett (Cambridge, 2010), 542. On Heraclitus' similarity to Anaximenes' view, see Daniel W. Graham, "A New Look at Anaximenes," *History of Philosophy Quarterly* 20 (2003): 1–20; Daniel W. Graham, "A Testimony of Anaximenes in Plato," *The Classical Quarterly* 53 (2003): 327–37.

7 Kirk, Raven, and Schofield, *The Presocratic Philosophers*, 198–99.

8 Aristotle, *Physics* (Oxford, 1999), VIII, 7, 260b, 10–4.

standing apart from one another in the void. But what kept the particles apart? What prevented particles of air, for example, from collapsing together and so condensing into water or even ice?[9]

Again, it was Aristotle who exposed the problematic nature of the atomist account. Aristotle pointed out that the atomist position rested on the assumption that the atoms of any substance were initially at some arbitrary distance from one another and hence depended upon the existence of what Aristotle called "self-determined voids."[10] In the atomist theory, as it were, gold (the densest substance) might be assumed to have particles which are touching one another but that air (composed of atoms of the same matter as gold) can only be so much lighter than gold by having its atoms intermingled with a greater amount of void.[11] The implication follows that air particles can somehow hold themselves apart in void space. If the pre-Socratic atomists themselves ever addressed this problem, their discussion is not recorded. Clearly, for Aristotle, the concept of "self-determined voids" was simply untenable.

Aristotle, always keen to resolve problems by carefully chosen definitions, believed that his own conceptions of rarity and density removed all difficulties. He simply defined condensation and rarefaction in terms of variations in the amount of matter in a given volume. A dense body has more matter in the same volume than a rare body; and a rarefied body has less matter in the same volume, or the same amount of matter spread continuously (without any voids) throughout a larger volume. Rarity and density are defined in terms of the ratio between the amount of matter in

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[9] David J. Furley, *Two Studies in the Greek Atomists* (Princeton, 1967).
[10] Aristotle, *Physics*, IV, 9, 216a, 31.
[11] It is important to note that all atoms are made of the same matter. We easily think of an atom of hydrogen as lighter than an atom of lead, but for the ancient atomists atoms were all made of matter, and all matter was qualitatively the same. This was in keeping also with Aristotelian hylomorphism—mattter could only be differentiated by form. Atomists rejected the notion of form, and so matter could not be differentiated but was always the same.

question and the space that the matter takes up.[12] But, of course, this view is not without its own problems. For example, how is it possible for the amount of matter in a given volume to be increased without the newly introduced matter interpenetrating with the matter that was already there? This seems to violate the unanimously held assumption that it is impossible for two bodies to occupy the same place at the same time. Similarly, if a certain amount of matter is taken out of a previously full volume, how can the remaining matter be held to fill that same volume? In short, Aristotle's account was essentially unintelligible – it might seem unproblematic as a definition, but it was not easy to see how the definition could be translated into actual physical terms. As Thomas Hobbes later suggested, Aristotle's definition depends upon illegitimately separating body from quantity, as though a body may have more quantity at one time and less at another time; but a body does not *have* a quantity that can be varied in this way, a body *is* a quantity.[13]

The historical success of Aristotle's attempt to define the problem out of existence (measured in terms of the longevity of his solution in the scholastic tradition) probably owes much to the fact that the atomist account seemed to depend upon action at a distance. If rarity consisted in the atoms of a body standing apart from one another, there must be some repulsive force operating between them to keep them apart. Even the later Epicurean atomists (at least as represented by Lucretius) fudged this issue. Lucretius did this by arguing that air particles simply moved in to fill the gaps between the atoms of a rarefying substance. Disregarding the atomist dictum that all can be explained by atoms and the void, Lucretius is ready to invoke the principle that Nature abhors a vacuum. He does not explicitly discuss rarefaction in his great poem, *De rerum natura*, but we can perhaps imagine how he might have addressed it by considering his account of how a magnet "attracts" iron:

[12] Aristotle, *Physics*, trans. P. H. Wicksteed and F. M. Cornford, vol. 1 (London, 1929), IV, 9, 217a 32–217b, 369, 371.
[13] Hobbes, *Elements of Philosophy*, 340.

Firstly, there must be a quantity of seeds that flows
Out from the [lode]stone, a streaming wave of seeds that, with its blows,
Knocks away the particles of air that intervene
Betwixt the iron and stone, and when the span that lies between
Is left empty, and a vacuum opens in that place,
The particles of iron slip forward to the empty space…
Because, wherever a vacuum opens up, either to the side
Or up above, the neighbouring particles at once will glide
Into the void, herded by blows that pelt from everywhere.[14]

Here it is necessary to envisage that particles flying out from the magnet drive out the air between the magnet and the iron, but then air particles behind the iron push it into this area of reduced air pressure, and thereby push the iron closer to the magnet. In this following passage Lucretius refers to the iron as "the ring" (having elected to use an iron ring in his account):

All at once, the air that lies behind the ring will shove
It forward from the back, and thus compel the ring to move.
The surrounding air forever rains its blows on everything…
This same air nimbly infiltrates the many passageways
Of iron down to its tiniest parts and pushes it, as gales
Of wind impel a ship along by bellying its sails.[15]

If we were able to reconstruct a Lucretian account of rarefaction along similar lines, the question would immediately arise as to what happens in the case of the rarefaction of air. Unfortunately, Lucretius never offers any account of the rarefaction of air. It seems likely that Lucretius was reluctant to introduce the notion of action at a distance into his system. It must be noted that the idea of action at a distance was even then regarded as an untenable view. The closest he came to acknowledging that action at a distance must be involved was when he wrote:

… if they would just admit that there is emptiness
Mixed up in things, then fire could rarefy or could condense.
And yet because their muse perceives some dangerous ground ahead,
And shies away from leaving unmixed void in things, instead,
They veer from the steep drops, only to wander off and stray,
From the true path. Nor do they see that if we take away,
The void from things, then all would be condensed into one mass.[16]

[14] Lucretius, *The Nature of Things*, Book VI: Lines 1002-7; 1018-20, 229.
[15] Ibid., Book VI: Lines 1026-1028; 1031-6, 230.
[16] Ibid., Book I: lines 656–61, 22.

This passage seems to imply that rarefaction is the result of the atoms of the rarefying substance spreading out and leaving a greater amount of "unmixed void" between the particles. However, as Lucretius says, opponents of atomism see "dangerous ground" here – because it seems to imply atoms can remain apart from one another in the void, instead of collapsing together. We cannot suppose that, in view of this comment, Lucretius must accept that atoms can somehow keep themselves apart in the void, because elsewhere he explicitly denies that the atoms have any powers or forces:

> If you should think these atoms have the power to stop and stay
> At a standstill, and set new motions going in this way,
> Then you have rambled far from reason and have gone astray.
> Since atoms wander though a void, then they must either go
> Carried along by their own weight or by a random blow
> Struck from another atom, seeing that when atoms crash
> Into one another, they bounce apart after the clash…[17]

Lucretius clarifies here that his readers misunderstand if they think that atoms have any intrinsic power, or if they think there are forces to compel action between atoms. The atoms are just moving: either as a result of their weight, or by collision with other moving atoms. Epicurean atomism is an austere system of physics, merely kinetic without any powers, virtues, or forces. Thus, it seems clear that Lucretius did not believe in "repulsive forces" between particles, capable of keeping them apart from one another. In terms of the explanation above, it seems likely that he would have believed that during the rarefaction of a substance, its particles spread out, and air enters into the spaces between them, keeping them apart. The best we can do if we wish to understand the rarefaction of air is to suppose that particles of fire drive the air particles further apart from one another, leaving greater voids between the particles—voids which are maintained simply by the subsequent independent motions of the air particles. But then the question arises as to whether fire can be rarefied, and if so, how? Certainly, in later traditions light was often seen as a

[17] Ibid., Book II: lines 80–7, 38.

rarefied form of fire (or fire was condensed light, as could be seen when using a lens to focus the rays of the Sun), but Lucretius nowhere discusses it.

To sum up, Lucretius seems to imply that rarity can be explained by a body having "more vacuum in it," and yet he implicitly denies actions at a distance and elsewhere implies that air flows in to fill the space between bodies and to keep those bodies apart. This was one of the most intractable problems of atomist philosophy. As I will suggest in what follows, it was not to be solved until Newton simply supposed, on what he regarded as unassailable empirical grounds, the existence of repulsive forces capable of operating at a distance between the particles of bodies.[18]

The fact that the ancient atomists did not properly address this point strongly suggests that their concern was less to do with the niceties of the problem of rarefaction and condensation, and more to do with establishing the existence of void space. There was a classical experiment that atomists presented as evidence supporting the existence of micro-vacua: a vessel filled with loose ashes could be shown to hold as much water as the vessel did when it was empty. Although the atomists tried to use this to confirm the existence of empty space between the particles of ash, their opponents simply claimed that there was air between the particles of ash and the water displaced the air.[19] The obvious inadequacy of this experiment for demonstrating the existence of void space strongly suggests the atomists themselves did not want to develop alternative scenarios in which they might be revealed as subscribing to actions at a distance.

If Aristotle's account of condensation and rarefaction had its own problems, it was nonetheless accepted without much dissent throughout the period of scholastic

[18] See below, section 6.5; and Henry, "Gravity and *De Gravitatione*".
[19] Saul Fisher, *Pierre Gassendi's Philosophy and Science: Atomism for Empiricists* (Leiden, 2005), 330. See also, Charles B. Schmitt, "Experimental Evidence for and against a Void: The Sixteenth-Century Arguments," *Isis* 58 (1967): 352–66.

domination, although there were disagreements about the details. Aristotle's suggestion that "all that grows or shrinks changes locally in that it changes its size", was taken up by William of Ockham who argued that rarefaction involved the local movement of a body into an adjoining space while still occupying its original place. Jean Buridan, however, noted that a bellows with its exit blocked could only be compressed up to a certain point, and so the air must have a distinct quantitative form or magnitude preventing it from being moved any further, and so condensation and rarefaction are not simply kinds of local movement.[20] Throughout the Middle Ages the atomist account was known only through Aristotle's critique of the pre-Socratic atomists, Democritus and Leucippus, and so it is hardly surprising that their views were never seriously considered. Those medieval philosophers who chose atomism as a way of exposing fault-lines in the Aristotelian system, thinkers like Nicholas of Autrecourt, William Crathorne, Roger Bacon, and even John Wyclif, did not discuss condensation and rarefaction but focussed instead on issues such as the continuum and the divisibility of body, and matter theory.[21] Things only began to change after the latter part of the fifteenth century when a number of crucially important Ancient atomist works became newly available in the Latin West: the full text of Plato's *Timaeus*, Lucretius' *De rerum natura*, and the three letters of Epicurus preserved in Diogenes Laertius' *Lives of the Philosophers*.[22]

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[20] Aristotle, *Physics*, 2: VIII, vii, 260b, 357. On Ockham's position see James A. Weisheipl, "The Interpretation of Aristotle's Physics and the Science of Motion," in *The Cambridge History of Later Medieval Philosophy: From the Rediscovery of Aristotle to the Disintegration of Scholasticism, 1100–1600*, ed. Anthony Kenny et al. (Cambridge, 1982), 531. On Buridan, see Jack Zupko, "John Buridan," in *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta, Fall 2018, accessed September 10, 2018, https://plato.stanford.edu/archives/fall2018/entries/buridan/.

[21] Christophe Grellard, "Nicholas Of Autrecourt's Atomistic Physics," in *Atomism in Late Medieval Philosophy and Theology* (Leiden, 2008), 107–26; Aurélien Robert, "William Crathorn's Mereotopological Atomism," in *idem*, 127–62; Emily Michael, "John Wyclif's Atomism," in *idem*, 183–220. A. G. Molland, "Roger Bacon's Corpuscular Tendencies (and Some of Grosseteste's Too)," in *Late Medieval and Early Modern Corpuscular Matter Theories*, (Leiden, 2001), 57–73.

[22] Klibansky, Raymond, *The Continuity of the Platonic Tradition during the Middle Ages: Outlines of a Corpus Platonicum Medii Aevi* (London: The Warburg, 1939); W. B. Fleischmann, "Lucretius Carus," in *Catalogus Translationum et Commentariorum: Medieval and Renaissance Latin Translations and Commentaries*, ed. Paul Oskar Kristeller, F. Edward Cranz, and Virginia Brown, vol. 2 (Washington, DC, 1960), 349–65; Greenblatt, *The Swerve*; Ilario Tolomio, "Editions of Diogenes Laertius in the

From Francis Bacon's coiling matter to Mathew Hale's natural states

If we now "fast-forward" to consider the scene in early modern England, we should begin with the first major philosopher to appear in England since the Middle Ages, Francis Bacon. The problematic nature of condensation and rarefaction was certainly noticed by Francis Bacon, who conducted a series of careful experiments to establish the relative densities of different substances, and who went on to discuss his results in a *Historia Densi & Rari* (*c*. 1622).[23] Taking issue with Aristotle's view, he wrote:

> it is… impossible to deny that there is ten times more matter in one barrel of water than in one of air. Thus if someone claims that a whole barrel of water could be one barrel of air that would be exactly the same as claiming that something could be reduced to nothing. For a tenth of the water would be enough for the purpose, necessarily leaving the other nine parts to be annihilated.[24]

Bacon developed his own view of condensation and rarefaction in his influential *Novum organum* (1620). As we might expect, he developed a theory of rarity and density which drew upon occult and vitalist ideas. He considered that matter itself has an inherent tendency to expand and contract, so that it "coils and uncoils itself in space without a vacuum interposing itself"; thus rarefaction and condensation were due to matter's own power.[25] This view of matter, on the other hand, was also conceived as having a close relationship with motion.

In *Novum Organum* he undertook to detail what he called "instances" of different kinds of "Quantity", the aim of which was to "measure virtues according to the *Quantum* of bodies, and show what the *Quantum of a Body* does to influence the

Fifteenth to Seventeenth Centuries," in *Models of the History of Philosophy: From Its Origins in the Renaissance to the "*Historia Philosophica*,"* ed. C. W. T. Blackwell and Philip Weller, 5 vols (Dordrecht, 1993), i: 154–160.

[23] Francis Bacon, "History of Dense and Rare; or of the Coition and Expansion of Matter in Space", in Bacon, *OFB XIII*. Silvia Manzo, "From *Attractio* and *Impulsus* to Motion of Liberty : Rarefaction and Condensation, Nature and Violence, in Cardano, Francis Bacon, Glisson and Hale," in *Early Modern Philosophers and the Renaissance Legacy*, ed. Cecilia Muratori and Gianni Paganini (Dordrecht: Springer, 2016), 99–117.

[24] Francis Bacon, *History of Dense and Rare; or of the Coition and Expansion of Matter in Space*, ed. Graham Rees, *OFB XIII: The Instauratio magna: Last Writings: Last Writings* (Oxford, 2000), 39.

[25] Francis Bacon, *Novum Organum*, Part II, Aphorism 48, 415.

Mode of the Virtue".[26] One of these categories was what he called "Instances of Wrestling" or "Instances of Ascendancy", which indicates "the ascendancy of virtues over each other or their submission to each other". Bacon added that he would therefore "set down first of all the main species of motions or active virtues to make clearer their comparative strength".[27]

Under this heading of instances of Wrestling or Ascendancy, Bacon included the motion of resistance in matter, the motion of connection, and the motion of liberty. The latter was most directly connected to his thinking on condensation and rarefaction:

> Let the third motion be the one we call motion of *Liberty*, the motion by which bodies exert themselves to be free of preternatural pressure or stretching, and to restore themselves to a dimension convenient to their body. Examples of this motion are countless … But because this motion of liberty is the most obvious of all, and touches on an infinite number of things, it would be a good idea to delimit it with clarity and precision.[28]

It is worth noting at this point that this statement shows the importance of condensation and rarefaction to Bacon – this motion is "the most obvious of all", and "it would be a good idea to delimit it with clarity and precision". He began his account by stating that:

> if air under compression wanted to take on the density of water, or wood the density of stone, there would be no need for *penetration of dimensions*, and yet their compression could be far greater than any that they actually sustain. In the same way if water wanted to dilate to the rarity of air, or stone to that of wood, there would be no need for a *vacuum* and yet their extension could be far greater than any that they actually sustain. Thus things do not come to *Penetration of dimensions*, and a *Vacuum*, except at the extremes of condensation and rarefaction, since these motions stop and leave off long before they get to that point, and are nothing more than the desires bodies have for conserving themselves in their proper consistencies (or, if people like, their own forms), and for not suddenly departing from them unless they are altered by gentle means and by consent.[29]

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26 Ibid., Part II, Aphorism 47, 381.
27 Ibid., 383.
28 Ibid., 385–87.
29 Ibid., 387.

In general, Bacon's account of this "third motion" is rather obscure, and thus it is difficult to know what Bacon truly had in mind. But, there are sufficient indications here that he was thinking of rarity and density as problematic phenomena that could only be explained by recourse to occult principles. Bacon seems to be assuming that bodies can restore themselves to their preferred, that is to say to their natural, state (i.e. neither too compressed nor too rarefied). Accordingly, he writes of inanimate bodies wanting to change themselves. Even more significantly, he speaks of the motion of liberty as "nothing more than desires which bodies have for conserving themselves in their proper consistencies". He also emphasizes here that we do not have to suppose interpenetration of matter in compression, or intervening void spaces in rarefaction, except in "the extremes of condensation and rarefaction".

Again, this is obscure because within this third motion Bacon never explains how normal compression and rarefaction take place, and within all "instances of strife" he never pursues the extreme cases. However, it is significant that he is obviously aware of the atomistic account, in which vacua are invoked; if Bacon is correct, "there would be no need for a vacuum", or so he claims. And yet, even he seems to admit that in extreme cases the vacuist account seems to be the only plausible explanation. Bacon explicitly accepted the possibility of actions at a distance, in the *Novum Organum* and elsewhere, and so he might have accepted an atomistic account of rarefaction, and yet he chose not to do so.[30] Indeed, he seems to have used the standard opposition to action at a distance as a reason for rejecting atomism. In his essay, "Cupid, or the Atom", in his *De sapientia veterum* (1609), for example, he objected that:

> Now whoever maintains the theory of the atom and the vacuum… necessarily implies the action of the virtue of the atom at a distance; for without this no

[30] On Bacon's acceptance of actions at a distance see Chapter 3 above. On his equivocal attitude to atomism, see Rees, "Atomism and 'Subtlety'"; Manzo, "Francis Bacon and Atomism".

> motion could be originated, by reason of the vacuum interposed; but all things would remain fixed and immovable.[31]

Clearly, Bacon preferred to see condensation and rarefaction in terms of his vitalistic, or even animistic, "motion of liberty" – and so he focuses not on the extreme cases of rarefaction and condensation but on those which come about "by gentle means, and by consent."[32]

This then raises the question: how exactly does Bacon explain the nature of rarefaction and condensation in his vitalistic or animistic way? Elsewhere under the heading of "Instances of Strife", Bacon made some key comments on the first two motions in answering this question. The "Motion of Resistance is absolutely rock solid and invincible", he stated, but he was undecided about the motion of connection: "I will not declare for certain that a vacuum can exist, be it collected or interspersed." "But", he continued,

> I am convinced that the reason why *Leucippus* and *Democritus* brought it [vacuum] in (namely that without it the same body could not embrace and fill larger and smaller spaces) is false. For there obviously exists a *Fold of Matter* which within certain limits coils and uncoils itself in space without a vacuum interposing itself. Nor is air made up of two thousand times more vacuum (for that is what it would take) than gold is.[33]

Bacon proposed natural propensities embedded in matter, so that everything in the material universe has a natural tendency to cohere and persist in its own situation, and its own natural state.

Returning to Bacon's third motion, it is clear that Bacon also uses it to explain some phenomena of violent motion. Bacon suggests that the motion of liberty plays a role in impacts and collisions. Remarkably, Bacon introduces elasticity into the

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31 Bacon, *The Philosophical Works of Francis Bacon*, ed. John M. Robertson, 841. Familiar with the kinetic theory of gases, as we all are, we can see that Bacon's "necessarily" does not hold. But, for Bacon, and many of his contemporaries, writing before Cartesian kinematics took hold, atomism seemed unavoidably to imply action at a distance.

32 Bacon, *Novum Organum*, Part II, Aphorism 48, 387.

33 Francis Bacon, *Novum Organum*, Part II, Aphorism, 48, 415. See also Rees, "Atomism and 'subtlety'".

discussion, by suggesting that when a body is thrust by the impact of another body there is no movement until the parts of the impacted body are compressed by the impelling body more than their nature will bear. As Bacon wrote:

> But it is far more necessary (for a great deal turns on it) to persuade men that violent motion… is nothing other than motion of liberty, i.e. from compression to relaxation. For in every simple thrust or flight through the air no movement or local motion takes place before the parts of the body are preternaturally acted on and squeezed by the body impelling it. Then, indeed, when some parts push others one after another, does the whole get carried forward…[34]

A stationary body, hit by another body, therefore, does not immediately move, but is first compressed by the impact, and the body's own internal "motion of liberty" will then cause it to move away from the impacting body, so that the parts "can free themselves or bear the strain more equally". It seems, therefore, that condensation and rarefaction did play an important role in Bacon's physics – as he said, "because… this motion… is the most obvious of all, and touches on an infinite number of things" – they are not simply changes that bodies passively undergo, but they reveal the ability of bodies to determine their own volume, to restore themselves to their natural state, and to react to maintain themselves during and after a violent collision.[35]

In short, Bacon held a vitalistic theory, of coiling and uncoiling matter, to explain rarefaction and condensation, as well as motion. He held to the view that bodies had a natural state which they somehow maintained; and so a body subject to compression would restore itself upon release, and similarly, a rarefied body would gather itself back together as soon as possible to regain its natural state. As a natural philosopher with no commitment to atomism, he also denied the atomist theory of particles moving apart and together in a void and thus avoided any need to suppose

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[34] Ibid., 387–89.
[35] Ibid., 387.

actions at a distance: "Now whoever maintains the theory of the atom and the vacuum… necessarily implies the action of the virtue of the atom at a distance."[36]

Bacon's coiling and uncoiling, matter is obscure, and the idea would soon be left behind as succeeding generations of English philosophers increasingly turned to corpuscularist philosophies. But his ideas were not completely without influence. Matthew Hale (1609–1676), leading jurist and a dilettante natural philosopher, also recognised the problematic nature of condensation and rarefaction, and evidently believed that his own ideas on the matter were superior to those of his contemporaries. Accordingly, it was one of the topics on which he published a short treatise. But it is clear that his *Observations Touching the Principles of Natural Motions, and Especially Touching Rarefaction & Condensation*, which he refers to as "this dark and intricate Enquiry touching Rarefaction and Condensation", was clearly influenced by Francis Bacon.[37] Hale obviously regards these phenomena as among the most difficult to understand. Firstly, like Bacon, he rejects the atomist account, which involves vacua between the particles;[38] and then he rejects the Cartesian account, which is similar to the atomist account but argues that the spaces between corpuscles are not void, but are filled with very fine (i.e. smaller) particles (and in the case of rarefaction, more fine particles are intruded in the space between the corpuscles).[39] Hale evidently sees his own account as defending the ideas of Aristotle, and yet he also acknowledges that he agrees with the ideas of Francis Bacon.[40] The Baconian aspect of Hale's thought can be clearly seen in his belief that bodies spontaneously revert back to their natural state, after being forcibly condensed,

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36 Francis Bacon, "De Sapientia Veterum", in *The Philosophical Works of Francis Bacon*, ed. John M. Robertson (London, 1905), 841.

37 Matthew Hale, *Observations Touching the Principles of Natural Motions; and Especially Touching Rarefaction & Condensation: Together with a Reply to Certain Remarks Touching the Gravitation of Fluids* (London, 1677), 133. See also Alan Cromartie, *Sir Matthew Hale, 1609-1676: Law, Religion and Natural Philosophy* (Cambridge, 1995).

38 Hale, *Observations*, 55–66.

39 Ibid., 67–77.

40 Ibid., 102, 105–6.

or forcibly rarefied. As he stated at one point, “in Rarefaction by Heat, or by tension, of a Cubical Foot of Air in a Vessel”,

> … it is visible that the Air, and every particle of it, gains a larger extent every way; for it will break the Vessel, unless it have vent, which it could not do, unless the entire body were extended, and not barely the *Superficies,* because unless the whole *Moles* [i.e. mass] were every way expanded, it would have room enough within it self for its reception without breaking the Vessel that contains it. Again, *when the Heat decays, and consequently the Air relaxed from that extent, it endeavours its own contraction to its just and natural size and texture which it lost for the time*, by the foreign violence of expansion by Heat or Tension, *and this by a natural motion of restitution to its natural texture…* [41]

And a bit later, Hale further explained that, “Air in its natural constitution, hath a certain determinate texture belonging to it, and consequently a just and natural extension proportionate to that texture.” Furthermore, it will endeavour to return to its natural state by a “motion of restitution”.[42]

But this ability of things to restore themselves to their natural states is in keeping with Hale’s theory of spontaneous motion. It is surely significant that before providing his theory of condensation and rarefaction Hale actually discusses in the first chapter “Motion, and its Original”.[43] At the end of this chapter, he states: “but that there are created Beings, that by the powerful and soveraign Institution of Almighty God, have an immediate Principle of Motion in and from themselves, is beyond Dispute.”[44] But he then goes on to suggest that even what we think of as inanimate bodies have an “immediate Principle of Motion in and from themselves.” He ends the chapter with these words:

> And the same is evident in the Motions of Augmentation and Conformation of Vegetables, the motions of Ascent and Calefaction in Fire, the Motions of Attraction and Aversation in Magnetical Bodies, and the very Motion of Descent in heavy Bodies; and infinite more instances of Physical Bodies, which have an intrinsick principle of exciting and communicating Motion… Now touching this internal immediate principle of Motion, is this Enquiry upon which I am.[45]

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41 Ibid., 100–2.
42 Ibid., 103.
43 Ibid., 1–7.
44 Ibid., 6.
45 Ibid., 6–7.

Significantly, Hale pointed out that this essay on condensation and rarefaction is actually an Enquiry into “this internal immediate principle of Motion”. He follows this up with a further discussion of the cause of motions, which begins by clarifying that there must be “a third kind of Existence or Entity”. This entity “giveth Life, Vigor, Activity, and Motion, immediately next under the Lord of Nature, to every self-moving Being.” Hale later referred to this third kind of entity as “vis, or *Virtus Activa*”, “superadded to Matter, and giving immediately those Motions to it, that are specifically appropriate to that *Vis,* or *Virtus Activa,* and without which, Matter would be stupid, dull, unactive, and alwayes at rest in it self, unless accidentally moved *ab extrinseco.*” Hale then went on to distinguish a hierarchy of *Virtutes Activae*, or “active qualities”.[46]

To sum up, Hale saw rarefaction and condensation as the result of an “internal immediate principle of motion,” namely, *vis activa*. It should be noted that Hale was writing in the 1670s much later than Bacon, when the Cartesian strict version of the mechanical philosophy was highly prominent in Europe. As an English natural philosopher, Hale developed the view of active qualities here not only as an answer to the causes of rarefactions and condensations but also the causes of motion, thereby rejecting the Cartesian account of completely passive matter in inertial motion. Although Hale’s work attracted critical responses from Henry More and Robert Boyle[47], it and Bacon’s account serve to show that the corpuscularian attempts to deal with the phenomena of condensation and rarefaction were perceived to be problematic themselves. As far as Hale was concerned, no philosopher had yet given a satisfactory account of it.

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[46] Ibid., 7.
[47] Michael Hunter and Edward B. Davis, “The Making of Robert Boyle’ s *Free Enquiry Into the Vulgarly Receiv’d Notion of Nature* (1686)”, *Early Science and Medicine* 1 (1996): 204–68.

The beginnings of the mechanical philosophy: Light metaphysics and atomism

Even before the mechanical philosophy became well known, before the major publications of Galileo, and Descartes, there were foreshadowings of it in the thought of scattered thinkers: Isaac Beeckman in the Netherlands, who inspired Descartes, and a group of thinkers in England, associated with the so-called "Wizard Earl", Henry Percy, 9th Earl of Northumberland, a leading patron of natural philosophy in England. This group included the much admired mathematician, Thomas Harriot, the ingenious Walter Warner, Nicholas Hill, Robert Hues, and Nathaniel Torporley. Harriot's atomism has been seen as a factor in his reputation for atheism; Warner was recognized by Thomas Hobbes as an early rival in developing a mechanical philosophy, and Nicholas Hill was one of the earliest modern philosophers to go into print with a new system of philosophy inspired by Epicurus, the *Philosophia Epicurea* of 1601.[48] In view of the problematic nature of condensation and rarefaction, it is hardly surprising that this group of new atomists should turn their attention to these phenomena.

Writing before the development of the mechanical philosophy, these thinkers had no resistance to ideas from the natural magic tradition, or other traditions beyond scholastic Aristotelianism. Thinkers like Warner and Hill posited some kinds of "agents", either material or immaterial, that could fill the spaces between the atoms and thus embellished the austere atomism of Lucretius, in which the only causative agents were the moving atoms themselves. Walter Warner, for example, drew upon the medieval tradition of "light metaphysics".

[48] Nicholas Hill, *Philosophia Epicurea, Democritiana, Theophrastica proposita simpliciter, non edocta* (Paris, 1601); Robert Hugh Kargon, *Atomism in England from Hariot to Newton* (Oxford, 1966); Jean Jacquot, "Harriot, Hill, Warner and the New Philosophy," in *Thomas Harriot, Renaissance Scientist*, ed. J. W. Shirley (Oxford, 1974), 107–28; John W. Shirley, *Thomas Harriot, a Biography* (Oxford, 1983).

We saw in the first chapter that the neo-Platonic tradition of light metaphysics, which had been adapted by Robert Grosseteste and Roger Bacon, had been revived by John Dee in his *Propaedeumata aphoristica*. It is possible that Warner learned the principles of light metaphysics, or what should more correctly be called "light physics", from Dee, or possibly from Robert Payne, whose "Short Tract on First Principles", as we have seen, was also indebted to the work of Roger Bacon, and was written when Payne was secretary to William Cavendish, Earl of Newcastle. Warner was a member of the so-called Welbeck Abbey Circle, a group of learned men who gathered around William and his brother, Sir Charles Cavendish, and he knew Payne personally.[49]

Warner took aspects of the light physics tradition and combined them with atomist ideas. This should not be seen as a surprising move for him to make, because even the medieval English contributors to this tradition, Robert Grosseteste and Roger Bacon, have been seen as showing "corpuscular tendencies".[50] Grosseteste's treatise *De calore solis* has been frequently referred to as a contribution to geometrical atomism i.e. atomism in which atoms are held to be indivisible by virtue of being geometrical (non-dimensional) points, but this work mainly focuses on the problem of the Sun's heat. In this treatise, Grosseteste considered "the general or univocal cause of heat" to be a "disgregation (*disgregatio*) or separation of the parts of the body being heated", and it was brought about "by motion or by concentration of rays".[51] After treating rays seemingly as an active principle and having the power to "disgregate", in another treatise, *De motu corporali et luce*, Grosseteste further

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[49] See Chapter 1, especially 1.4 and 1.5 above. For Warner's personal knowledge of Payne, see Malcolm, "Robert Payne," 85, 88–89. See also: British Library, Walter Warner, Correspondence with R. Payne: 1634-1636; Add MS 4279, Vol. II, ff 182, and 307.
[50] Molland, "Corpuscular Tendencies". See also Brandt, *Thomas Hobbes*, where Payne's "Short Tract", attributed by Brandt to Hobbes, is seen as a corpuscularian work.
[51] Molland, "Corpuscular Tendencies", 66.

explained this generation of matter and local motion by means of the propagation of rays or light:

> I hold that the first form of a body is the first corporeal mover. But this is light, which as it multiplies itself and expands without the body of matter moving with it, makes its passage instantaneously through the transparent medium and is not motion but is a state of change. But, indeed, when light is expanding itself in different directions it is incorporated with matter, if the body of matter extends with it, and it makes a rarefaction or augmentation of matter; *for when light is itself charged with the body of matter it produces condensation or rarefaction*.[52]

It should be noted that Grosseteste uses the spontaneous dissemination of light outwards from a point source as justification for the claim that light can act as a driver – driving, or giving activity to, matter. Specifically, in this text he suggests that the spreading out of light can also result in the spreading out, or rarefaction, of matter. We can see the same argument used in his *De luce*:

> I say that light through the infinite multiplication of itself equally in all directions extends matter on all sides equally into the form of a sphere, and as a necessary consequence of this extension, the outermost parts of matter are more extended and more rarefied than those within, which are closer to the center.[53]

This idea of Grosseteste's had a clear influence upon Roger Bacon, who later similarly understood "disgregation" by light as a means of separating corpuscles. In a discussion about heat in his *Opus maius*, Roger Bacon argued that "heat would not be produced except by rarefaction".[54] Grosseteste and Bacon were positing a view which was opposed to that of Aristotle and was closer to an atomist stance. Aristotle sees heat as causing rarefaction, implying that heat acts as the external power to rarify. However, Grosseteste and Bacon adopted an opposed view: it was the process of rarefaction which generates heat, and the cause of rarefaction was the propagation of rays or light.

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[52] Quoted from A. C. Crombie, *Robert Grosseteste and the Origins of Experimental Science, 1100-1700* (Oxford, 1971), 107. See also, Neil Lewis, "Robert Grosseteste", *The Stanford Encyclopedia of Philosophy* (Summer 2013 Edition), Edward N. Zalta (ed.), URL = https://plato.stanford.edu/archives/sum2013/entries/grosseteste/.

[53] Robert Grosseteste, *On Light (De Luce)*, translated by Clare C. Riedl (Milwaukee, 1978), 13, see also 14.

[54] Roger Bacon, *The "Opus Majus"*, edited by John Henry Bridges, in 2 vols (Oxford, 1897), II: 57, quoted from Molland, "Corpuscular Tendencies", 66. See also Crombie, *Robert Grosseteste*, 149.

It was this English tradition which the early modern atomists of the Northumberland Circle tapped into. As Stephen Clucas has claimed, there is a rarely acknowledged set of intellectual debts to this medieval discussion in the atomist views of some of the members of the Northumberland Circle. To be specific, Clucas suggests a conceptual continuity here between medieval metaphysicians, such as Grosseteste and Bacon, and Walter Warner, Thomas Harriot, and Nicholas Hill.[55] Using the resources of Henry Percy's remarkable Library, the library of John Dee, and those of the Oxford Colleges, the philosophers of this circle noticed that Grosseteste's and Bacon's usage of *vis radiativa*, rarefaction and condensation could be used to introduce new, and useful, elements or explanatory tools into the recently revived atomist theory.[56] Hence they remoulded the medieval theory of *vis radiativa*, turning it into an early notion of a conceptual "patch" and an effective and flexible concept approximating a force of atomic cohesion and formation.

The writings of Walter Warner upon matter theory, for instance, make extensive references to a concept of "*vis radiativa*" (radiative force) to explain corpuscular division and composition. Warner states "*vis*" as an "effect power ore vertue which may be called liet whether sensibell or insensi", and the rays of *vis* are propagated in "the form of cones"[57]. He adds that the differences of powers or virtues, "is according to the raet of the cones or Pyramides that rise from one ore sondry bodies and ende in sundri poyentes ma[tters] or plases"[58] Warner continued to develop the notion of "*vis radiativa*" in his writings on matter theory, and used it to explain a wide range of physical phenomena. He explained "weight", for example, as "nothing

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55 Stephen Clucas, "Corpuscular Matter Theory in the Northumberland Circle." in *Late Medieval and Early Modern Corpuscular Matter Theories* (Leiden, 2001), 181–207.

56 Robert Payne, a close associate of Warner, compiled a list of manuscripts which had recently been donated to the Bodleian Library (by Sir Kenelm Digby), and which he particularly wanted to read. This list included works by Grosseteste and Bacon. He also transcribed works by Roger Bacon from the manuscript collection of various Oxford dons. See, Malcolm, "Robert Payne," 86–87. Judging from Payne's and Warner's own works, it is clear that they both read Grosseteste and Bacon.

57 Lambeth Palace Library, Sion College MS L.40.2 (E10), fol. 88v.

58 Ibid.

els but the sensation of *vis* that doth light vpon bodies or impell them w^{ch} is more or lesse according ... to the (quantitie of the) superficies."[59] He then continues:

> Seing therefore nether time and space alone nor time and space wth matter are sufficient wthout the position of some fourth thing for the production of all the species, motions, alterations and effects wh[ich] are actually apparent in the Universe, some such fourth thing, i.e. *vis* therefore to be admitted.[60]

It is evident that the concept of *vis* in Warner's matter theory was to be the active causative principle which acted upon the "discontinuall…parts" of matter, and it was "the squarer and cutter of atomi". It is important to note that Warner considered matter itself to be without any active power – "unactiue and impassible", and incapable of self-moving. Hence the cause of local motion could only be "*vis*" in Warner's account. More importantly, this conception seems to allow Warner to avoid the difficulties of a vacuist position. As he argued, "matter and vertue radiative do fill the uniuersall space", and "*vis*" is omnipresent although "not apparent but upone some positiones and in som degre of [virtue] to move our sences", since *vis* is "enfenet [infinite] and eternall and everywhere" except where it is "hendred by matter."[61]

As John Henry has suggested, "the force or power in and radiating from bodies could be invoked as a cause of motion or interaction when needed, but he [Warner] combined this with more mechanistic modes of interaction."[62] Warner came to the conclusion that substances are merely an effect of atomic composition, particular things are "nothing els but several portions of matter invested wth divers and severall formes."[63] He then maintained that colour and weight were effects of *vis*, by the same token, "rarity and density of parts" are also the effects of *vis*, for "this rarity

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59 British Library, Add. MS 4395, fol. 399r.
60 Ibid., Add. MS 4394, fol. 389r.
61 Lambeth Palace Library, Sion College MS L.40.2 (E10), fol. 831r.
62 John Henry, "The Origins of the Mechanical Philosophy in England. Thomas Hobbes's Debt to Walter Warner," *Occasional Papers of the Thomas Harriot Society* (Durham, 1985), 23.
63 British Library, Add. MS 4394, fol. 396*v*.

and density relates directly to the proportion of *vis* to matter."[64] It seems that Warner used *vis* to explain rarefaction by its ability to spread out the atoms of various bodies. He even uses the term "disgregation" to suggest a weakening of the virtue of atoms ("annihilating of virtue by disgregation").[65]That is, he believed the atoms were held apart from one another, not by an action at a distance between particles, but by the continual flow of *vis radiativa* through the rarefied body, thereby holding its particles apart. This view clearly relates to that of Grosseteste and Bacon, as Clucas suggested. Consequently, *vis radiativa* could be seen as a satisfactory explanation for rarefaction.

Other philosophers of the same circle took a similar line. *Vis radiativa* likewise plays an important part in the natural philosophy outlined in Nicholas Hill's *Philosophia Epicurea*. With regards to the notion of rarefaction and condensation, the similarities between Hill's idea and that of Warner are evident. Like Warner, he augments his belief in atomic composition with *vis radiativa* as an active principle, which seems to have been influenced by the theories of Grosseteste and Bacon.[66] In the same way, *vis radiativa* makes a noticeable appearance in the manuscript notes of Thomas Harriot, who also alluded to an atomic explanation of refraction in his correspondence with Kepler. Harriot refers to whiteness (albedo), for example, as "nothing else but accidentall forme generated by the acte of radiatiue vertue."[67] In addition, in his notes on the parabolic motion of projectiles he refers to the action of "*vis*... materiall or immateriall,"[68] an uncertainty which recalls the ambiguous nature of *vis* in Warner's theory of *vis radiativa*.

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64 Ibid., fol. 384*v*.
65 Ibid., fol. 397*r*.
66 Hugh Trevor-Roper, "Nicholas Hill, the English Atomist," in *Catholics, Anglicans & Puritans* (London, 1989), 1–39.
67 British Library, Add. MS 6786, fol. 428r.
68 Ibid., Add. MS 6789, fol. 30v.

In short, it is clear from these brief considerations that Warner, Hill and Harriot all had recourse to the mediaeval light metaphysical concept of *vis radiativa*. There was an intense interest in mediaeval natural philosophy at the Elizabethan court, initiated by John Dee who was interested in the magnetic theories of Pierre de Maricourt (Peter Peregrinus), and in Roger Bacon's reputation as a magician, but this also spread into the English universities, where a number of the dons collected medieval manuscripts on natural philosophy and natural magic.[69] The direct influence of mediaeval light metaphysics in shaping late sixteenth- and early seventeenth-century English conceptions of force and power has also been shown in the case of John Dee's natural philosophy.[70] However, this influence still needs to be further reinforced. As has been argued in this section, in the case of Hill and Warner, this medieval concept of *vis radiativa* was an important component of their mechanical corpuscular philosophy, providing them with an effective and flexible concept, a radiating force, which could be called upon to explain, amongst other things, the spreading out in space of the particles of rarefied bodies. The particles of rarefied bodies would not be standing apart as a result of their own actions at a distance, but as a result of the lines of force radiating between them and through them, as Warner insisted, "matter and vertue radiative do fill the uniuersall space".[71]

The Renaissance period can be seen as a period of revival of natural magical traditions and of increased recourse to supposedly occult principles, as an alternative to what was frequently perceived to be the moribund scholasticism of the Middle Ages. The revival of ancient atomism initially went hand in hand with this increasingly occult natural philosophy, but the beginning of the seventeenth century saw the emergence of a radically anti-occult version of corpuscular philosophy, the

[69] Mordechai Feingold, *The Mathematicians' Apprenticeship: Science, Universities and Society in England 1560-1640* (Cambridge, 1984).
[70] Clulee, *John Dee's Natural Philosophy*. See also Chapter 1 above.
[71] Lambeth Palace Library, Sion College MS L.40.2 (E10), fol. 831r.

so-called mechanical philosophy, in which the emphasis was upon "matter in motion," rather than "atoms and the void." Specifically, it was summed up in Descartes's statement in *Principia Philosophiae* (1644) that "there are, in rocks or plants, no forces so secret, no marvels of sympathy or antipathy so astounding, and finally, no effects in all of nature which are not properly attributed to purely physical causes".[72] Clearly, "self-determined voids" and self-moving particles would be as unacceptable to the mechanical philosophers as they had been for scholastic Aristotelians.[73]

Even the most ingenious and philosophically astute of the new mechanical philosophers, Descartes, failed to deal in a satisfactory way with the phenomena of rarefaction and condensation. "Rarefied bodies," he suggested, "are those with many spaces between their parts which are filled by other bodies. And rarefied bodies only become denser when their parts, by approaching one another, either diminish or completely eliminate these spaces."[74] Implicit in this suggestion is the assumption that the bodies occupying the spaces between the particles of the supposed rarified body are somehow less dense than the rarefied body (otherwise, the rarefied body would not become denser as its parts came closer together and excluded those intruding bodies). This immediately raises the question as to how their lesser density is explained – any attempt to suggest it is due to there being many gaps between their parts leads to an infinite regress, and so Descartes has to assume these bodies simply are less dense – which begs the question. By providing the example of a sponge, Cartesian philosophy shows its clumsiness in terms of the explanation of rare and dense.

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72 Descartes, *Principles of Philosophy*, Part IV, § 187, 275; Hugh Trevor-Roper, "Nicholas Hill."
73 Carla Rita Palmerino, 'The Isomorphism of Space, Time and Matter in Seventeenth-Century Natural Philosophy', *Early Science and Medicine* 16 (2011): 296–330.
74 René Descartes, *Principles of Philosophy*, Part II, § 6, 41–42.

Descartes considers that rarefaction takes place when a squeezed sponge is released and the holes in its structure spring back open, but the holes are immediately filled with air or the subtle matter which Descartes invokes in order to fill in the gaps between larger particles. He then argues that this is "the only intelligible way of explaining rarefaction."[75] Descartes did not allow void space, and so he cannot consider voids as another intelligible way of explaining rarefaction, but his own explanation is by no means as intelligible as he professes. Given that matter is defined solely in terms of extension, we have no grounds to assume that one piece of extended matter is any more or less dense than any other part – so the particles filling the holes in the sponge must be as dense as the sponge itself (in the Cartesian plenum there can be no empty spaces, so all matter is effectively continuous throughout the universe), so there can be no difference in density between a squeezed sponge and a released sponge. Although Descartes seems to have been completely unaware of his error, the fact that he begged the question about the causes of rarity and density in this way surely indicates that ancient atomism provided the model for his account and that rarefaction involved "more vacuum" between the particles. Clearly, Descartes could not allow "more vacuum" between particles, so he unthinkingly substituted "more rare particles" between particles.

Pierre Gassendi did not fall into the same solecism. Gassendi was never convinced by Cartesian mechanical philosophy and always allowed for empirically justified occult elements or active principles within his atomist natural philosophy. Even so, his adaptation of Epicurean atomism meant that he inescapably confronted the same difficulty as his atomist predecessors.[76] In *Syntagma philosophicum*, Gassendi cited a number of chemical phenomena as examples – the saturation of water with salt, the dissemination of dyes through water, and the penetration of air and water by light,

[75] Ibid.
[76] Margaret J. Osler, *Divine Will and the Mechanical Philosophy: Gassendi and Descartes on Contingency and Necessity in the Created World* (Cambridge, 1994).

heat, and cold (all of which he assumed to be corpuscular). Noting that water saturated with some salt was still as competent in dissolving alum as pure water would have been, he therefore drew the conclusion that there must be miscellaneous variously shaped micro-vacua in the water, each type of which receives exactly one type of (suitably shaped) corpuscles. From this, he simply confirmed his point that interstitial voids are an undeniable aspect of the atomic theory of matter.[77] It is important to note, however, that the picture he presents is one of atoms touching one another in such a way that they define differently shaped interstitial void spaces. So, atoms might form a lattice with square-shaped holes, between them, or star-shaped holes, and so on. Each of these holes can be filled (e.g., in chemical reactions) by other appropriately shaped particles. Gassendi's voids are not self-determined but are determined by the geometry of the particles themselves, the way they are stacked, and so forth. In this way, Gassendi avoids any suggestion that atoms stand apart from one another in the void – they are touching one another. But this schema only allows for very limited rarefactions and condensations – we can imagine particles stacked with square holes between them being compressed so that the particles end up, let us say, with smaller triangular holes between them. The effect would be that the body made up by these particles would be denser after compression. It is impossible to second-guess how Gassendi might have dealt with cases of extreme rarefaction, however, as revealed in experiments using the air pump developed later in the century.

Another leading mechanical philosopher, Thomas Hobbes, was evidently so baffled by rarefaction and condensation that he even went so far as to deny their existence. For Hobbes, the action of a so-called wind-gun, or air gun, which was generally assumed to depend upon compressed air, simply derived from the motion of air. The pumping process to charge the gun did not compress the air in its cylinder, according

[77] Ibid., 185–86.

to Hobbes, but merely put the air in the cylinder into violent motion. It was the violent motion of the air, not some imagined compression, which forced the bullet out of the gun. Similarly, effects in the chamber of the air pump which were generally attributed to extreme rarefaction of the air were said by Hobbes to be caused by violent motions of the air generated by pumping. Given the invisibility of the air, it was impossible to say whether a candle in the air pump was extinguished by lack of air or by a strong gust of air, or so Hobbes insisted. Hobbes's critics, however, were not slow to point out that the same substance could be made to vary in density – something which Hobbes was committed to denying.[78]

The problem of rarefaction and condensation provides an excellent example of both the strength and weakness of the mechanical philosophy in the early modern period. On the one hand the atomist account of rarefaction is immediately intelligible in comparison to all rival efforts, but on the other it seems to demand a concept of repulsive forces operating over the distance between the particles of the rarefied substance—as Bacon wrote: "whoever maintains the theory of the atom and the vacuum… necessarily implies the action of the virtue of the atom at a distance".[79] The problem of how atoms hold themselves apart, or cease to do so and come closer together, was still not satisfactorily explained.

The problem was very clearly stated by Sir Kenelm Digby in his *Treatise on Body* of 1644. Digby calculated that gold is 7,600 times heavier than air. "If all matter *qua* matter is uniform in weight", he said, then "this difference in weight can only be explained by the fact that there is correspondingly less matter in a volume of air equal to a volume of gold."[80] Notice that Digby is still adhering to the pre-modern view that matter is matter—uniform and qualitatively the same, it is not the case that

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78 Simon Schaffer, "Wallifaction: Thomas Hobbes on School Divinity and Experimental Pneumatics," *Studies in History and Philosophy of Science* 19 (1988): 275–298.
79 Bacon, "De Sapientia Veterum", 841.
80 Digby, *Two Treatises*, 20–1.

some matter is heavier or denser than other matter. It follows that the "body of air", when compared with the body of gold occupying the same volume, must "appeare to be like a net, whose holes and distances are to the lines and thriddes in the proportion of 7,600 to one".[81] Digby considered this exaggerated proportion to be absurd, and thus denied it on the basis that

> If such vacuities were the cause of rarity, it would follow that fluide bodies being rarer than solid ones, they would be of themselves standing, like nettes or cobwebbes: whereas contrariwise, we see their natures are to runne together, and to fill up every little creek and corner: which effect, following out of the very nature of the things themselves, must needes exclude vacuities out of that nature.[82]

Digby himself, who was engaged on developing a peculiar hybrid of atomism and Aristotelianism, was content to reaffirm the scholastic view:

> the definitions which Aristotle hath given us of Rarity and Density, are the same wee drive att: hee telleth us, that that body is rare whose quantity is more, and its substance lesse; that, contrariwise dense, where the substance is more and the quantity lesse.[83]

But for those new philosophers who made a point of denouncing Aristotelianism as completely unintelligible, this would never do.

The revival of Epicurean atomism: From moving particles to interparticulate forces

The next significant development in the new philosophy in England was a serious attempt to present an adapted form of Lucretian Epicureanism in England, based largely on the work of Pierre Gassendi. This was Walter Charleton's *Physiologia Epicuro-Gassendo-Charltoniana* of 1654.[84] In this treatise, Charleton offers a standard atomist account of condensation and rarefaction, as he states, that

> whoever shall with due attention of mind profound the nature of Rarefaction and Condensation, must soon perceive; that by those motions a Body doth suffer no more then a meer Mutation of Figure, but its Quantity admits of neither Augmentation, nor Diminution… So as those Bodies may be said to be Rare, betwixt whose parts many Intervals or Interstices, repleted with no Bodies, are

[81] Ibid., 18, 19.
[82] Ibid., 21.
[83] Ibid, 23.
[84] Charleton, *Physiologia Epicuro-Gassendo-Charltoniana*.

> interspersed; and those Bodies affirmed to be Dense, whose parts mutually approaching each to other, either diminish, *or totally exclude all the Intervals or intercedent Distances*.[85]

After showing his atomist approach above, Charleton continues to talk of empty spaces between the particles in keeping with the atomist dictum "atoms and the void", but does not fudge the argument, as we have seen Lucretius did, by introducing air or some subtle aether in between the particles:

> whatever of Extension is found in the Pores, or Intervals made by the mutually receding parts, ought not to be ascribed to the Body rarified, but to those small Inanities that are intercepted among the dissociated particles… into a more lax and open contexture.[86]

Charleton is writing before the air-pump made the phenomenon of extreme rarefaction hard to deny, and it looks as though he is suggesting here that the structure of a rare body is more "open" but that the constituent particles of the body remain in contact. So, if we imagine star-shaped particles, the body in question would be rarefied when the particles remain in contact merely by the tips of the points of the stars, and condensed when the points of the stars lay alongside, or overlapping with, one another. He can talk of void spaces between the particles, therefore, without supposing the need for any actions at a distance.

After setting this up, Charleton's next step was to query how the air returns to its natural state after rarefaction or condensation – or, rather, he asks how the vacuities between particles return to their normal dimensions: "What Elaters or Springs are in the aer, which may cause its suddain restitution to its natural constitution of insensible particles?"[87] Charleton's answer perhaps shows the influence of Bacon, because he suggests this restitution is in keeping with a widespread law of nature – a law of conservation. According to this, the air particles restore themselves to their natural contexture, or natural state. It is interesting to note, however, that where Bacon was happy to talk in terms of vitalist or occult principles in matter itself,

[85] Ibid., 17.
[86] Ibid., 17, 25–29.
[87] Ibid., 34.

enabling it to return to its natural state, Charleton avoids such talk by introducing the concept of a law of nature. Charleton is aware of the spreading influence of Descartes, and the praise being garnered by the mechanical philosophy and its rejection of occult qualities and principles, and does not want to weaken his own philosophical system by making it seem overtly occult.

Even so, Charleton seems to accept that particles can move themselves:

> as Water by Rarefaction, or Attenuation becomes a Vapour; so may we conceive Flame by Attenuation to become Light circumfused in the aer: and as a Vapour is nothing else but Water so rarefied into small discontinued particles, as that it doth scarce moisten the body on which it is impacted; so is Light nothing else but Flame so dilated by Rarefaction, that it doth hardly warm the body it toucheth. Lastly, as a Vapour how finely soever rarefied, is still substantially Water; because only by the Coition of its diffused particles it returns again to Water, as in all distillations: so must we account Light however rarefied, to be still substantially Flame; because only by the Coition, or Congregation of its dispersed rayes it is reducible into absolute Flame…[88]

More importantly, this passage shows that Charleton does not regard rarefaction as merely an effect caused by heat, or fire. Flame itself can be rarefied to form light—a light that "doth hardly warm the body it toucheth". Clearly, the logic of this suggests that the process of rarefaction is not an effect of heat—if it was, we would expect light to be hotter than flame, since it is a rarefied form of flame. It now seems that in spite of the increasing dominance of Descartes on the philosophical scene, Charleton seems to be smuggling non-mechanical ideas into his natural philosophy. One way or another, his account of rarefaction and condensation seems to suffer from the same problems confronting all earlier writers. As Kenelm Digby wrote of condensation in his *Treatise on Body*, "how this comprehension of more body in equall roome is effected, doth not a litle trouble Philosophers",[89] and Charleton fares no better than any of his predecessors.

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[88] Ibid., 205.
[89] Digby, *Two Treatises*, 16.

Robert Boyle, too, was not a little troubled by condensation and rarefaction. In his *Defence of the Doctrine Touching the Spring and Weight of the Air*, of 1662, a reply to the criticisms of the English Jesuit, Francis Line, Boyle conveniently summed up the alternative explanations as Aristotelian, Cartesian, or Atomist,[90] but he found reasons to doubt each of them. The atomist position must result in "incontiguous Corpuscles"—that is to say, particles which are not touching. Although Boyle does not say so, this is open to the objection that the voids between the particles must somehow be "self determined" (Boyle tacitly excludes from consideration the Gassendist implication that particles are shaped in such a way that they maintain contact while still allowing void spaces between them). Boyle was always sceptical of the Cartesian aether. His own experiments with the air-pump, some of them deliberately designed to test the Cartesian claims, suggested that there was no such thing as an all-pervasive aether, so thin that it could return to the chamber of the air-pump through the glass of the receiver. As for the Aristotelian account, Boyle simply dismisses it on the grounds that it "necessarily supposes such a Rarefaction and Condensation, as is, I confess, to me, as well as to many other considering persons, *unintelligible*."[91]

Boyle brings out the unintelligible nature of the Aristotelian account with a *reductio ad absurdum*:

> if one portion of Air may so easily be brought exactly to fill up a space two thousand times as big as that which it did *but* fill before [i.e. before the operation of the air-pump] without the addition of any new substance; I see not (I say) why the matter contained in every of these two thousand parts of space may not be further brought to fill two thousand more, and so onwards, since each of these newly replenished spaces is presumed to be exactly filled with Body.[92]

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[90] Boyle, *Works*, iii: 42. See also, Franciscus Linus, *Tractatus de Corporum Inseparabilitate; in quo Experimenta de Vacuo, tam Torricelliana quam Magdeburgica & Boyliana Examinantur* (London, 1661).
[91] Ibid., iii: 41.
[92] Ibid., iii: 43.

The problematic nature of condensation and rarefaction became even more urgent for Boyle after various experiments which he recounted in his *A Discovery of the Admirable Rarefaction of Air (even without Heat)*, of 1670. Here, Boyle came to the conclusion that,

> if we make our estimate according to the most prosperous of our Trials, we must allow the Air to be rarefiable at least 13000 times (I say again *at least*) because I am not sure, that in that Tryal it was reduc'd (not fully, though perhaps very near) to the uttermost degree of rarefaction attainable in our Engin.[93]

The other puzzling aspect of these experiments, for Boyle, was that this extreme rarefaction was accomplished not by heating the air, but by using the air's "own spring", that is to say, its own power of expansion. Subsequently, Boyle was able to establish an even greater rarefaction:

> when the uncomprest Air was highly rarefied… [it] will amount to 520000, for the number of times, by which the Air at one time exceeds the same portion of Air at another time: which is a difference of Expansion so great, that I hope it will keep you from thinking the Title of the fore-going Epistle, where the Expansion of the Air is called *admirable*, immodest…[94]

In view of these experimental results, it is hardly surprising that Boyle subsequently wrote of "the scarce credible *Rarefaction* of the *Air*".[95]

In these later writings, Boyle follows his own self-professed Baconian approach, describing the experiments he performed, and reporting their results, but offering no theoretical explanation of such extreme rarefactions. What he did do, however, was to discuss these matters, when he had the opportunity to talk with one of the most brilliant theorists of the age, Isaac Newton. Judging from the apologetic opening of the letter which Newton eventually sent to Boyle, it seems that Newton had also joined the ranks of those philosophers who were "not a little troubled" by condensation and rarefaction—especially in the light of the extreme rarefaction that Boyle had been able to demonstrate using the air-pump. Newton's letter begins:

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93 Ibid., vi: 374.
94 Ibid., vi: 387.
95 Ibid., ix: 123.

> I have so long deferred to send you my thoughts about the physical qualities we spake of, that did I not esteem myself obliged by promise, I think I should be ashamed to send them at all. The truth is, my notions about things of this kind are so indigested, that I am not well satisfied my self in them, and what I am not satisfied in, I can scarce esteem fit to be communicated to others…[96]

Newton was right to be so apologetic. His account depended upon the initial supposition that "there is diffused through all places an aethereal substance," but from then on he simply begged the question. The aether was declared to be "like air in all respects but far more subtile". Moreover, it was said to pervade "all gross bodies, but yet so as to stand rarer in their pores than in free spaces, and so much rarer, as their pores are less."[97] This in turn was "explained" (if that is the correct word) in terms of "a certain secret principle in nature, by which liquors are sociable to some things, and unsociable to others."[98]Newton now uses this supposed density gradient in the aether to explain "the more or less permanency of aereal substances, in their state of rarity".[99] "[T]he excess of density of the external aether above that of the internal" is said to be the cause "which should keep… other such particles [i.e. particles of "gross bodies"] at a distance from one another".[100] It is evident from this last comment that Newton adopts something like the Cartesian view of rarefaction: a spreading out of the particles of a body to take up a greater space, but with the spaces between particles filled by an aether. Unfortunately, however, Newton has already simply assumed that this aether has "graduated rarity".[101]

Whether Boyle responded critically to Newton (certainly, Boyle would have been disappointed to see Newton assuming the existence of a subtle aether—a supposed entity which Boyle believed he had shown by experiment to be non-existent)[102], or

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96 Newton to Boyle, February 28, 1678/79, in Newton, *Papers & Letters on Natural Philosophy*, 250.
97 Ibid.
98 Ibid, 251.
99 Ibid, 252.
100 Ibid, 253.
101 Ibid, 250.
102 Consider, for example, Boyle's comment in *New Experiments Physico-Mechanical, Touching the Spring of the Air and its Effects* (1660): "the *Plenists* (if I may so call them) do not prove that such spaces are replenish'd with such a subtle Matter as they speak of, by any sensible effects, or

whether Newton was simply "ashamed" of this theory (as he indicated at the beginning of his letter), he soon began to think more seriously about the problem of rarefaction. Newton's next attempt to solve the problem of rarefaction was altogether different, and can be seen as an important landmark in the development of Newtonian physics. This appeared in an unfinished manuscript, "De aere et aethere" ("On Air and Aether"), written shortly after his letter to Boyle.[103]

In "De aere et aethere" Newton simply accepts Bacon's insistence that "whoever maintains the theory of the atom and the vacuum… necessarily implies the action of the virtue of the atom at a distance", and develops a coherent theory which, for the first time in the long history of discussions of condensation and rarefaction, explicitly states that particles can hold themselves apart from one another in empty space by virtue of repulsive forces operating between the particles. As in the letter to Boyle, Newton supposes, first of all, that air (not just aether) "seeks to avoid the pores or intervals between the parts of… bodies; and so… the air is more rare [between bodies] than in wider spaces".[104] But he extends this supposed tendency to avoid mutual contact to all bodies: "Moreover air does not only seek to avoid bodies, but bodies also tend to fly from each other."[105]

Interestingly, at this point during the composition of "De aere et aethere" Newton's resolve momentarily failed him and he offered some question-begging explanations of these mutual repulsions:

> Many opinions may be offered concerning the cause of this repulsion. The intervening medium may give way with difficulty or not suffer itself to be much

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operations of it (of which divers new Tryals purposely made, have not yet shown me any) but onely conclude that there must be such a Body, because there cannot be a Void." Boyle, *Works*, i: 198.

[103] Newton, *Unpublished Scientific Papers*, 214–28. The editors suggest this was written between 1672 and 1675, but because it is the first work where Newton explicitly accepts the possibility of actions at a distance, which subsequently forms a major and characteristic aspect of Newton's natural philosophy, it must come after the letter to Boyle. For further discussion, see Henry, "Gravity and *De Gravitatione*".

[104] Newton, *Unpublished Scientific Papers*, 221 [Newton's original Latin, 214–15].

[105] Ibid., 222 [215].

> compressed… Or it may be in the nature of bodies not only to have a hard and impenetrable nucleus but also a certain surrounding sphere of most fluid and tenuous matter which admits other bodies into it with difficulty. About these matters I do not dispute at all.[106]

This passage is crossed out, however, and Newton turns instead to Robert Hooke's reports in his *Micrographia* (1665) that, in the air-pump, air can be "expanded to double or treble or even a hundred or a thousand times its normal space". As Newton immediately infers, this

> would hardly seem to be possible if the particles of air were in mutual contact; but if by some principle acting at a distance [they] tend to recede mutually from each other, reason persuades us that when the distance between their centres is doubled the force of recession will be halved.[107]

This last point conforms to Hooke's experimental findings of the relationship between pressure and condensation or rarefaction.[108]

Newton evidently still assumes the existence of an aether in this work, although it is perhaps significant that he breaks off from writing "De aere et aethere" after writing only one paragraph "De aethere". But the aether is now said to be simply a very attenuated form of air, even "the spirit of air", and it too maintains its rarity by repulsive forces operating at a distance between the particles.[109]

By readily accepting actions at a distance between particles to account for rarefaction and condensation, Newton might be said to have cut the Gordian knot. Except, of course, for the fact that actions at a distance were still held to be deeply problematic. As far as Newton was concerned, however, actions at a distance seemed to offer a way out of all philosophical difficulties. As R. S. Westfall wrote:

> What we do know is that Newton had recast his entire philosophy of nature by 1686–7. In papers composed with the *Principia*… Newton applied action at a distance to virtually all the phenomena of nature.[110]

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[106] Ibid., 223 [216].
[107] Ibid., 223 [216–17].
[108] Hooke, *Micrographia*, 226. Newton's notes "Out of Mr Hooks Micrographia" are reprinted in Newton, *Unpublished Scientific Papers*, 400–13.
[109] Newton, *Unpublished Scientific Papers*, 227–8 [Newton's original Latin, 220].
[110] Westfall, *Never at Rest*, 388.

The actions at a distance in question were, on the one hand, attraction, as exemplified by gravity, and repulsion, as indicated by the phenomena of extreme rarefaction. In the "Conclusio" which Newton drafted for the first edition of the *Principia* (1687) he wrote that

> The particles of vapours and air… not yet assuming the form of vapours or air, cohere with contiguous particles. But as soon as they are separated by the motion of heat or fermentation and recede beyond a certain distance from… each other, they fly apart (as we said) and in receeding from each other compose a Medium which has a strong tendency toward expansion.[111]

Newton went on to make these repulsive forces general: "just as magnetic bodies repel as well as attract each other, so also the particles of bodies can recede from each other by certain forces."[112] He spoke here of a "double force":

> The first force is an attractive one and is the stronger, but it quickly decreases with distance from the particle, the second is a repulsive force which decreases more slowly and on that account extends more widely.[113]

Newton omitted this Conclusion from the published *Principia*, but he drafted a Preface in which he made the same points:

> When the particles of air, exhalations, vapours… are at a distance they repel each other; but when they are brought to touch each other the particles at last cohere and by cohering are turned into solid bodies again. The contiguous particles of all bodies cohere, and their distant ones frequently repel one another.[114]

In the end, Newton avoided these dogmatic statements and restricted himself to saying, in the published version of the Preface that:

> many things lead me to have a suspicion that all phenomena may depend on certain forces by which the particles of bodies, by causes not yet known, either are impelled toward one another and cohere in regular figures, or are repelled from one another and recede.[115]

His readers must have been puzzled by this comment, since they could not have known about the attempts to understand extreme rarefaction in the unpublished "De aere et aethere" which led him to this "suspicion".

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[111] Newton, *Unpublished Scientific Papers*, 337 [324].
[112] Ibid., 336 [324].
[113] Ibid., 338 [Newton's original Latin, 325].
[114] Ibid., 306 [303].
[115] Newton, *Principia*, 382–3.

Even so, Newton's *Principia Mathematica* was soon to make actions at a distance an accepted part of physics (although there were always those who held out against it, such as Huygens, Leibniz, Euler, and others), as demonstrated in the universal principle of gravitation. Accordingly, when Newton finally did set out in print his thinking about interparticulate repulsive forces, in the "Queries" added to the *Opticks*, his account of rarefaction and condensation soon became authoritative. In Quaestione 23, added to the *Optice* (1706), which later became Query 31 in the *Opticks* of 1717, Newton introduced the idea of a repulsive virtue between particles:

> And that there is such a Virtue… seems also to follow from the Production of Air and Vapour. The Particles when they are shaken off from Bodies by Heat or Fermentation, so soon as they are beyond the reach of the Attraction of the Body, receding from it, and also from one another with great Strength, and keeping at a distance, so as sometimes to take up above a Million of Times more space than they did before in the form of a dense Body. Which vast Contraction and Expansion seems unintelligible by feigning the Particles of Air to be springy and ramous, or rolled up like Hoops, or by any other means than a repulsive Power.[116]

If the attractive forces accounted for gravity, cohesion, and condensation, the repulsive forces accounted for change of state and rarefaction. The Queries became immensely influential throughout the long eighteenth century, and Newtonianism was usually associated with the attempt to explain physical phenomena in terms of attractive and repulsive forces operating between bodies. The attractive force originated from attempts to understand gravity, but the repulsive force originated from Newton's attempts to understand rarefaction. Once again, as with Anaximenes, rarefaction and condensation came to be seen as fundamental aspects of the natural world, but now they were seen as major exemplifications of Newton's repulsive and attractive forces.

[116] Newton, *Opticks*, 395–96.

Conclusion

It was shown in Chapter 3 how Newton came to accept attractive forces in his physics, and in this chapter we considered the developments which led him to accept the repulsive forces which he also claimed, in the Preface to the *Principia*, were at work in the world. Newton came to believe in repulsive forces operating between particles as a result of thinking about the extreme rarefactions which Boyle and Hooke were able to achieve using the air-pump. Newton evidently came to believe that no other explanation for such extreme rarefactions was plausible, but it was not a conclusion that he came to easily. Here again actions at a distance seemed to be involved, and at a time when he had not yet thought of writing the *Principia*, this was a difficult idea to accept. In order to show the difficulties presented by rarefaction, and its opposite, condensation, this chapter looked at salient points in the history of ideas about these related phenomena. It was shown that the history of condensation and rarefaction was always problematic, and frequently led thinkers to suggest that there must be some activity inherent in matter. The culmination of such speculations about active matter was Newton's use of interparticulate repulsive forces to explain rarefaction.

The first section showed the problematic nature of condensation and rarefaction among the Ancient Greeks. One of the major problems for the ancient atomist view, as revealed by Aristotle, was that rarefaction seemed to require the formation of "self-determined voids". Even the later atomists, represented here by Lucretius, found this difficult to accept, and failed to give satisfactory accounts of rarefaction. Before looking at attempts to deal with condensation and rarefaction by early modern corpuscularists, the second section looked at early modern thinkers who did not accept atomist, or corpuscularian, philosophies. Again, these efforts, represented here by Bacon and Hale, were shown to be essentially unintelligible. Significantly, however, the theories of both thinkers required matter to be active, and capable of moving itself. Picking up on the tradition of light metaphysics which we have looked at in Chapter 1, the third section showed that the ability of light to expand itself outwards from its source was used as a way of explaining how matter could be expanded to fill a greater volume. As we saw in chapter 1, this tradition was not simply confined to the Middle Ages, but had seventeenth-century proponents—in this case we considered chiefly the writings of Walter Warner. We then looked at the leading atomists and corpuscularians, Gassendi, Descartes, Hobbes, and Kenelm Digby, and showed the difficulties they confronted in trying to avoid the "self-determind voids" that Aristotle had rejected.

The following section turned to the second generation of corpuscularian thinkers in England, Walter Charleton and Robert Boyle. Charleton was shown to have resorted, as earlier thinkers did, to active matter capable of self-movement. Boyle resorted instead to Baconian experiment, and after initial analogies between atoms and wool or springs, refused to commit himself to any explanatory theories. He did, however, ask Newton if he could explain the extreme rarefactions that he and Hooke were achieving with the air-pump. It was shown that Newton's dissatisfaction with his first attempt to answer Boyle led him to write the unfinished "De aere et aethere". This was the first work, written in 1679, where Newton explicitly mentions repulsive forces operating at a distance between particles as a solution to the problem. Extreme rarefaction is only possible if the particles of air are capable of holding themselves apart from one another in space; this required repulsive forces, and since they were standing apart in void space the forces must be acting at a distance. Newton had finally solved the problem and his solution proved influential throughout the eighteenth century.

Conclusion

Throughout the foregoing chapters of this thesis it has become clear that the various aspects of Newton's natural philosophy which can be seen as occult or non-mechanical, those aspects which led R. S. Westfall to see Newton as a participant in the so-called Hermetic tradition, were already current in English natural philosophy, as a result of the influence of major English thinkers who also embraced occult principles. John Dee, Francis Bacon, and William Gilbert formed their ideas before Descartes, or anyone else developed the mechanical philosophy. Reacting against Aristotelian scholasticism, these English thinkers, like other pre-mechanistic thinkers, looked first of all to various occult principles as a new and potentially fruitful way of explaining natural phenomena. Although the scholastics admitted that there must be occult qualities at work in the world, such as magnetism, the purging power of rhubarb, and other phenomena that could not be attributed to the four so-called *manifest* qualities, these occult qualities were hardly discussed in scholastic natural philosophy, and were simply dismissed as "asylums of ignorance."[1] Given this under-exploitation of occult qualities in previous scholastic philosophy, it is hardly surprising that late Renaissance would-be innovators in natural philosophy all turned to occult principles of one kind or another as the most likely way to develop new systems of philosophy.[2]

This situation changed when Descartes and Hobbes, building upon the earlier work of Isaac Beeckman and Galileo, developed strictly mechanical systems of natural philosophy which they believed excluded all occult or unexplained principles. Descartes's mechanical philosophy came the closest to replacing the Aristotelian system, as an equally complete and comprehensive system, and so should be seen as

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1 On occult qualities as "Asylums of Ignorance", "Santuaries of Ignorance", and similar phrases, see, for example, Millen, "The Manifestation", 188–89.

2 For example, Hutchison, "Occult Qualities", 233–53; Henry, "The Origins of the Experimental Method", 702-14.

the most successful of the new philosophies. But not everyone was convinced that the Cartesian system was workable.[3] This seemed to be especially true in England, where Descartes's essentially rationalist approach was immediately seen as incompatible with the advice Bacon gave about the best way to reform natural philosophy. English natural philosophers after Descartes did not simply embrace his strict version of the mechanical philosophy, but developed instead the kind of hybrid natural philosophy, which R. S. Westfall saw in Newton's work. For Westfall Newton's natural philosophy was essentially occult (he called it Hermetic) "disguised by mechanistic veneers".[4] As we have seen in this thesis, however, this was equally true of the leading natural philosophers in England in the generation before Newton, all of whom (except for Hobbes) still accepted what Descartes would have regarded as occult principles and continued to promote their occult or non-mechancial philosophies throughout the time that Cartesianism was spreading in France, the Netherlands, and the German states.

We saw in Chapter 1 how the tradition of light metaphysics, or rather light physics, developed first of all in the work of John Dee, and intimately connected with his insistence that natural philosophy could only be properly understood by analysing the world and natural phenomena mathematically, was taken up by members of the Northumberland Circle (as seen in the work of Walter Warner in Chapter 6), and the Cavendish Circle (as seen in the work of Robert Payne in Chapter 1), and culminated in Newton's belief that light and matter could be converted into one another, and that light could act as an active principle within bodies. It has also been shown (in Chapter 2) how assumptions about inherent principles of activity in bodies, already present in the work of Dee, were developed in detail by Francis Bacon and subsequently shaped the matter theory of the leading English natural philosophers,

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[3] Gabbey, "Mechanical Philosophies and Their Explanations", 441–64.
[4] Westfall, "Newton and the Hermetic Tradition", 185.

including Newton himself (as covered in chapters 4 and 5). And we saw in Chapter 3 how the magnetical cosmology developed by Gilbert and Bacon led to analogies between magnetism and gravity and the assumption that gravitational attraction worked at a distance, as magnets do. Moreover, it has been shown how this magnetical philosophy, principally through the work of Robert Hooke, was taken up by Newton and turned into the universal principle of gravitation. Finally, we saw in Chapter 6 how difficulties in understanding the phenomena of condensation and rarefaction, made especially demanding by the production of extreme rarefaction in the air-pump experiments of Boyle and Hooke, seemed to point to one conclusion—a conclusion that was finally taken by Newton himself when he assumed the existence of repulsive forces operating at a distance between particles of matter. Furthermore, it has been shown how these occult ideas were closely linked with the two most prominent developments in scientific methodology during our period—the mathematization of natural philosophy and the experimental method (Chapters 1 and 2). The former first appeared in England in the work of John Dee, who used it to promote his "mathematical astrological physics". The latter was developed, of course, by Francis Bacon, and, as is well known, was subsequently promoted by the Royal Society.[5] Newton used both methods to great effect—arguably to greater effect than anyone before him—and in so doing was taking further these two innovatory methodologies of the sciences.

It is not necessary to assume that Newton was directly influenced by any of these thinkers, and their particular philosophical positions. The aim has been to show that these non-mechanical ways of thinking, and the use of the methodologies to support them, were fairly commonplace in English natural philosophy and were available for Newton to take them up or to reject them as he saw fit. The evidence suggests that

[5] William Gilbert used the experimental method, but he did not discuss the philosophy behind it, in a bid to persuade his contemporaries of its usefulness. It was Bacon who did that in his *Novum organum* (1620) and other works.

Newton never was a convinced Cartesian, and even his earliest writings, such as his early alchemical piece, "Of Nature's Obvious Laws & Processes in Vegetation", show a combination of occult ways of thinking with more mechanistic approaches (light and aether are assumed to be self-active, but there is an attempt to provide a mechanistic theory of gravity).[6] As he matured, Newton's natural philosophy maintained these same English characteristics, and continued to combine actions at a distance, and what Leibniz dismissed as "occult qualities of the schools; which some men begin to revive under the specious name of forces", with other more thoroughly mechanical concepts.[7] Even before his death, Newton's natural philosophy was seen as a huge advance on any previous attempts to understand, and explain, the natural world. It soon displaced Cartesianism from the Netherlands, and even from France by the 1730s. Part of the reason for its success, as Westfall noted, was undoubtedly its highly fruitful combination of occult principles with the mechanical philosophy. It is hard to imagine any thinker who was not raised within the distinctively English tradition which we have been examining in this thesis who could have successfully combined the mechanical philosophy and occult ways of thinking, the way Newton did. Part of the reason for Newton's success, therefore, was the fact that he was a participant in this unique *English* way of doing natural philosophy. Newton came to maturity as a natural philosopher within this tradition, and in coming to maturity himself, he brought that philosophical tradition to its own maturity.

In a recent paper asking "What was Mechanical about the Mechanical Philosophy?" Alan Gabbey considered what the term "mechanical philosophy" might be taken to mean:

> Is the mechanical philosophy a theory of explanation of phenomena in the non-qualitative terms of the configurations and motions of atoms or corpuscles, or other homogeneous matter individuated into bodies? Is it a theory in which the key notion is action by contact, the way machines operate?

[6] Newman, "Preliminary Reassessment", 454–84, 456 and 476–77.
[7] Alexander (ed.), *Correspondence*, Leibniz's Fifth Paper, § 113, 92.

> A theory characterized by the notion that the universe and every system within it is a machine or machine-like? Or characterized by the ideal of mathematizing the world picture? Or by the belief in necessary laws of nature or laws of motion? Is it a theory in which the spiritual and the immaterial have been excluded from the domain of investigation? Each of these is distinct from the others, yet each of them is a possible candidate for inclusion under the umbrella of "the mechanical philosophy".[8]

It is surely significant that all of Gabbey's alternative meanings are compatible with the strict versions of the natural philosophy as developed by Descartes or by Hobbes. If these were the only possible meanings of the term, then the philosophies of Charleton, Petty, Boyle, Hooke, and others, including of course Newton, could not be said to be included "under the umbrella" of the mechanical philosophy.

Similarly, in a recent survey of "The Mechanical Philosophy", by Helen Hattab, it is recognized that there are a number of varieties of mechanical philosophy, promoted by different thinkers, and therefore that the term "came to function as a… wide ranging umbrella".[9] Hattab never acknowledges, however, that active matter was a feature of English mechanical philosophies. Indeed, at one point she says that if the mechanical philosophy is defined in terms of its matter theory, and is based on the view that "matter is a passive extended substance… set in motion by an external force", then it was effectively dismissed "with the reintroduction of active powers and forces into matter".[10] Even though she admits that "Boyle was committed to the existence of incorporeal entities that lay beyond the scope of mechanism", she goes on to say that Boyle believed "all occult qualities are, in principle, explicable in mechanical terms".[11] She sees Boyle, therefore, as an "epistemic optimist" because he believes that "in the long run, sensible qualities will be reduced to mechanical affections." But, it is clear that the "mechanical affections" she has in mind here are those which she sees as best exemplified in the philosophies of Descartes and

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8 Gabbey, "What was Mechanical", 16.

9 Helen Hattab, "The Mechanical Philosophy", in Desmond M. Clarke and Catherine Wilson (eds), *The Oxford Handbook of Philosophy in Early Modern Europe* (Oxford, 2011), 71–95.

10 Ibid., 79.

11 Ibid., 88.

Hobbes.[12] She attributes Boyle's optimism about future developments to his commitment to experimentalism, but fails to note that for Boyle, his experimentalism means that he can introduce occult operators into his philosophy. Boyle's optimism, that all phenomena will eventually be explicable in terms of "mechanical affections", was in large part due to the fact that he (unlike Descartes and Hobbes) included self-active matter among those affections.

It was noted at the outset of this thesis, however, that a number of scholars have recently suggested that the meaning of "the mechanical philosophy" should be expanded beyond the limits implied by Gabbey and Hattab, and which are still generally accepted by the majority of historians of science, especially those who are not early-modern specialists. It is clear that Boyle saw himself as a mechanical philosopher, as did Hooke, and Newton clearly included attractive and repulsive forces as "mechanical principles" in the preface to his *Principia*.[13] Either we deny that these thinkers were mechanical philosophers, and explain away all those occasions where they describe themselves in those terms, or we accept that the designation "mechanical philosophy" should include the kind of philosophizing, from the late 1640s onwards, that has been the focus in this thesis.[14] This thesis, therefore, is an extended contribution to the historiographical claim that the term "mechanical philosophy" should be recognized as a wider umbrella than that envisaged in the quotation by Gabbey, and in much of the more general historiography of science.[15]

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[12] Ibid., 89; Descartes and Hobbes are acknowledged as "the most consistent mechanists" at 73.

[13] Newton, *Principia*, 382.

[14] Attempts have been made to insist that Boyle and Hooke, and other fellows of the Royal Society are best seen as "experimental philosophers". This does bring out a significant difference between English and Continental thinkers in the late 17th Century, but it is misleading to insist upon it as an absolute distinction, given that the English philosophers often referred to themselves as mechanical philosophers. See, for example, Peter Dear, "*Totius in verba*: Rhetoric and Authority in the Early Royal Society", *Isis*, 76 (1985): 144–61; and idem, "Miracles".

[15] For further discussion, see the Introduction, especially the fourth section, "Recent Reassessments of the Mechanical Philosophy".

It should be clear from the material presented in this thesis that English mechanical philosophy developed in a national context which had been shaped by three leading English thinkers who made international reputations for themselves during the Elizabethan Renaissance, Dee, Gilbert, and Bacon. Writing before the mechanical philosophy was invented, these three thinkers all turned to occult principles as the foundations for their proposed reforms of natural philosophy. Their occult philosophies set the scene for further developments and were not displaced when the mechanical philosophy was introduced into England, as has been demonstrated in the pages of this thesis, but came to be blended with it. It seems impossible to deny that this blending of occult ideas with mechanicism, unlikely as it may seem, was supremely successful, because it enabled Newton to achieve what he did. The English scene formed the context which enabled Newton to claim that his use of occult active principles was “a very great step in Philosophy, though the Causes of those Principles were not yet discover’d”.[16]

[16] Newton, *Opticks*, 401–02.

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