43 *Works*, II, 178, 180.
44 Ibid., II, 451.
45 Ibid., I, 316; II, 451, 557–8, 638.
46 "Videtur enim omnis vivificatio esse quiddam medium inter detentionem et emigrationem spiritus. Ubi enim spiritus . . . incidit in materiam obedientem et sequacem . . . ita tamen ut spiritus dilatet se localiter, et vias ad exeundum tentet . . . sequitur vivificatio, et membrificatio, et corpus organicum, et huiusmodi. Etenim simplex illa et mollis protrusio . . . est procul dubio rerum rudimentum . . . et principium ipsius vivificationis . . . Itaque plane cernitur quandoque muscus paulo arctior devenire herbidus, et formatus, et instar pusillae plantae. Putredo autem facile transit in vermiculos, etiam motu se manifestante antequam efformatio sit absoluta" (fol. 15^{v}).
47 *Works*, I, 604.
48 "Quod si detur copia se sibi continuandi, et per hoc natura sua utendi et fruendi, tum demum se incendit, et se gerit pro potestate sua, unde primo corpus ad integrale figurat et determinat . . . Quod si non tantum diffundere se spiritus possit per canales illos et ramos, sed etiam sedem aliquam et cellam sibi parare ubi in quanto aliquo notabili congregari possit, tum vero sequuntur effecta multa nobilia . . . ex regimine spiritus in cella, spiritus in canalibus se comprimit et dilatat unde sequitur pulsus et motus localis."
49 See *Works*, I, 329.
50 Also see ibid., II, 120–1.
51 Ibid., II, 359, 507, 557–8.
52 Ibid., II, 452.
53 Ibid., III, 362; VI, 760–1.
54 See Rees, "Matter Theory," pp. 118–21.
55 See *Works*, I, 223.
56 See "Letter to Burghley" (1592?), in Spedding, *Letters and Life*, I, 108–9; "Mr. Bacon in Praise of Knowledge (1592?), ibid., I, 123–6; "Gesta Grayorum" (1594), ibid., I, 334–7; "A device to celebrate Queen's Day" (1595), ibid., I, 379–85. "Mr. Bacon in Praise of Knowledge" is only one section of a longer text, the whole of which was published in a record-type transcription by Spedding: see *A Conference of Pleasure*. The manuscript from which Spedding worked is lodged at Alnwick Castle, MS. 525 (safe 4), fols. 3–25.
57 These are large issues that cannot be examined fully here. The documents of the 1590s are difficult to interpret: They are allusive and ambiguous. There are also very great risks that an interpreter may unwittingly allow knowledge of Bacon's later writings to impose upon a reading of the early sources. However, it is certain that Bacon had clear speculative commitments in the early 1590s (see Spedding, *Letters and Life*, I, 124–5). No *specific* methodological commitment is evident in these early texts. There is a general commitment to the reform of knowledge for the material benefit of mankind, a reform to be accomplished by drawing the empirical and rational faculties into a new relationship (ibid., I, 108–9, 123–4), but no reference to induction, the natural-historical program, etc. The earliest reference to the speculative philosophy is coupled with a profoundly sceptical attitude to established authority in astronomy and cosmology. The scepticism spills over into a generalized call for the reform of knowledge (ibid., I, 124–6). In other words, the evidence of allegiance to specific speculative doctrines is linked to general programmatic declarations by criticism of views rivaling the speculative doctrines.

in B. Vickers (ed.) Occult and scientific mentalities in the Renaissance, Cambridge: Cambridge Univ. Press, 315–335, 1984.

10

Newton and alchemy

RICHARD S. WESTFALL

On the whole, Newton preferred not to publicize his involvement in alchemy. Unlike his other major pursuits, nothing of his alchemy, or at least nothing explicitly labeled as alchemy, appeared in print during his lifetime or in the years immediately following his death. A few people did know about it. A fascinating correspondence between Newton and John Locke following the death of Robert Boyle reveals that the three men, possibly the last three men from Restoration England whom one would have expected, only a generation ago, to find so engaged, exchanged alchemical secrets and pledged each other to silence.[1] John Conduitt, the husband of Newton's niece, who gathered material about his life, knew of his experiments in Cambridge and reported that his furnace there remained an item of curiosity shown to visitors. Nevertheless, the adjective Conduitt used was "chymical," not "alchymical,"[2] and in a similar manner knowledge of Newton's interest in the art quickly sank from view. When David Brewster found alchemical manuscripts in Newton's own hand among his papers, he was appalled and quickly dismissed them as a curious relic of an earlier age.[3] It waited until the twentieth century for the record to become public, with the auction of the papers still in the hands of the Portsmouth family, and for scholars to come to grips with it. Lord Keynes purchased some of the alchemical papers at the auction and insisted forcefully on their importance,[4] but only in our own generation have scholars ready to take the papers seriously systematically studied the entire corpus, or rather that part – well over 90 percent – of the corpus known to exist that is available to the public. Betty Jo Dobbs and Karin Figala have been the leaders of this investigation.[5] As a result of their outstanding work, we probably know more today about Newton's endeavors in alchemy than anyone, including even his confidants in the art, Locke and Boyle, ever has.

The record is subject, of course, to varying interpretations. Newton was the single most important figure in establishing modern science with its unique view of reality and of the proper procedures to study it. Alchemy was one of the enterprises that modern science put out of business. Indeed, as David Brewster's references to "the most contemptible alchemical poetry," and, in regard to another paper, "the obvious production of a fool and a knave" make manifest, it appears to many as the quintessential embodiment of all that modern science opposes.[6] Not surprisingly then, some scholars, some very considerable scholars, reject the suggestion that alchemy played a significant role in Newton's intellectual life. Despite the manuscripts – and it should be obvious, as they contend, that the existence of the manuscripts does not of itself establish Newton's attitude toward their content – alchemy was in their view an activity peripheral to his central concerns. Those concerns manifested themselves in his *Principia*, his *Opticks*, and his fluxional calculus, the achievements that both shaped the modern scientific tradition and ensured their author's undying fame. Thus Bernard Cohen's recent *Newtonian Revolution* presents an analysis of the development of the *Principia* that focuses on problems internal to the science of dynamics and on Newton's transformation of received concepts of mechanics without saying more than a single word about alchemy. The single word is his emphatic rejection of the argument made by several scholars, including me, that Newton drew the concept of attraction out of the alchemical tradition.[7] Rupert Hall is uneasy that attention to Newton's alchemy will "cloud the clarity of reason and intellectual integrity . . . I would have regarded Newton as a founder of reason; so I think he wished to be regarded (for him reason included God, of course) not as flotsam on the weltering sea of the human unconscious. You must see that if you deny Freud in Manuel, you admit Jung with alchemy. *That* I am sorry about."[8] Cohen and Hall are names to be reckoned with in any discussion of Newton. A consideration of Newton and alchemy that proceeds by ignoring their opinions cannot hope to be taken seriously.

As there are those who reject the contention that alchemy was a central aspect of Newton's career, so there are others who make it the most central aspect. David Castillejo's recent *Expanding Force in Newton's Cosmos* presents the most fully developed expression this position has yet received. Significantly, the *Principia* scarcely appears in a work whose title proclaims the exact opposite of universal gravitation, and Newton's achievement in mathematics receives no mention at all. Castillejo opens, rather, with a chapter on alchemy, moves on to a chapter on the prophecies, and primarily from those two topics weaves a fabric that portrays not merely a Newton who let alchemy influence him, but a Newton whose entire intellectual life was thoroughly occult. In Castillejo's opinion, that intellectual life focused always on one investigation of which Newton's various studies were only specific facets, an investigation of two opposing forces, capable both of spiritual and material manifestations, the cyclical pattern of whose contentions has shaped both the universe and human history.[9] Castillejo does not enjoy the renown that Cohen and Hall command. Nevertheless, the book rests on very extensive research in the manuscripts, and it is written with insight and conviction. No serious discussion of Newton and alchemy can afford to ignore it any more than Cohen and Hall.

My goal in this chapter is to neglect neither of the two positions, represented by Cohen and Hall on the one hand and by Castillejo on the other, but also to agree with neither. I shall attempt rather to define and defend a position between them, one that asserts the significance of alchemy in Newton's scientific career while it refuses to equate him with the occult.

I begin by taking my stand on three empirically established facts. First, Newton left behind a corpus of papers about alchemy which testify that he took an interest, the nature of which requires definition, in the art. Second, as a natural philosopher Newton introduced a major revision in the prevailing mechanical philosophy by asserting the existence of forces, attractions and repulsions between particles of matter that are not in mutual contact. Third, there was a chronological nexus between the first two points, the interest in alchemy spanning the period that witnessed the revision of natural philosophy. My argument must, of course, include elaborations drawn from the nature of the alchemical papers, but it rests squarely on these three foundation stones and depends directly on their solidity.

As far as I can tell from the surviving manuscripts, alchemy was not among the topics that introduced Newton to natural philosophy while he was still an undergraduate in a university that, like all universities of the age, did not energetically promote anything we would call science. Chemical questions of any sort scarcely figured in his initial reading in natural philosophy. Not long after taking his bachelor's degree, however, Newton did discover chemistry, and according to his custom with any new study, he attempted to systematize what he was learning in a glossary of chemical terms.[10] The distinction between chemistry and alchemy in the seventeenth century, if indeed it is valid to speak of a distinction, is difficult to place with precision, but most people, I think, would incline without hesitation to place the glossary squarely on the side of chemistry. Robert Boyle was his primary authority at this time. His studies did not remain on the chemical side of the line for long, however. His accounts show that on a trip to London in 1669 he purchased *Theatrum chemicum*, the huge collection of alchemical writings in six quarto volumes. He also purchased two furnaces, glass equipment, and chemicals.[11] As we shall see, he quickly learned to put the equipment to work. For the moment note that he also did not allow *Theatrum chemicum* to lie idle. Notes from the essays it contains began to appear among his papers, and a few years later he compiled a list of its most important items.[12] Nor did he confine himself to the *Theatrum*. He ransacked other major collections, such as *Ars aurifera*, *Musaeum hermeticum*, and *Theatrum chemicum britannicum*. In collections, collected works of single authors, and individual books, he consulted all the major authorities of the long alchemical tradition: Morien, Rosinus, the *Turba philosophorum*, the *Scala*, the *Rosary*, Ripley, Michael Maier, Sendivogius, Eirenaeus Philalethes, and many others it would be pointless to list exhaustively. As he read, he developed criteria of judgment such that, for example, he canceled one passage of notes with a curt dismissal: "I believe that this author is in no way adept."[13] In the opinion of Professor Dobbs, Newton probed "the whole vast literature of the older [i.e., pre-seventeenth-century] alchemy as it has never been probed before and since."[14] A similar assessment of his reading in seventeenth-century alchemists from Sendivogius and Michael Maier to Eirenaeus Philalethes, Theodore Mundanus, and Didier does not seem excessive. Eventually he compiled a massive "Index chemicus," the likes of which alchemy has never seen, to guide him to relevant discussions – over 100 pages crammed with 879 separate headings and approximately 5,000 page references to more than 150 different works.[15] At the same time he began to assemble what must have been one of the great collections, in his day, of alchemical works, so that at his death, nearly thirty years after he had ceased to buy alchemical literature, alchemy still constituted more than 10 percent of his library.[16]

One interesting feature of Newton's alchemical papers, and one that helps to illuminate his interest in the art, is the appearance among them of copies, in Newton's own hand, of unpublished treatises. Some of them would later see publication. Thus he made extensive notes on Philalethes's *Ripley Reviv'd* about ten years before it appeared in print and copied out a version of his "Exposition upon Sir George Ripley's Epistle to King Edward IV" that differs from the published one.[17] Over a period of nearly thirty years, he appears to have had access to manuscripts that remain unpublished to this day: for example, an anonymous "Sendivogius Explained" and John DeMonte-Snyders's "Metamorphosis of the Planets."[18] A sheaf of unpublished treatises, in at least four different hands, among his papers and his own copies elsewhere of five of the treatises suggest what appears to me as the only plausible interpretation of these papers.[19] Someone lent him the collection to study and copy, and in this case, for reasons we cannot

possibly know, he never returned the originals. Similarly, a treatise named "Manna," which is not in his hand, concludes with two pages of variant readings added by Newton together with the information that they were "collected out of a M.S. communicated to M^r F. by W. S. 1670, & by M^r F. to me 1675."[20] I do not see how to account for these copies of unpublished papers without admitting that Newton was in touch with the largely clandestine circle of English alchemists from whom he received manuscripts to copy and to whom, quite possibly, he himself communicated others. In 1683 one Fran. Meheux wrote to him about the progress of some unnamed third man in alchemical experimentation. In 1696, scarcely two weeks before his appointment as warden to oversee His Majesty's coinage in gold and silver, Newton received a visit from a Londoner who was a friend of Boyle and of Dr. Dickinson (a well-known alchemist of the day) who stayed for two days to discuss the work.[21] Mr. F., who lent copies of "Manna," was probably Ezekiel Foxcroft, a fellow of King's College.[22] W. S., Meheux, and the Londoner have all the solidity of shadows at this distance in time, but Newton knew them as sources of information on alchemy.

Newton did more than read. Almost from the beginning he experimented as well. When he moved into the chamber beside the great gate of Trinity in 1673, he set up a laboratory in the garden outside, and there he continued to experiment for more than twenty years.[23] At first glance, nothing could look less alchemical than his laboratory notes. They described severely quantitative experiments with specific substances, even if we cannot always identify the substances Newton's symbols represented; frequently, for example, he systematically varied the amount of a single ingredient (measured by weight) in order to determine the ideal proportions in a given compound.[24] Nevertheless, Professor Dobbs has succeeded in correlating some of the early experiments with the alchemical manuscripts and has shown that two substances he learned to produce, the star regulus of antimony and the net, were forms of the alchemical hermaphrodite, in which the sulfuric seed of iron (or Mars) was planted in a mercuric matrix, of antimony in the one case, of copper (or Venus) in the other.[25] Hence it appears impossible to avoid the conclusion that the early experiments were alchemical. No one has yet unraveled the later experiments, but it seems suggestive at least that Newton used materials such as the net and the oak, names drawn from the imagery of alchemy that appeared in his alchemical papers, and that he sometimes interrupted his notes with interpretive interjections couched in the imagery of alchemy. "I understood the trident." "I saw sophic sal ammoniac." "I made Jupiter fly on his eagle."[26]

The experimental notes aside, Newton's alchemical papers are sometimes said to consist solely of reading notes. This is simply incorrect.

Indeed, the concept of reading notes is itself less clear than one might think. Although some papers are certainly that, others reveal a typically Newtonian effort to organize information, to bind various authorities together into a systematic statement of the art. Thus one early paper drew up a list of forty-seven axioms with references to the authors on whom they were based.[27] He began to correlate the varied imagery he met.

> Concerning Magnesia or the green Lion [he wrote in a list of "Notae" which also treated other terms]. It is called prometheus & the Chameleon. Also Androgyne, and virgin verdant earth in which the Sun has never cast its rays although he is its father and the moon its mother: Also common mercury, dew of heaven which makes the earth fertile, nitre of the wise . . . It is the Saturnine stone.[28]

Some passages of this sort listed as many as fifty different images.[29] In a later paper, Newton distilled the work down to seven aphorisms. "This process," he stated, "I take to be y^{e} work of the best authors, Hermes, Turba, Morien, Artephius, Abraham y^{e} Jew & Flammel, Scala, Ripley, Maier, the great Rosary, Charnock, Trevisan. Philaletha. Despagnet."[30] He collected at least two sets of "Notable Opinions,"[31] and in his most extensive effort at synthesis he set out to compile a treatise in nine "works," for separate parts of which he left in one case seven, in another five, drafts.[32] Newton put these compilations together entirely from the writings of others. Nevertheless, to describe them as mere "reading notes" does not begin to suffice.

And finally, he also composed alchemical treatises himself. Professor Dobbs identified a paper from the late 1670s, entitled "Clavis," as Newton's own composition.[33] Although I find her argument, based on the paper's apparent use of Newton's own experimental results, wholly convincing, the identification has been challenged.[34] No one, I think, could challenge his authorship of another from the same period, entitled "Separatio elementorum," or his latter commentary on the "Tabula smaragdina."[35] Both papers are filled with emendations, Newton's typical habit with his own writing but one he never exercised on the writings of others. Undoubtedly his most important composition was an essay he finally called "Praxis," apparently composed in the summer of 1693.[36] It also is undoubtedly his own. We have four successive drafts of it,[37] and it cited Fatio's letter to Newton of May 1693.[38] At its climax, "Praxis" described a process that achieved multiplication, the ultimate goal of alchemy, in which the active essence of gold is set free to function.

> Thus you may multiply each stone [alchemical ferment] 4 times & no more for they will then become oyles shining in y^{e} dark and fit for magicall uses. You may ferment it wth ☉ [gold] by keeping them in fusion for a day, & then project upon metalls. This is y^{e} multiplication in quality. You may multiply it in quantity by the mercuries of w^{ch} you made it at first, amalgaming y^{e} stone wth y^{e} ☿ [mercury] of 3 or more eagles [?] and adding their weight of y^{e} water, & if you designe it for metalls you may melt every time 3 parts of ☉ wth one of y^{e} stone. Every multiplication will encreas it's vertue ten times &, if you use y^{e} ☿ of y^{e} 2^{d} or 3^{d} rotation wthout y^{e} spirit, perhaps a thousand times. Thus you may multiply to infinity.[39]

When Newton wrote this passage, he was in the state of acute tension that led to his breakdown in September 1693, and we must accordingly use it with caution. On grounds of scientific opinion, I cannot believe that Newton achieved multiplication. Because of his personal state when he wrote it, the passage does not convince me that he thought he had done so. I do accept it as valuable evidence of the extent of his immersion in the world of alchemy.

As another measure of the extent of his immersion, I propose the sheer quantity of the alchemical papers. Indications of their extent have appeared throughout my discussion, but we all know how readily one can contrive to inflate the impression of a small number of papers. Hence it has seemed important to me to arrive at a quantitative measure of these manuscripts by counting pages and words per page. There would be no point in estimating in a similar way the number of words Newton devoted to mathematics or dynamics or even theology, enterprises his commitment to which no one questions. The estimate is, of course, very crude; implicitly it equates the effort devoted to copying a page of a treatise with the effort given to composing a page of his own or to filling a page with experimental notes. Such a count serves only two purposes. It gives substance to the claim that the papers are very extensive, and when it is divided into chronological periods, it gives a rough measure of the intensity of his involvement with alchemy at different times. Restricting myself for the moment to the first, I note that Newton left behind about 1,200,000 words on alchemy. I see no way to dismiss it as an occasional interest. I think the other evidence I have brought forward indicates beyond reasonable doubt that the interest was sympathetic, the interest of a man who took the art seriously.

Meanwhile, alchemy did not exhaust the whole of Newton's intellectual life. As I suggested, he had found natural philosophy several years earlier. Specifically, about 1664, he had found the new natural philosophy that the seventeenth century called the mechanical philosophy, and in a notebook he recorded his initial contact with it under the heading "Quaestiones quaedam philosophicae."[40] For about three years, as his earlier notes indicate, the university had been feeding him on the dry bones of an Aristotelian philosophy desiccated beyond any hope of renewal. The "Quaestiones quaedam" recorded a conversion experience, not unlike the revelation we find in the pages of Galileo and Descartes, that natural philosophy could be done in a different way. Under his title Newton later returned to record a slogan: "Amicus Plato amicus Aristoteles magis amica veritas." He had discovered the world of the mechanical philosophy, his new friend Truth, for whom he brusquely abandoned Plato and Aristotle.

If he never returned to the old academic philosophy, he did not long remain entirely happy with his new friend either. About 1668 or 1669 he started a treatise with the title *De gravitatione et equipondio fluidorum*.[41] The Introduction, which was a discussion of the general questions of space, time, body, and motion, together with a couple of propositions, was all he completed. Only four or five years earlier, Descartes had functioned as the guide who led Newton into the new world of the mechanical philosophy. Nevertheless, *De gravitatione* was not merely an anti-Cartesian treatise; it was a violently anti-Cartesian one. The focus of his objection was the charge of atheism. Years later Newton would tell John Craig that "the reason of his showing the errors of Cartes's philosophy, was because he thought it was made on purpose to be the foundation of infidelity."[42] Although Newton showed more sympathy, both in *De gravitatione* and elsewhere, for Gassendi's alternative mechanical system, the weight of his objection to Descartes, that he set up the material world as an autonomous order, did not fall exclusively on the Cartesian version of the mechanical philosophy. Nor did Newton confine himself to hurling the general charge of atheism. The title of the piece suggested a work on fluid mechanics, and his conflict with Descartes took the form of an argument on natural philosophy and on its subtopic, motion. From the time of the composition of *De gravitatione*, Newton regarded the mechanical philosophy with ambiguous feelings. He never made the slightest move to return to academic Aristotelianism, which remained for him as dead as dead could be. At the same time, he never ceased to believe that the mechanical philosophy of nature in its received form required fundamental revision. I do not find it entirely accidental that the composition of *De gravitatione* fell very close to the first recorded manifestations of Newton's interest in alchemy, which embodied a view of nature that gave primacy to spiritual agents.

The ambiguity of his stance appeared in the "Hypothesis of Light" which he sent to the Royal Society in 1675.[43] With its universally diffused ether that he employed in mechanistic explanations of the reflection and refraction of light and the descent of heavy bodies toward the earth, the "Hypothesis" reads easily as a mechanical system of

nature. Other aspects of it fit that mold less readily. Indeed, it has been described as an alchemical cosmology, and one can see why.

> For nature is a perpetuall circulatory worker [Newton asserted], generating fluids out of solids, and solids out of fluids, fixed things out of volatile, & volatile out of fixed, subtile out of gross, & gross out of subtile, Some things to ascend & make the upper terrestriall juices, Rivers and the Atmosphere; & by consequence others to descend for a Requitall to the former.[44]

He ascribed a "principle of motion" to the corpuscles of light, and, in regard to chemical phenomena, he spoke of a "secret principle of unsociablenes," which kept certain substances from mixing together.[45] He specifically denied that the latter could be explained solely by the sizes of particles and pores, as mechanical philosophers tended to do.

About three years later, early in 1679, Newton wrote a long letter to Robert Boyle which was in some ways similar to the "Hypothesis of Light."[46] In discussing the cause of solubility, he again introduced his "secret principle in nature by w^ch^ liquors are sociable to some things & unsociable to others," and again he denied that the mere sizes of pores and particles could explain it. The question of volatility further drew upon the principle of unsociability, while the tendency of bodies to recede from each other gave the discussion a veneer of mechanical respectability by relating the causes of both phenomena to a universal ether. An unfinished treatise, *De aere et aethere*, from about this time appears to have been an effort to put the content of the letter to Boyle into a systematic form.[47] It began with a consideration of the tendency of air to expand and to avoid bodies, proceeded to note that in general bodies avoid each other, and concluded that air is composed of particles of bodies "torn away from contact, and repelling each other with a certain large force." Once again he apparently set out to explain the repulsion by means of an ether, but he abandoned the effort after only a few lines and never returned to it. Well he might have abandoned it, for his principle of unsociability and related ideas were moving steadily away from orthodox mechanical philosophy. It cannot have been long after *De aere et aethere* when Newton performed a carefully designed experiment with a pendulum, described in the *Principia*, that encouraged him to abandon belief in the very existence of an ether.[48] An ether, the invisible medium called upon as a causal agent for every apparently nonmechanical phenomenon, was the sine qua non of a workable mechanical philosophy of nature.

When we consider his constant probing of the mechanical philosophy over a period of nearly two decades, we are not surprised that Newton's masterpiece, the *Principia*, based celestial dynamics on a concept no ordinary mechanical philosopher would have considered, a principle of universal attraction. As we now know, Newton intended at one point to go further. In a drafted "Conclusio," he proposed a general revision, based on forces that act at a distance, of all natural philosophy. Nature, he noted, is simple and conformable to itself.

> Whatever reasoning holds for greater motions, should hold for lesser ones as well. The former depend upon the greater attractive forces of larger bodies, and I suspect that the latter depend upon the lesser forces, as yet unobserved, of insensible particles. For, from the forces of gravity, of magnetism and of electricity it is manifest that there are various kinds of natural forces, and that there may be still more kinds is not to be rashly denied. It is very well known that greater bodies act mutually upon each other by those forces, and I do not clearly see why lesser ones should not act on one another by similar forces.[49]

Newton was well aware that he was proposing a major philosophic innovation, and he tried to shield himself from expected criticism. When, in Book I, he came to Section XI and the mutual attraction of bodies, which suggested a more concrete notion of force than earlier abstract propositions had implied, he assured his readers that the demonstrations were purely mathematical. "I here use the word *attraction* in general for any endeavor whatever, made by bodies to approach to each other," he asserted, "whether that endeavor arise from the action of the bodies themselves, as tending to each other or agitating each other by spirits emitted; or whether it arises from the action of the ether or of the air, or of any medium whatever, whether corporeal or incorporeal, in any manner impelling bodies placed therein towards each other."[50] Similarly, some years later, in Query 31, he would declare once more that attractions could be performed by impulses.[51] He went on there to argue for the general necessity of "active Principles" since a purely mechanical universe would run down, and again he attempted to blunt expected objections. "These Principles I consider, not as occult Qualities, supposed to result from the specifick Forms of Things, but as general Laws of Nature, by which the Things themselves are form'd; their Truth appearing to us by Phaenomena, though their Causes be not yet discover'd. For these are manifest Qualities, and their Causes only are occult."[52] Since Book II of the *Principia* had demonstrated both the impossibility that the heavens can be filled with a material medium and the impossibility that a mechanical system can sustain itself without the constant addition of new motion, demonstrations he sought only to strengthen in subsequent editions, Newton had also made it evident to discerning readers that his vision of reality was even farther removed from orthodox mechanical philosophy than the mere concept of action at a distance implied.

Newton was not the only one who recognized that he was proposing a fundamental reordering of natural philosophy. For a generation, mechanical philosophers on the Continent, though they recognized the mathematical power of Newton's demonstrations, refused to have truck with a concept of attraction. Leibniz hinted that it was a return to the "enthusiastic philosophy" of Robert Fludd.[53] He was by no means alone, and more than one mechanical philosopher applied to it the very pejorative, "occult," that Newton had sought to avoid. For their part, Newtonians eventually seized on the concept of forces at a distance as the central characteristic of a new approach to the whole of natural philosophy. Not only British followers, such as Cotes, Pemberton, and McLauren, but early Continental Newtonians, such as Voltaire, 'sGravesande, and Algarotti, all grasped attractions and repulsions, not as mathematical abstractions, but as forces that really exist, and treated them as the foundation on which both a different picture of nature and a different form of scientific investigation rested. By the middle of the eighteenth century, there was no one who mattered left to argue with them.

My third premise is the close chronological correlation between the appearance of the Newtonian concept of force and his interest in alchemy. I shall assume that any further discussion of the chronology of the concept of force, which emerged fully with the *Principia*, is unnecessary. Newton's concern with alchemy, however, has not been public knowledge. In describing the papers, I mentioned some dates. Let me be explicit that for most of the papers dating rests solely on the hand in which they were written. Hence a degree of imprecision about their chronology appears unavoidable. The imprecision is less than the uninitiated might think, however. Newton's hand developed through a number of distinctive phases. To me it seems virtually impossible, for example, to confuse the tiny perpendicular hand of the 1660s with the large, sloping, careless hand of the 1690s or the medium-sized but shaky and crabbed hand of the old man. In a number of cases, some of which I mentioned, dates internal to the manuscripts support evidence drawn from the hand. The laboratory notes are sprinkled with dates that extend from 1678 to 1696. It is relevant to note that Newton performed one set of experiments in the spring of 1686, when the *Principia* was still under composition. Correspondence, such as the letter from Meheux and the exchange with Locke, inevitably carries dates, and Newton dated his memorandum about the Londoner who stayed two days discussing the work. His citation of Fatio's letter of May 1693 establishes the time before which "Praxis" could not have been written. In all, I feel complete confidence about the general period as long as one does not insist on precise years. Newton began serious study of alchemy in the late 1660s. I know of nothing that extends it back into his undergraduate career. Once aroused, his interest continued for nearly thirty years, well into the 1690s. Allow me to note that the alchemical papers come from the years of Newton's intellectual maturity, from the very time when, with his capacity at its highest pitch, he produced the book that has made him immortal. There are a few scraps about alchemy on papers associated with his early years at the Mint, but the manuscripts strongly imply that his active involvement with the art ended near the time when he moved to London.

My central question is implicit in the three premises of my argument. Given Newton's interest in alchemy, given his concept of forces that act between particles, and given the fact that the concept of forces appeared during the period when he was immersed in alchemy, can we establish a connection between the two? In my own view, my question is equivalent to asking whether Newton's alchemy was an activity isolated from the rest of his natural philosophy or whether it exerted an influence on his work in physics. Thus the question also implicitly asks if the structure of modern science embodies concepts that trace their lineage in part to alchemy.

In attempting to answer the question, we must plunge into the content of the alchemical papers. One of the earliest of them, a paper of Newton's own composition though it is not a single connected essay, which is known as "The Vegetation of Metals" from a phrase in the opening lines, probed the distinction between vegetation and purely mechanical changes. Rearrangements of particles effect mechanical changes; vegetation brings about more profound alterations.

> There is therefore besides y^e^ sensible changes wrough in y^e^ textures of y^e^ grosser matter a more subtile secret & noble way of working in all vegetation which makes its products distinct from all others & y^e^ immediate seate of thes operations is not y^e^ whole bulk of matter, but rather an exceeding subtile & inimaginably small portion of matter diffused through the masse w^ch^ if it were seperated there would remain but a dead & inactive earth.[54]

As the concept of the vegetation of metals implies, Newton did not limit vegetation to the realm of plants, but treated it as a process present throughout nature. He sometimes called the principle of vegetable action a spirit, which he described as a "Powerfull agent"; sometimes he referred to it, in the plural, as seeds or seminal virtues, which are nature's "only agents, her fire, her soule, her life."[55] That is, what he found in the world of alchemy was the conviction that nature cannot be reduced to the arrangement of inert particles of matter. Nature contains foci of activity, agents whose spontaneous working produces results that cannot be accounted for by the mechanical philosophy's only category of explanation: particles of matter in motion.

The ultimate active agent of nature is what alchemists called the philosophers' stone, the goal of their search. They applied to it images of all sorts, all of them embodying a concept of activity that contrasted with the passivity of matter in the mechanical philosophy. Flammel called it "a most puissant invincible king"; Philalethes, the "miracle of the world" and "the subject of wonders." The author of *Elucidarius* proclaimed that "it is impossible to express [its] infinite virtues."[56] Sometimes activity took on the form of attraction, which was likened to a magnet. Whereas mechanical philosophers explained magnetic attraction away by imagining whirlpools of invisible particles, alchemists embraced it as a visible image of nature's mode of operation. "They call lead a magnet," Newton learned from Sendivogius, "because its mercury attracts the seed of Antimony as the magnet attracts the Chalybs." He also noted that "our water" is drawn out of lead "by the force of our Chalybs which is found in the belly of Ares [i.e., iron]."[57]

His laboratory experience constantly reinforced the message of the alchemical literature. Thus it is relevant to note the steady appearance of active verbs in his experimental notes. When he added spelter to a solution of aqua fortis and sal ammoniac, "y^e^ menstruum [solvent] wrought upon y^e^ spelter [zinc] continually till it had dissolved it." A solution often "fell a working w^th^ a sudden violent fermentation." The spirit, he sometimes noted, "draws" or "extracts" the salts of metals, a usage similar to Sendivogius's magnetic image. When one substance combined with another, it "laid hold" on it; if the two sublimed, one "carried up" the other; if they failed to sublime, one "held" the other "down."[58] It citing these verbs, I seek only to record Newton's immediate perceptions of spontaneous activity in many chemical reactions. The alchemical concept of active agents directly expressed such perceptions. Mechanical philosophers argued that the perceptions were illusions and that the reality behind them consisted solely of inert particles in motion. One cannot infer a choice between two philosophies of nature from the verbs in Newton's experimental notes. They do suggest, however, how he would have been able to understand the images alchemy employed because he too had witnessed the activity the images expressed.

As he was completing the *Principia* in 1686, Newton composed a "Conclusio," from which I have already quoted, an essay that expanded the message of the book beyond universal gravitation into a manifesto of a new philosophy of nature based on forces that act at a distance. In the end he suppressed the "Conclusio," but twenty years later he expanded it into what we know as Query 31. Newton drew upon a number of sources for his assertion that a wide range of forces exists in nature – phenomena such as the expansion of gases, capillary action, surface tension, and the cohesion of bodies, which had seized his attention already in his undergraduate "Quaestiones" and had appeared in later speculations, such as the "Hypothesis of Light," that probed the limits of the mechanical philosophy. Above all, however, he drew upon chemical phenomena.

> Hitherto I have explained the System of this visible world [the "Conclusio" began], as far as concerns the greater motions which can easily be detected. There are however innumerable other local motions which on account of the minuteness of the moving particles cannot be detected, such as the motions of the particles in hot bodies, in fermenting bodies, in putrescent bodies, in growing bodies, in the organs of sensation and so forth. If any one shall have the good fortune to discover all these, I might almost say that he will have laid bare the whole nature of bodies so far as the mechanical causes of things are concerned.[59]

The chemical reactions that impressed Newton fell into two general types. Reactions that produce heat formed one of them.

> If spirit of vitriol (which consists of common water and an acid spirit) be mixed with Sal Alkali or with some suitable metallic powder, at once commotion and violent ebullition occur. And a great heat is often generated in such operations. That motion and the heat thence produced argue that there is a vehement rushing together of the acid particles and the other particles, whether metallic or of Sal Alkali; and the rushing together of the particles with violence could not happen unless the particles begin to approach one another before they touch one another . . . So also spirit of nitre (which is composed of water and an acid Spirit) violently unites with salt of tartar; then, although the spirit by itself can be distilled in a gently heated bath, nevertheless it cannot be separated from the salt of tartar except by a vehement fire.

The other type of reaction that he called upon displays selective affinities analogous to his secret principle of sociability and unsociability. Thus he argued that the ability of salt of tartar to precipitate bodies dissolved in acids stems from "the stronger attraction by which the salt of tartar draws those acid spirits from the dissolved bodies to itself. For if the spirit does not suffice to retain them both, it will cohere with that which attracts more strongly."[60]

Newton did not discover the reactions cited here. He could have found them all in the writings of mechanical chemists such as Boyle, with which he was certainly familiar. In Boyle, however, he could not have found the conclusion he derived from them: that particles of matter attract and repel each other. For that matter, he could not have found the conclusion, in the form stated above, in alchemical literature either. What he could have found there, as I have indicated, was a concept of active principles that bears a close resemblance to the manner in which Newton frequently expressed his concept of forces. It is also of some importance to my argument to insist that, without exception, all the chemical phenomena cited in the "Conclusio" had appeared in Newton's experimental notes during the previous decade.

It is further relevant to note that Newton composed a paper, "De natura acidorum," in which we can observe the transition from the alchemical concept of active principle to the Newtonian concept of attraction expressed in his own words. In Newton's alchemy, philosophic sulfur, the male principle, was the ultimate causal agent in nature. "De natura acidorum" argued that the activity of sulfur, perhaps common sulfur in this case, springs from the acid it conceals. "For what attracts and is attracted strongly, we call acid." Under the images of dragons and serpents that devoured uncounted kings and queens, acids were also active in the world of alchemy. The particles of acids, Newton asserted in a statement that grasps that world in one embrace with his own concept of force, "are endowed with a great attractive force and in this force their activity consists by which they dissolve bodies and affect and stimulate the organs of the senses."[61]

Newton composed "De natura acidorum" during the early 1690s, in the years immediately following the *Principia*. It was a period of almost manic intellectual activity in his life. Buoyed by the twin successes of the *Principia* and the Glorious Revolution, in which he had played a significant if minor role, he apparently set out to codify his philosophic legacy. He devoted extensive energy to revising the *Principia*. The book had taken shape, developing and expanding as Newton explored its topic, during a period of about thirty months that began in August 1684. There is every reason to think that he did not regard the form in which it appeared in 1687 as final. We have the manuscripts for important revisions both of the early demonstrations in Book I and of the opening propositions of Book III. The proposed new edition never saw publication in the form then planned, but the surviving manuscripts leave no doubt that Newton worked at it. The same years saw intense mathematical endeavor, including the composition of a definitive exposition of his fluxional calculus. He began to write his *Opticks*, not the volume he published ten years later, but an *Opticks* in four books, which used optical phenomena to support the Newtonian natural philosophy based on forces between particles. Hence it seems to me a matter of major significance that during this period – in the years, I repeat, immediately following the *Principia* – Newton also invested an enormous effort in alchemy. I suggested before that one use of the quantitative measure of his alchemical papers was the establishment of a rough chronological index of the effort expanded. He wrote about half of the estimated 1,200,000 words on alchemy during the period of seven or eight years that followed the *Principia*. The mere existence of papers from that time cannot, of course, demonstrate a connection between alchemy and the Newtonian concept of force. To me, at least, the papers offer powerful evidence that Newton regarded his alchemical endeavors as a harmonious part of his total philosophical program.

I do not want my argument to be misunderstood. I am seeking the source of the Newtonian concept of forces of attraction and repulsion between particles of matter, the concept that fundamentally altered the prevailing philosophy of nature and ushered in the intellectual world of modern science. I am offering the argument that alchemy, Newton's involvement in which a vast corpus of papers establishes, offered him a stimulus to consider concepts beyond the bare ontology of the mechanical philosophy. It appears to me that the Newtonian concept of force embodies the enduring influence of alchemy upon his scientific thought. As I mentioned, Professor Cohen takes issue with the argument in his recent *Newtonian Revolution*. He presents an analysis of the *Principia*'s development that confines itself to the science of dynamics and its application to orbital motion and treats the concept of attraction as a conclusion that emerged solely from Newton's consideration of such problems. To the suggestion that alchemy influenced Newton, he replies that Newton repeatedly asserted that his success with gravitational attraction led him to consider the possibility of other forces between particles.[62] I wish to say two things in this respect. First, I do not know the assertions to which Professor Cohen alludes. I think he refers primarily to the statement, very similar to the one I quoted above from the "Conclusio," that Newton inserted in the Preface to the *Principia*. What I find in it is an argument from the analogy of nature, not an autobiographical account of his discovery. Second, it appears to me that the technical problems of dynamics, which were of unavoidable importance to Newton's concept of force, can be separated from the conceptual issue with which I have concerned myself in this chapter. Indeed, I believe we have empirical evidence that they were separated in the seventeenth century. Next to Newton, there was no one alive better able to appreciate the technical problems of dynamics than Huygens, Leibniz, and Bernoulli. Each of them studied the *Principia* and appreciated the full extent of its achievement. Even with the book open before him, not one of the three ever admitted the possibility of attractions at a distance. It is my contention that Newton's readiness to consider the possibility derived from the influence of alchemy.

I am not discussing technical dynamics, in which Newton made enormous strides that are obviously related to his concept of force. I am talking rather about a conceptual innovation – an innovation, that is, in relation to the prevailing mechanical philosophy of nature. There are, I insist, strong arguments, summarized in this chapter, for tracing it in part to the influences of alchemy.

J. E. McGuire has recently advanced quite a different argument against the case for alchemy. In a number of articles, McGuire has traced the influence of the Cambridge Platonists on Newton. Why call upon alchemy, he asks, when we have Cambridge Platonism to supply a similar influence?[63] There are also two things I would say in reply to McGuire. First, I see no necessary opposition between us. I do not argue that alchemy exercised the sole influence on Newton. I take McGuire's articles to have demonstrated that Cambridge Platonism, in which one can find a concept of active principles, also influenced Newton. I see no reason why two influences could not operate in the same direction. I say, secondly, that whatever the influence of Cambridge Platonism, the alchemical papers remain. Indeed it is necessary to remark in this respect that for every page in Newton's papers of direct reference to More and Cudworth there are well over a hundred on alchemy. I cannot make those papers disappear.

To say as much is in no way to suggest that Newtonian science – and hence derivatively all of modern science – is a covert form of alchemy. I emphatically reject any attempt to distort my argument in that direction. Hence I must distinguish my position from Castillejo's. No doubt it oversimplifies his book to speak of an equation of Newtonian science with alchemy; but unless I completely misunderstand the work, that statement of his position is far more true than false. With Castillejo's conviction that we need to integrate Newton's alchemical activity into the rest of his intellectual life I am in obvious agreement; beyond that I cannot go. His argument appears to me to neglect the most important aspects of Newton's scientific endeavor – his mathematics, his quantitative science of dynamics, his experimental investigation of light – and to ignore as well the implications of its aftermath – the enormous growth of modern science, three centuries of experimental confirmation, and two centuries of practical confirmation through the successes (and even the disasters) of scientific technology.

Far from equating Newtonian science with alchemy, I emphasize the extent to which Newton altered what he received. His success in practicing alchemy on alchemy itself may be the ultimate measure of its influence on him. If he derived his concept of force partly from the alchemical active principle, he also transformed it in fundamental ways. Above all, he quantified it, so that it could fit smoothly into the structure of his quantitative dynamics. There is no sense in which I deny the relevance of the technical problems internal to dynamics, which

Professor Cohen analyzes so well. Newton may have found an idea of attraction in Sendivogius, but we cannot imagine Sendivogius writing the *Principia*. To that extent Newton transformed what he received.[64]

Hence Newton could see the final result of his work as the perfection of the mechanical philosophy rather than its denial. Physical nature remained for him what it had been for mechanical philosophers: particles of matter in notion. With the quantified concept of force, he called natural philosophy back from its preoccupation with imagining invisible mechanisms and gave decisive demonstration of the power exact mathematical description wields. Perhaps we can best say, using Professor Cohen's approach, that the Newtonian concept of force transformed natural philosophy into modern science. With only modest surprise, I note how close I see myself to Professor Hall for all our surface disagreements. For me also, Newton represents reason; his success in weaving a single fabric from a multiplicity of strands constitutes in my eyes one of the supreme exercises reason has known. We differ, if I understand it correctly, on my readiness to admit that a different standard of rationality in the seventeenth century may have encouraged Newton to open himself to the influence of a tradition that appears to us almost as the antithesis of reason.

Hence also I need to close by pointing as well to the final act in the drama. Newton did in the end turn away from alchemy. Every time I think seriously about Newton and alchemy this final act assumes greater significance. Alchemy formed an integral part of the intense intellectual activity of the early 1690s. The essay "Praxis," composed in the summer of 1693, suggests that the breakdown of that year also had an alchemical dimension. Newton's interest in alchemy did not end suddenly at that moment; there were, for example, dated experimental notes that extended to 1696. Nevertheless, his intense involvement in the art did come to an end about then. A few scraps on alchemy can be dated to his early London years, but only a few. His library contained only three alchemical books published after 1700, two of them by William Y-Worth, presented to him by the author in 1702.[65] Alchemy was the one intellectual pursuit of Newton's Cambridge years that did not follow him to London. Am I wrong then in placing alchemy within the precincts of Newtonian rationality if in the end he turned away from it? "Praxis," with its claim of successful multiplication, does seem to have moved beyond the realm of reason, but 1693 was an extraordinary year for Newton when everything ran over the edge. If that extravagant dream – or nightmare – ended in disillusionment, I suggest that the end of Newton's active involvement in alchemy marked his realization that he had in fact achieved a different success. With his quantified concept of force, he had extracted the essence of the art. Alchemy itself told him to reject the dross as dead and lifeless

matter. The seed had found a fertile matrix where it has flourished ever since.

Notes

1 *The Correspondence of Isaac Newton*, ed. H. W. Turnbull et al., 7 vols. (Cambridge, 1959–77), III, 192–3, 195, 215, 216, 217–19.

2 Conduitt's memorandum of 31 August 1726; King's College, Cambridge, Keynes MS. 130.10, fol. 3^{v}.

3 David Brewster, *Memoirs of the Life, Writings, and Discoveries of Sir Isaac Newton*, 2 vols. (Edinburgh, 1855), II, 371–6.

4 Lord Keynes, "Newton the Man," in Royal Society, *Newton Tercentenary Celebrations* (Cambridge, 1947), pp. 27–34.

5 B. J. T. Dobbs, *The Foundations of Newton's Alchemy: The Hunting of the Greene Lyon* (Cambridge, 1975), and "Newton's Copy of *Secrets Reveal'd* and the Regimen of the Work," *Ambix*, 26 (1979), pp. 145–69. Professor Dobbs is presently completing a second book that will extend her study into the alchemical manuscripts that belonged to a later period in Newton's life. As far as I know, Karin Figala's dissertation has, regrettably, not been published; see Karin Figala, "Die 'Kompositionshierarchie' der Materie: Newton's quantitative Theorie und Interpretation der qualitativen Alchemie," unpublished Habilitationsschrift, Technischen Universität, Munich. She presented a brief view of her work in "Newton as Alchemist," *History of Science*, 15 (1977), pp. 102–37, an essay-review of Professor Dobbs's book.

6 Brewster, II, 375.

7 I. Bernard Cohen, *The Newtonian Revolution* (Cambridge, 1980). The specific passage to which I refer is on p. 10.

8 I quote, with Professor Hall's generous permission, from a private letter to me about my recent biography of Newton.

9 David Castillejo, *The Expanding Force in Newton's Cosmos* (Madrid, 1981).

10 Bodleian Library, Oxford, MS. Don.b.15.

11 Accounts in the notebook in the Fitzwilliam Museum, Cambridge.

12 Manuscript in the Countway Medical Library, Harvard University, item 3, fol. 10^{v}.

13 Jewish National and University Library, Yahuda MS. 259, no. 9.

14 Dobbs, *Foundations*, p. 88.

15 Keynes MS. 30. See my analysis of its content: "Isaac Newton's Index Chemicus," *Ambix*, 22 (1975), pp. 174–85.

16 John Harrison, *The Library of Isaac Newton* (Cambridge, 1978).

17 Keynes MSS. 51 and 52.

18 Keynes MS. 55 and a manuscript in the Yale Medical Library. Other examples are Keynes MSS. 22, 24, 31, 33, 39, 50, 58 (part only), 62, 65, and 66.

19 The sheaf is Keynes MS. 67; the notes are Keynes MS. 62.

20 Keynes MS. 33.

21 Newton recorded the visit in two largely identical memoranda: Keynes MS. 26 (published in *Correspondence*, IV, 196–8) and MS. 1075-3 in the Joseph Halle Schaffner Collection, University of Chicago Library.

22 Professor Dobbs so identified him, convincingly: *Foundations*, p. 112.

23 Early experiments are recorded in Cambridge University Library, Add. MS. 3975, pp. 81–4. Later ones, frequently dated and extending from 1678 to

1696, are found in Add. MSS. 3973 and 3975, pp. 101–58, 267–83. The first examination of Newton's records of his chemical experiments, which remains an indispensable guide to them, is A. R. Hall and Marie Boas [Hall], "Newton's Chemical Experiments," *Archives internationales d'histoire des sciences*, 11 (1958), pp. 113–52.

24 See, for example, Add. MSS. 3973, fols. 5v–6, 13–13v, and 3975, p. 143.

25 Dobbs, *Foundations*, pp. 146–63.

26 Add. MSS. 3975, p. 121; 3973, fol. 17; 3975, p. 149.

27 Countway MS., item 4.

28 Ibid., item 3, fol. 7.

29 While similar passages abound, the "Index chemicus" (Keynes MS. 30) is especially rich in them.

30 Keynes MS. 49, fol. 1.

31 Keynes MSS. 38 and 56. Keynes MS. 57, which has no title, is a similar compilation.

32 They are found in Keynes MSS. 40 and 41; Babson College Library, Babson MS. 417; and Dibner Collection, Smithsonian Institution Libraries, Burndy MS. 17.

33 Dobbs, *Foundations*, pp. 251–5.

34 Figala, "Newton as Alchemist," p. 107; D. T. Whiteside, "From his Claw the Greene Lyon," *Isis*, 68 (1977), p. 118.

35 Burndy MS. 10 and Keynes MS. 28.

36 Babson MS. 420.

37 The first two, under different names, in Keynes MSS. 21 and 53.

38 *Correspondence*, III, 265–7.

39 Babson MS. 420, p. 18a. In the final draft of this passage (p. 17), Newton toned it down somewhat.

40 Add. MS. 3996, fols. 88–135.

41 Add. MS. 4003. Published in A. R. Hall and M. B. Hall, *Unpublished Scientific Papers of Isaac Newton* (Cambridge, 1962), pp. 90–121; English trans., pp. 121–56.

42 Keynes MS. 132.

43 *Correspondence*, I, 362–86.

44 Ibid., I, 365–6.

45 Ibid., I, 368–70.

46 Ibid., II, 288–95.

47 Published in Hall and Hall, *Unpublished Papers*, pp. 214–20; English trans., pp. 220–8.

48 *Principia*, Motte-Cajori trans. (Berkeley, 1934), p. 325. See ed. 1, p. 353, for two important concluding sentences Newton omitted from the second and subsequent editions.

49 Hall and Hall, *Unpublished Papers*, p. 333.

50 *Principia*, pp. 164, 192.

51 *Opticks*, based on 4th ed. (New York, 1952), p. 376.

52 Ibid., p. 401.

53 In an "anonymous" review of John Freind's chemical lectures, *Acta eruditorum* (September 1710), p. 412.

54 Burndy MS. 16, fol. 6v.

55 Ibid., fols. 5–5v.

56 I cite from Newton's notes: Keynes MSS. 40, fols. 20, 19v; 41, fol. 15v; Babson MS. 417, p. 35.

57 Keynes MS. 19, fols. 1, 3.

58 Add. MSS. 3973, fol. 42; 3975, pp. 281, 104–5; 3973, fols. 13, 21; 3975, pp. 108–9.

59 Hall and Hall, *Unpublished Papers*, p. 333.

60 Ibid., pp. 333–5.

61 *Correspondence*, III, 209–12.

62 See the reference above, note 7, and a fuller discussion in an article published after the paper on which this chapter is based was presented: I. B. Cohen, "The *Principia*, Universal Gravitation, and the 'Newtonian Style,' in Relation to the Newtonian Revolution in Science," in *Contemporary Newtonian Research*, ed. Zev Bechler (Dordrecht, 1982), pp. 67–74.

63 J. E. McGuire, "Neoplatonism and Active Principles: Newton and the *Corpus Hermeticum*," in Robert S. Westman and J. E. McGuire, *Hermeticism and the Scientific Revolution* (Los Angeles, 1977).

64 My inability to write this paragraph without Professor Cohen's concept of transformation must be significant.

65 Harrison, *Library*, items 1138, 1302, 1644.