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MAGIC AND SCIENCE IN THE SIXTEENTH AND SEVENTEENTH CENTURIES

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The claim that various magical beliefs and procedures played a crucial, even formative, role in the history of early modern science is currently being debated. In spite of the significant body of scholarship dedicated to establishing the thesis that magic has influenced science, there remain dissenters. However, this opposition does not support its contention that magic did not influence science with evidence; instead it either ignores the suggestion or simply denies it as a prima-facie impossibility. The latter argumentative strategy seems to derive from the assumption that magic was an unscientific delusion which could not have influenced so supremely rational an enterprise as modern science. Clearly, this position is utterly subjective and must therefore be regarded as a questionable basis for any historical account. The aim of this survey, therefore, is to recapitulate the major elements of the 'magic and science' thesis, with only the occasional aside to consider the opposing view. First of all, however, we must be clear about the nature of sixteenth and seventeenth century magic.

1. THE NATURE OF MAGIC

1.1. The initial premisses

Magic was (and continues to be) a system of beliefs underpinning a body of technical or craft knowledge and practice, which sought to capture and control the powers and processes of nature for man's (or perhaps merely the individual adept's) advantage. Such magical traditions appeared in the earliest civilisations and manifested themselves in a number of different but related arts and

sciences. There are major divisions, such as those between Spritual, Demonic and Natural Magic, or astrology and alchemy, and innumerable smaller divisions between different sorts of divination – palmistry, scrying, sortilege, hariolation and many more. These different forms of magic had their own techniques and procedures and their own specific justifications but they were all founded upon a particular view of the world. Broadly speaking, the magical world-view of the Latin West was that nature was created by God in a hierarchy of creatures so ordered as to form the 'Great Chain of Being'. (See art. 24, sect. 1.) Each level in the hierarchy was connected directly to the beings immediately above and below but, in addition, there were a number of 'correspondences' between different parts of the Chain. Thus, there might be a correspondence between the seven planets and the seven metals; between the noblest men, kings, and the noblest metal, gold; between the inconstant moon and womankind. These putative connections and correspondences promoted magical beliefs about the secret influence of one thing on another and, therefore, the belief that knowledge about, or control of, one thing could be gleaned by study and manipulation of other things even though they might be as remote as a flower and a star. This is what John Donne meant in his *Anatomie of the World* (1611) when he asked despairingly,

> What Artist now dares boast that he can bring
> Heaven hither, or constellate any thing,
> So as the influence of those starres may be
> Imprison'd in an Hearbe, or Charme, or Tree,
> And doe by touch, all which those stars could do?[1]

The difficulty inherent in all efforts to master the magical art derived from the assumption that the way in which one entity might influence another was entirely 'hidden' or *occult*. Success as an adept depended not on a theoretical grasp of supposed causal mechanisms but on a working knowledge of the many and varied occult qualities and powers. Some magical traditions advocated the use of short cuts to the discovery of correspondences and occult virtues. The assumption of demonic magic, for example, was that even if the magician himself did not know how to bring about a desired natural effect, he could summon a demon with much greater knowledge of God's creation to bring about the result he wanted. It is important to note here that not even the Devil was believed to be capable of producing a genuinely supernatural effect – like the magician he had to rely on harnessing the powers inherent in nature:

> Though the divel indeed, as a Spirit, may do, and doth many things above and beyond the course of some particular natures: yet doth hee not, nor is able to rule or commaund over generall Nature, or infringe or alter her inviolable decrees . . . For Nature is nothing els but the ordinary power of God in althings created,

among which the Divell being a creature, is contained, and therefore subject to that universall power.[2]

Alternatively, the aspiring adept might prefer to rely on an interpretation of the 'signatures' of things. The doctrine of signatures held that God had provided 'signs' by which the correspondence between one thing and another could be discovered. The shape or colour or even the common name of one creature could suggest its sympathetic influence upon another. The moonstone, the sunflower and the walnut, for example, bore the signatures of their correspondence with the moon, the sun and the human brain respectively. However, both of these means of taking short cuts to magical knowledge were widely condemned, often by magicians themselves. The invocation of demons was heretical and downright dangerous, while reliance on the symbolic significance of various appearances was frequently regarded as subjective and prone to error. For many magicians, therefore, the only reliable methods for discovering the influence of one thing on another were, as we shall see, empirical investigation and mathematical analysis.

It should already be clear that magic was characteristically utilitarian in its aims. The knowledge of natural influences which the magician tried to amass was not usually regarded as an end in itself; it was merely the first stage in a pragmatic exercise which depended equally on a set of practical procedures, ranging from the astronomical mathematics of the astrologer to the technical craft of the alchemist.

Magic flourished throughout the Middle Ages and the Renaissance, receiving a series of major fillips with the recovery of various ancient magical texts. The most important of these were the writings attributed to the supposed founders of the magical arts, Hermes (or Mercurius) Trismegistus and Zoroaster. The *Corpus Hermeticum* and the *Oracula Chaldaica* were magical writings of the second and third centuries AD which combined Neoplatonic, Neopythagorean, Stoic, Persian and Gnostic Christian ideas. However, Renaissance scholars assumed that they were the geniune productions of these two ancient sages who were widely believed to have been contemporaries of Moses. Many leading scholars, such as Marsilio Ficino, Giovanni Pico della Mirandola and Francesco Patrizi, believed that the Hermetic and Chaldean writings represented an ancient wisdom derived, like Moses's writings, directly from God. Furthermore, this revival of interest in magic led to an increased appreciation of those medieval thinkers who were reputedly the best magicians; notably Roger Bacon, but also Arab thinkers like Alkindi and Avicenna.

These magical writings enjoyed a tremendous vogue throughout the sixteenth century and well into the seventeenth. Indeed, so pervasive were these ideas that Frances Yates has pointed to the 'Hermetic Tradition', as she called it, as a 'necessary preliminary to the rise of science'. Scholarly opinion now

rejects her suggestion that the core of these Renaissance movements was 'Hermetic' and prefers the admittedly looser terms of Neoplatonism and magic. Yates herself wrote only in a programmatic way and much of the evidence she cited in favour of the thesis that magic was a major influence on science is circumstantial and tenuous. Lacking any detailed knowledge of the history of science, Yates all too often summed up her argument by vaguely pronouncing that 'there was indeed a vast change in the conception of man's relation to the cosmos'.[3] Nevertheless, in the hands of other scholars, Yates's ideas have proved highly suggestive.

1.2. Magic and rationality

Magic is not a monolithic subject and it is important to stress that major aspects of the history of magic seem to play no role in the rise of modern science; for example, Demonic Magic, chiromancy and the cabala. The crucial aspects of the magical tradition for the historian of science were those encompassed by the term *Natural* Magic which embraced all those arts which relied upon natural lore; for example, astrology and alchemy. However, even the general ethos of magic could provide a useful and fruitful stimulus to scientific thought. The magical and scientific world-views were not incompatible and the question of magical influence on science should not be dismissed out of hand, as some historians have tried to do, on the grounds that magic is *irrational.*[4] At the beginning of the seventeenth century, there was nothing irrational in the belief in 'correspondences' between entities and institutions. Indeed, to deny these correspondences or to act as though they had no validity was to descend into irrationality and madness, as Shakespeare demonstrated so marvellously in *King Lear.* Moreover, at a time when the world was believed to be populated by angels and demons there was nothing irrational about trying to summon them; at a time when the Church insisted that 'In the beginning was the Word' (*John*, I.1) and that the uttering of words could affect (or create) the world, there was nothing irrational about trying to discover the spells to bring about a desired result.

We cannot agree, therefore, with A. R. Hall's claim that 'the writings of some recent English historians of the more esoteric currents in Renaissance thought do tend directly to diminish the historical significance of rational discourse'. Hall also asks: 'If Copernicus wrote *De revolutionibus* because he was a Pythagorean metaphysician, what is the value of technical research into Copernicus' or Kepler's astronomical mathematics, or even into their explicit arguments for maintaining one opinion in preference to another?'[5] However, a closer analysis of Copernicus shows the importance of these 'esoteric currents' for historical explanation. (See art. 14, sects. 2 and 4; art. 15, sects. 3.1 and 3.2.)

It would clearly be wrong to suggest that *De revolutionibus* owed its origins

solely to the fact that Copernicus was a 'Pythagorean metaphysician'. The claim of the historians which Hall challenges is, rather, that the influence of newly revived Neopythagorean attitudes (closely associated with, if not identical to, magical beliefs) was one of the factors which made Copernicus's *De revolutionibus* as revolutionary as it was. One of the most significant aspects of Copernicus's work was his insistence (pusillanimously disguised by Andreas Osiander in an anonymous preface) that his mathematical theory presented a *true* account of how the universe was constructed. No amount of 'technical research into Corpernicus' . . . astronomical mathematics' will explain why he believed this. Within the tradition of technical astronomy it had long been assumed that astronomical mathematics was merely hypothetical, merely a series of techniques and manipulations for predicting planetary movements, with no relevance to the physical reality of the heavens. The fact that Copernicus rejected this instrumentalist position and insisted that the mathematical system must be compatible with, and even demonstrative of, the actual physical system of the world owed much to the revival of Pythagorean and Platonic beliefs. His willingness to countenance so counter-intuitive and (by the canons of the day) so scientifically absurd a notion as the motion of the Earth merely because it provided a more 'harmonious' mathematical system and a closer fit between mathematical analysis and a putative physical reality is clear testimony to the strength of Neoplatonic influence on his thinking.

Current opinion about the mystical and anti-rational nature of magic should not blind us to the fact that many leading intellectuals in the past regarded it as a perfectly rational and legitimate source of truth about the nature of the world. Indeed, the historical evidence suggests that our present, derogatory view of magic has resulted from the fact that the most naturalistic and rational aspects of the magical belief system were absorbed into the new philosophy of the seventeenth century and only those parts of the system which were rejected continued to be called magic. Frequently associated with charlatanry and heterodoxy, magic had a bad public image, and many practitioners or other interested parties had to apologise for or simply deny their magical leanings. John Wilkins (1612–72), for example, published a book entitled *Mathematical Magick* (1648) but intimated in the preface that it was so called merely to accommodate the vulgar conceptions of these matters. The rhetorical import of Wilkins's statement is that the kind of mechanical devices whose operations are explained were not really magical but that the common people thought they were. However, it will not do for the historian to take such rhetoric at face value and believe that Wilkins was right while the common people were wrong. The fact that some aspects of what had long been part of the magical tradition were appropriated by natural philosophers in the sixteenth and seventeenth centuries cannot be used to argue that magic was irrelevant to the development of science.

It is admittedly very difficult for us, in our technological age, to see what is

'magical' about Roger Bacon's famous claim that 'chariots can be made to move without an animal with inestimable force . . . Also there can be made instruments of flying with a man sitting in the middle of the instrument and revolving a contrivance by means of which artificially composed wings beat the air like a flying bird'.[6] Nevertheless, we must accept that such 'mechanical marvels', because of the occult and secret nature of their mechanisms, were then regarded as products of the magical art. Aristotelian physics drew a distinction between natural motions (to and from the centre of the Earth in the case of heavy and light bodies; around the centre, circularly, in the case of heavenly bodies) and unnatural or forced motions. The scholastic natural philosophy of the universities concerned itself with natural motions and did not consider the unnatural operations of mechanical devices. (See art. 35.)

It is unhelpful to regard the attempts of seventeenth-century philosophers to explain the workings of such devices merely as an unexplained expansion of the scope of natural philosophy. It should rather be seen as a recognition by natural philosophers of the importance, both practical and theoretical, of certain aspects of the magical arts. The new philosophers, like the medieval philosopher Roger Bacon, believed that the study of nature could benefit from the study of artificial devices since, ultimately, their operations depended on natural laws. As Henry Power put it: 'Art being the imitation of Nature . . . the works of the one must prove the most reasonable discoveries of the other'; while for Ralph Cudworth nature was:

> another kind of art, which, insinuating itself immediately into things themselves, and there acting more commandingly upon the matter as an inward principle, does its work easily, cleverly, and silently. Nature is art as it were incorporated and embodied in matter.[7]

2. NATURAL MAGIC AND THE ORIGINS OF MODERN SCIENCE

2.1. Magic and the experimental philosophy

We can readily see that a number of characteristic features of the magical tradition, which had no significant place in medieval natural philosophy, were rapidly incorporated into the 'new philosophy' during the Scientific Revolution. (See art. 15.) For example, the emphasis on the experimental method, which is regarded as one of the most fruitful aspects of the new philosophy, derives from the magical tradition which assumed that the influences of one thing upon another could only reliably be discovered by observation and by other empirical methods. This is apparent in Cornelius Agrippa's defence of magic in *De incertitudine et vanitate scientiarum* (*The uncertainty and vanity of science*, 1531):

> Therefore, natural magic is that which having contemplated the virtues of all natural and celestial things and carefully studied their order proceeds to make known the hidden and secret powers of nature in such a way that inferior and superior things are joined by an interchanging application of each to each; thus incredible miracles are often accomplished not so much by art as by nature, to whom this art is a servant when working at these things. For this reason 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; . . . therefore those who believe the operations of magic to be above or against nature are mistaken because they are only derived from nature and in harmony with it.[8]

The mixing of 'actives' and 'passives' to see how they interacted was a fundamental part of the natural magician's work. Only thus could he learn how to produce the effects he sought. For Giambattista Della Porta, one of the most prominent of natural magicians, only an empirical knowledge of 'the whole course of Nature' could teach us 'by the agreement and disagreement of things, either so to sunder them, or else to lay them so together by the mutual and fit applying of one thing to another, as thereby we do strange works'. Similarly, Pietro Pomponazzi pointed out that if the correspondences between things are real,

> It follows also . . . that there are herbs, stones, or other means of this sort which repel hail, rain, winds, and that one is able to find others which have naturally the property of attracting them. Assuming that men are able to know them naturally, it follows that they are able, in applying the active to the passive, to induce hail and rain and to drive them away; as for me, I do not see any impossibility.[9]

Pomponazzi may have been mistaken about the existence of such herbs or stones but his assumption that there was nothing impossible about the suggestion and that it should be tested empirically is indistinguishable from what might be called the 'scientific mentality'. After all, the thinkers who refused to look through Galileo's telescope, on the grounds that what it revealed was *impossible*, were not magicians but natural philosophers; natural philosophers, moreover, who regarded any combination of lenses (or mirrors) as a magician's prop!

The natural magician's world-view was a powerful stimulus towards, and justification for, empirical investigation of nature as even Francis Bacon recognised:

> Man being the servant and interpreter of Nature can do and understand so much and so much only as he has observed in fact or in thought of the course of Nature: beyond this he neither knows anything nor can do anything.

> Towards the effecting of works, all that man can do is put together or part asunder natural bodies. The rest is done by Nature working within.

Francis Bacon's conviction that the empirical method of the magicians was the most effective way of understanding nature was not merely academic. Like the magicians themselves, Bacon believed that the knowledge of nature should be used to enlarge 'the bounds of Human Empire, to the effecting of all things possible'.[10] This kind of utilitarianism was entirely characteristic of the natural magician and served to distinguish him further from the academic natural philosopher. For, while the natural philosopher was concerned to understand the first principles involved in natural processes, the natural magician might be satisfied merely with the ability to produce consistently, or to demonstrate, a particular effect even though the cause remained hidden or occult. However, paradoxical as it may seem, this did not mean that magic proved less fruitful as a means of studying nature than the prevailing natural philosophy. On the contrary, the adoption of the magical approach by the new philosophy contributed significantly to the overthrow of scholastic natural philosophy. (See art. 15, sects. 3.1 and 3.2.)

The traditional role of the academic natural philosopher was to explain the workings of nature in terms of causes. The artisan might know how to bring about certain effects in his workshop, laboratory or forge, but only the natural philosopher could explain how these came about. Such explanations were almost exclusively couched in terms of the four Aristotelian causes (material, efficient, formal and final) which ultimately depended on the substances and the appropriate qualities of the interacting ingredients. The fact that many natural effects had to be attributed to occult qualities, faculties and powers was something of an embarrassment to scholastic natural philosophy. The natural magician, however, was unconcerned. By the same token, while the natural philosopher tried to live up to the rigours of Aristotelian syllogistic logic, in which the conclusion was explained by the combination of major and minor premisses, the natural magician was perfectly content with inductive logic. We can see why if we consider a standard example of an inductive argument taken from a leading text-book of logic of the sixteenth century, Thomas Wilson's *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.[11]

There has been no attempt here to explain why or how wine heats the body of

the drinker; it is regarded as sufficient merely to show that it does do so, and to imply that this can be tested by administering wine to someone.

It was this concern with what natural objects do rather than with the niceties of how they do it, with effects rather than causes, which led Francis Bacon to extol the virtues of inductive logic – the very logic which was implicit in the natural magic tradition. Bacon's adoption of inductive logic, his 'theory-free' empiricist method of gathering 'facts' and his conviction that natural philosophy should have a utilitarian dimension were directly inspired by the methods of natural magic. Furthermore, his endorsement of these notions made it comparatively easy, particularly in England, for the new breed of natural philosophers to appropriate these aspects of the magical tradition. The experimental method could be presented, by its advocates in the Royal Society for example, as the only certain and reliable method of discovering truth because, unlike other methods, it was concerned not with preconceived, and thus inherently biased, theories or hypotheses but with clearly demonstrable matters of fact.

It followed from this methodology that occult powers and qualities could be held to be just as real as the 'mechanical qualities' of size, shape and motion. (See art. 38.) Thus, Robert Hooke allowed the introduction of 'unheard of Powers, Operations, Effects or Motions' into natural philosophy provided the experimenter could 'daily try, see, and find the regular working' of them. Robert Boyle, similarly, defended certain speculative qualities which he attributed to matter as 'not meerly fictitious Qualities: but such, whose Existence I can manifest, . . . by real Experiments and Physical Phaenomena'. The experimental philosopher need not assign the true cause to either gravity, the spring of the air, or any other occult quality; he need only show by experiment that bodies possess such a quality. The culmination of this magically-inspired trend can be seen in Newton's defence of his treatment of gravity and other putative 'active principles' as unexplained or occult qualities of matter (see art. 16, sect. 5):

> In this philosophy particular propositions are inferred from the phenomena and afterward rendered general by induction . . . to us it is enough that gravity does really exist . . . [12]

Until fairly recently, historians of science believed that the new philosophy explained natural phenomena in terms of contact actions between particles of matter in motion, and deliberately eschewed all occult qualities. However, it is now realised that the ability of the new philosophy to deal with occult qualities in an internally consistent and fruitful way was taken by its proponents as a clear sign of its superiority over scholastic natural philosophy. (See art. 38.) The new philosophers, who were virtually unanimous in their belief that physical phenomena could best be explained in terms of the behaviour of insensible corpuscles of matter, were concerned to argue that such insensible particles

were not unintelligible. By showing that their philosophy could easily accommodate occult qualities they were able to claim that their philosophy of invisible and insensible corpuscles was, paradoxically, more intelligible than the Aristotelian philosophy, which could not adequately account for those same occult qualities.

It may be concluded that the natural magical belief in the usefulness of an inductive knowledge of the occult qualities of bodies and the necessarily experiential and observational discovery of the precise effects of such occult virtues were all absorbed into the new natural philosophy of the seventeenth century.

2.2. Magic and the mathematisation of natural philosophy

A similar case could be made for the role of magic in suggesting to Renaissance thinkers that mathematics could be a useful and valid means of understanding the physical world. At a time when the almost exclusively qualitative natural philosophy paid scant attention to the mathematical sciences, Cornelius Agrippa could insist that

> The mathematical disciplines are so necessary and cognate to magic that, if anyone should profess the latter without the former, he would wander totally from the path and attain the least desired result. For whatever things are or are effected in the inferior natural virtues are all effected and governed by number, harmony, motion and light, and have their root and foundation in these.[13]

Certainly there was a great deal of latitude in the interpretation of such a pronouncement. For some thinkers the belief that 'number' could express something of the nature of the world led numbers to be viewed merely as symbols for other kinds of entity. Johannes Kepler (1571–1630), to take a prominent example, rejected this kind of numerology, but he believed nonetheless that the answer to the numerological question of why there are only six planets deserved serious attention. He repudiated numerology when the signification alloted to numbers was merely contingent upon a numerologist's whim because he believed that the answer to numerological questions had to derive from the formal structure of mathematics itself. Believing that mathematics was 'co-eternal with the mind of God' and that 'geometry provided God with a model for the Creation', Kepler felt that there must be a geometrical archetype which limited God's creation of planets, by internal geometrical rules, to only six. Otherwise, he insisted, 'we shall be driven to admit that God acted arbitrarily in the universe . . . And this is a conclusion I will not accept on anyone's authority'. Kepler guessed and subsequently established to his own satisfaction that God had placed the planets in space so that the five regular or Platonic solids could be nested between their orbits:

> That is why, if I am asked why there are only six planetary orbits, my reply will be as follows: there ought not to be more than six inter-relationships, for that is the total number of the regular mathematical bodies, and six terms will fully provide that number of relationships.[14]

Idiosyncratic as this may seem, it was exactly the same belief in the mathematical structure of the world which enabled Kepler to make his discovery that planetary orbits are elliptical rather than circular. Kepler continued to struggle with Tycho Brahe's Mars data for eight years because of his paramount commitment to the Neoplatonic and magical belief that mathematics was not merely a convenient tool for 'saving the phenomena' but actually revealed the way things are. Here, then, is a clear case of a magical belief leading to a scientific discovery. (See art. 14, sect. 4.)

Kepler may be regarded as a godsend for the magic and science thesis but there is much evidence indicating the magical antecedents to the mathematisation of early modern science. Unfortunately, though, 'mathematical magic' has not yet received sufficient scholarly analysis and its role is, consequently, difficult to assess with confidence. However, there is a clear tradition within magic of regarding mathematical analysis as a means of guaranteeing the veracity of magical theories.

This can be seen not only in writers such as Cornelius Agrippa and John Dee but also in a mathematical engineer like Simon Stevin who claimed that the certainty of magical knowledge resulted from mathematics. This argument cuts both ways. Although the supreme exemplar of the new mathematical science, Isaac Newton's *Philosophiae Naturalis Principia Mathematica* (*Mathematical Principles of Natural Philosophy*, 1687), shows no sign of magical preoccupations, a number of draft Scholia intended for a second edition drew explicitly upon Pythagorean ideas concerning the harmony of the spheres in order to justify and confirm the concept of universal gravitation. Moreover, Newton carried his belief in the magical notion of the harmony of the spheres into his studies of light for the *Opticks* (1704). The British tradition of the seven-coloured rainbow stems directly from Newton's conviction that 'the Spaces which the several Colours . . . take up' were 'divided after the manner of a Musical Chord'.[15] Such views of mathematics and its applicability to an understanding of the natural world can be traced back at least as far as Roger Bacon. It would seem, therefore, that the mathematical analysis of nature was not so much an innovation in natural philosophy as an appropriation from natural magic.

3. CONCLUSION

The magic and science debate has frequently been taken beyond such general considerations of methodology and ethos. There is no shortage of detailed

historical studies in which magical ideas such as sympathy and antipathy, astrological or alchemical beliefs, have been shown to constitute or effect the actual scientific theories of various natural philosophers. Among the most important of these are the works of Walter Pagel on Paracelsus, J. B. van Helmont, William Harvey, and several of their respective followers, but the *cause célèbre* in this historiographical endeavour is the claim that Newton's concept of force owed much to his meticulous and seemingly obsessive studies in alchemy. Studies of alchemical and other magical texts known to Newton and also of his own extensive alchemical manuscripts, suggest that alchemy provided him with a body of evidence and a set of concepts and arguments which he used to infer the existence of attractive and repulsive forces between particles of matter. (See art. 16, sects. 4–5.) In arguing for interparticulate forces capable of acting at a distance Newton was flouting the canons of both Aristotelian physics and Cartesian mechanics, but he was actually advocating ideas that had been commonplace in natural magic and which had recently been absorbed, at least in England, into the new natural philosophy. This did not mean that Newton accepted all the tenets of alchemy; as R.S. Westfall has said, 'with his quantified concept of force' Newton 'had extracted the essence of the art'.[16]

Newton's interest in alchemy, his development of Neoplatonic concepts of spirit (as a possible cause of gravitational and electrical phenomena), his defence of occult qualities in natural philosophy and his belief in mathematical 'harmonies' (as a means of discovering the precise nature of God's Creation) have all been recognised as indicative of the profound influence of magical traditions on his creative scientific work. For earlier historians this meant that Newton must be seen as a 'Great Amphibium' who spanned 'two worlds'. 'With one foot in the Middle Ages and one foot treading a path for modern science', he was 'not the first of the age of reason' but 'the last of the magicians'.[17] However, we no longer have to assume the existence of such tensions and contradictions in Newton's thought. It is now recognised that the transformation of natural philosophy from an academic study of one branch of 'scientia' in the medieval university to a mathematical and empirical pursuit with utilitarian ends increasingly conducted outside the cloisters of universities, was brought about by the appropriation of natural magic into natural philosophy. Accordingly, it now seems correct to say that Newton's greatness as a scientist was achieved not in spite of but because of his easy acceptance of the traditions of natural magic.

NOTES

1. John Donne, *An anatomie of the world. The first anniversary* [many editions], lines 391–95.
2. John Cotta, *The triall of witch-craft* (London, 1616), p. 34.
3. Frances A. Yates, 'The hermetic tradition in renaissance science', in Charles S. Singleton (ed.), *Art, science, and history in the renaissance* (Baltimore, 1968), pp. 255–74, 255, 257. For qualifications of Yates's views see R. S. Westman and J. E. McGuire, *Hermeticism and the Scien-*

tific Revolution (Los Angeles, 1977); Charles B. Schmitt, 'Reappraisals in renaissance science', *History of science*, 16 (1978), 200–14.

4. A. Rupert Hall, 'Magic, metaphysics and mysticism in the Scientific Revolution', in M. L. Righini Bonelli and William R. Shea (eds.), *Reason, experiment and mysticism in the Scientific Revolution* (London, 1975), pp. 275–82; Mary Hesse, 'Reasons and evaluation in the history of science', in M. Teich and Robert Young (eds.), *Changing perspectives in the history of science: essays in honour of Joseph Needham* (London, 1973), pp. 127–47; and Brian Vickers, 'Introduction', in Brian Vickers (ed.), *Occult and scientific mentalities in the renaissance* (Cambridge, 1984), pp. 1–55.
5. Hall, 'Magic, metaphysics and mysticism in the Scientific Revolution', p. 276.
6. Roger Bacon, *Opera quaedam hactenus inedita*, ed. J. S. Brewer (London, 1859), p. 553.
7. Henry Power, *Experimental philosophy, in three books: containing new experiments, microscopical, mercurial, magnetical . . .* (London, 1664), p. 192; Ralph Cudworth, *The true intellectual system of the universe* (London, 1678), Chap. III, Sect. xxxvii, Para. 9.
8. Henry Cornelius Agrippa von Nettesheim, *De incertitudine et vanitate omnium scientiarum et artium* (n.p., 1531), Chap. 42 [unpaginated].
9. John Baptista Porta, *Natural magick* (London, 1658), pp. 1–2. Pietro Pomponazzi, *Les causes des merveilles de la nature ou les enchantements* (Basle, 1556), reprinted ed. by Henri Busson (Paris, 1930), p. 124.
10. Francis Bacon, *Novum organum*, Aphorisms I and IV; in R. L. Ellis, J. Spedding and D. D. Heath (eds.), *The works of Francis Bacon* (7 vols., London, 1887–92), vol. 4, p. 47; Bacon, *New Atlantis*, *Works*, vol. 3, p. 156.
11. Thomas Wilson, *The rule of reason* (London, 1551), sig. H5v.
12. Robert Hooke, *De potentia restitutiva*, reprinted in R. T. Gunther (ed.), *Early science in Oxford* (14 vols., Oxford, 1921–45), vol. 8, p. 179. Robert Boyle, *Cosmicall qualities*, in *The works*, edited by Thomas Birch (6 vols., London, 1772), vol. 3, p. 307. Isaac Newton, *Mathematical principles of natural philosophy*, trans. by A. Motte, revised by F. Cajori (Berkeley, 1960), pp. 546–7.
13. Henry Cornelius Agrippa von Nettesheim, *De occulta philosophia* (n.p., 1533), II.1.
14. Johannes Kepler, *Harmonice mundi*, IV.1, in *Gesammelte Werke*, ed. by W. von Dyck, M. Caspar, F. Hammer, *et al.* (Munich, 1938–), vol. 6, p. 233. *Mysterium cosmographicum*, Preface; *Werke*, vol. 1, p. 11.
15. John Dee, 'Mathematical Preface' to *The elements of geometrie of the most auncient philosopher Euclide of Megara*, trans. by Sir Henry Billingsley (London, 1570), sig, *jr-v. Simon Stevin, *The principal works*, ed. by E. J. Dijksterhuis, D. J. Struik, A. Pannekoek *et al.* (5 vols., Amsterdam, 1955–66), vol. 3, p. 607. Isaac Newton, *Opticks: or, a treatise of the reflections, refractions, inflections and colours of light*, based on the Fourth Edition London, 1730 (New York, 1952), p. 126, 128.
16. R. S. Westfall, 'Newton and alchemy', in Brian Vickers (ed.), *Occult and scientific mentalities in the renaissance* (Cambridge, 1984) pp. 315–35.
17. Hugh Kearney, *Science and change 1500–1700* (London, 1971), p. 196; John Maynard, Lord Keynes, 'Newton, the man', in the Royal Society, *Newton tercentenary celebrations* (Cambridge, 1947), pp. 27–34.

FURTHER READING

B. J. T. Dobbs, *The foundations of Newton's alchemy, or 'the hunting of the greene lyon'* (Cambridge, 1975).

John Henry, 'Occult qualities and the experimental philosophy: active principles in pre-Newtonian matter theory', *History of science*, 24 (1986), 335–81.

Keith Hutchison, 'What happened to occult qualities in the Scientific Revolution?', *Isis*, 73 (1982), 233–53.

J. E. McGuire and P. M. Rattansi, 'Newton and the "pipes of pan" ', *Notes and records of the Royal Society of London*, 21 (1966), pp. 108–43.

Walter Pagel, *Paracelsus: an introduction to philosophical medicine in the era of the renaissance* (Basle, 1958).

—— *William Harvey's biological ideas: selected aspects and historical background* (Basle, 1967).

—— *Joan Baptista Van Helmont: reformer of science and medicine* (Cambridge, 1982).

Paolo Rossi, *Francis Bacon: from magic to science*, translated by Sacha Rabinovitch (London, 1968).

Lynn Thorndike, *A history of magic and experimental science* (8 vols., New York, 1923–58).

Brian Vickers (ed.), *Occult and scientific mentalities in the renaissance* (Cambridge, 1984).

D. P. Walker, *Spiritual and demonic magic from Ficino to Campanella* (London, 1958).

Charles Webster, *From Paracelsus to Newton: magic and the making of modern science* (Cambridge, 1982).

Frances A. Yates, *Giordano Bruno and the hermetic tradition* (London, 1964).