Religion, science, and worldview

ESSAYS IN HONOR OF RICHARD S. WESTFALL

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Conceptual problems in Newton's early chemistry: a preliminary study

B. J. T. DOBBS

Isaac Newton's chemistry has been studied primarily in the material he published in his old age in the Queries of the *Opticks*.[1] Valuable though the analyses of that material are, they tell us only about Newton's chemical thought thirty to forty years after he took up the study of the field and almost nothing about the devel-

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[1] Marie Boas (Hall), "Newton and the Theory of Chemical Solution," *Isis, 43* (1952), 123; Marie Boas (Hall) and A. Rupert Hall, "Newton's Theory of Matter," *Isis, 51* (1960), 131–44; G. Daniel Goehring, "Isaac Newton's Theory of Matter: A program for chemistry," *Journal of Chemical Education, 53* (1976), 423–5; William J. Green, "Models and Metaphysics in the Chemical Theories of Boyle and Newton," *Journal of Chemical Education, 55* (1978), 434–6; Joshua C. Gregory, "The Newtonian Hierarchic System of Particles," *Archives internationales d'histoire des sciences, 7* (1954), 243–7; Thomas S. Kuhn, "Newton's '31st Query' and the Degradation of Gold," *Isis, 42* (1951), 296–8; idem, "Reply to Marie Boas (Hall)," *Isis, 43* (1952), 123–4; Douglas McKie, "Some Notes on Newton's Chemical Philosophy Written upon the Occasion of the Tercentenary of his Birth," *Philosophical Magazine, 33* (1952), 847–70; Hélène Metzger, *Newton, Stahl, Boerhaave et la doctrine chimique* (reprint of the 1930 ed.; Paris: Librairie scientifique et technique Albert Blanchard, 1974); Lyman C. Newall, "Newton's Work in Alchemy and Chemistry," in *Sir Isaac Newton, 1727–1927. A Bicentenary Evaluation of His Work. A Series of Papers Prepared under the Auspices of The History of Science Society in Collaboration with The American Astronomical Association of America and Various Other Organizations* (Baltimore: Williams & Wilkins, 1928), pp. 203–55; J. R. Partington, *A History of Chemistry*, 4 vols., (London: Macmillan Press; New York: St. Martin's Press, 1961–70), *II*, 468–77; Arnold Thackray, *Atoms and Powers. An Essay on Newtonian Matter-Theory and the Development of Chemistry*, Harvard Monographs in the History of Science (Cambridge, Mass.: Harvard University Press, 1970); idem, " 'Matter in a nut-shell': Newton's *Opticks* and Eighteenth-Century Chemistry," *Ambix, 15* (1968), 29–53; S. I. Vavilov, "Newton and the Atomic Theory," in *The Royal Society Tercentenary Celebrations 15–19 July 1946* (Cambridge: Cambridge University Press, 1947), pp. 43–55.

opment of his concepts. Since Newton left behind a huge legacy of unpublished manuscripts, his developing thought in mathematics and in many areas of science has been exhaustively explored by philosophers and historians, but it has heretofore been impossible to study his development as a chemist because his chemical papers had been misclassified as alchemical. The recent isolation from the mass of his alchemical manuscripts of some early Newton chemical papers, however, provides a unique opportunity to launch a study of his chemical development, and it is the purpose of this article to offer a preliminary excursion into the conceptual problems Newton faced in his early chemical work.

NEWTON'S EARLY CHEMICAL PAPERS AND THE CHALLENGE THEY PRESENT

The manuscripts that record Newton's early chemistry were, for a considerable period, confused with his alchemical papers. It is sometimes admittedly difficult to distinguish between seventeenth-century chemistry and alchemy in the texts and manuscripts of the period, but here we shall follow a relatively simple distinction. Chemistry, even in the seventeenth century, was concerned with the practical operations of metallurgy, pharmacy, and food preservation; the manufacture of glass, porcelain, pottery, or mortar; the dyeing of cloth and the tanning of leather; distillation, and so forth. Alchemy, on the other hand, though it might employ ordinary chemical techniques, had as its overarching goal the preparation of an agent of perfection (the philosopher's stone) or the achievement of some form of perfection itself – in metals (gold), in medicine (a universal medicine), in soul (salvation), in cosmos (the redemption of matter). Newton himself made a differentiation between chemistry and alchemy that was similar to this, calling the first type common, vulgar, or mechanical chemistry. The second type, our alchemy, he called "vegetable" chemistry.[2] With both the vulgar and the vegetable chemistries treating extensively of transformations in matter, however, Newton's distinction has not always been apparent to those who have preserved and orga-

[2] Isaac Newton, "Of nature's obvious laws and processes in vegetation," Smithsonian Institution, Washington, D.C., Burndy MS 16, fol. 5^{r,v}; cf. B. J. T. Dobbs, "Newton Manuscripts at the Smithsonian Institution," *Isis, 68* (1977), 105–7; idem, "Newton's Alchemy and His Theory of Matter," *Isis, 73* (1982), 511–28.

nized his papers since his death in 1727, and the manuscripts with chemical content of any sort have been dispersed according to other criteria.

Newton died intestate, and virtually all of his papers were retained by the family until the nineteenth century when the earl of Portsmouth, to whom they had descended, undertook to present the scientific materials among them to the University of Cambridge.[3] A university-appointed syndicate examined the entire collection of books and manuscripts in the possession of the family, separating the collection into "scientific" and "nonscientific" portions. We can now see that the judgments of members of the syndicate were, to a certain extent, based on nineteenth-century preconceptions about what was "scientific," and even then were not entirely consistent. Thus, the syndicate placed the laboratory record of Newton's own experimentation on the transformations of matter in the "scientific" portion, where it remains with the Portsmouth Collection in University Library, Cambridge.[4] Newton's record of his experiments was almost totally empirical, with no stated rationales for most of the experimental procedures, and most of it is cryptic to the point of indecipherability in the present state of our knowledge. Newton even encoded the names of many of his chemicals in his own idiosyncratic symbolic system. Yet some of the experiments and some of the terminology have now been correlated with other papers of Newton's that derive from alchemical sources, and on balance it seems likely that much, perhaps all, of that experimental work was directed toward alchemical ends.[5] Presumably the syndicate made its decision to retain the laboratory record because of its obviously experimental character and never recognized the alchemical nature of the experiments, for it returned all of the other alchemical papers to the family as being "nonscientific" and thus of no interest to the university. Similarly,

[3] Isaac Newton, *The Mathematical Papers of Isaac Newton*, ed. Derek T. Whiteside with the assistance in publication of M. A. Hoskin, 8 vols. (Cambridge: Cambridge University Press, 1967–80), *I*, xv–xxxvi.

[4] The record consists of a notebook and several loose sheets, University Library, Cambridge, Portsmouth Collection, MSS Add. 3973 and 3975. Cf. Marie Boas (Hall) and A. Rupert Hall, "Newton's Chemical Experiments," *Archives internationales d'histoire des sciences, 11* (1958), 113–52.

[5] B. J. T. Dobbs, *The Foundations of Newton's Alchemy, or "The Hunting of the Greene Lyon"* (Cambridge: Cambridge University Press, 1975), esp. pp. 16–17, 139–86, and 249–55; Richard S. Westfall, *Never at Rest: A Biography of Isaac Newton* (Cambridge: Cambridge University Press, 1980), esp. pp. 290–301 and 361–71.

drafts of the Queries for the *Opticks* went into the Portsmouth Collection, even though modern scholarship finds some profound affinities between alchemical doctrine and the "scientific" ideas expressed in the drafts, and indeed in the published Queries.[6]

Lumped together with the papers that were so clearly and distressingly alchemical[7] and were returned to the family as being "nonscientific," were a few chemical manuscripts composed by Newton in the 1660s before he became immersed in the alchemical enterprise. Along with personal papers and theological manuscripts, these chemical/alchemical materials remained with the family until they were dispersed at auction in 1936.[8] It was not until I systematically surveyed all of the scattered "alchemical" papers to which I could gain access in the 1970s that the orthodox chemical nature of a few of them was recognized. Of the 121 lots of "alchemical" materials auctioned by Sotheby's in 1936, at least three (lot nos. 16, 49, 79) and possibly four more (lot nos. 36, 88, 96, 115) should now be reclassified as chemical, for, according to Newton's own distinction, they are concerned with common or vulgar chemistry only.

These manuscripts demonstrate that Newton made himself into an accomplished chemist, probably not long after his *annus mirabilis* of 1666. The most extensive and systematic of the chemical papers is Sotheby lot no. 16, now in the Bodleian Library, Oxford.[9] Organized alphabetically as a sort of chemical dictionary of sixteen small quarto pages, it is written in Newton's tiny early handwriting and appears to be the production of a young man who has set out to master a new field of inquiry and is now busy reducing the information he has acquired into an orderly and useful form. In it are brief but graphic explanations of commercial as

[6] Dobbs, "Newton's Alchemy and His Theory of Matter" [see note 2].

[7] For the classic statement of nineteenth-century horror at Newton's interest in alchemy, see David Brewster, *Memoirs of the Life, Writings, and Discoveries of Sir Isaac Newton*, 2 vols. (Edinburgh: Thomas Constable; Boston: Little, Brown, 1855), *II*, 374–5: ". . . we cannot understand how a mind of such power, and so nobly occupied with the abstractions of geometry, and the study of the material world, could stoop to be even the copyist of the most contemptible alchemical poetry, and the annotator of a work, the obvious production of a fool and a knave."

[8] *Catalogue of the Newton Papers sold by order of The Viscount Lymington to whom they have descended from Catherine Conduitt, Viscountess Lymington, Greatniece of Sir Isaac Newton* (London: Sotheby, 1936); the chemical/alchemical materials from the sale are also listed in Dobbs, *Foundations* [see note 5], pp. 235–48.

[9] Bodleian MS Don. b. 15, quotations by permission of the Bodleian Library, Oxford.

well as laboratory preparations, what the best ores are and how to refine them, the practical uses of various substances, and much more. Citations to Robert Boyle's *Origine of Formes and Qualities* suggest that Newton was working on the dictionary about 1666–8,[10] and it will be our primary point of reference for Newton's early chemical knowledge and understanding.

Chemical postulates about matter were in some ways sharply at odds with the assumptions about matter employed by the mechanical philosophers, of which Newton was one. The mechanical philosophers had come to think of matter in terms of minute *particles,* whereas the chemists thought of matter in terms of specific *substances* with distinct chemical properties. The two strands of thought were never adequately fused before the early nineteenth century, when John Dalton finally identified each variety of chemical substance with its own specific type of particle. What conceptual blockage prevented that fruitful identification of substance and particle in the seventeenth and eighteenth centuries? The puzzle is present in an especially acute form in the Newton papers. For although Newton had become a mechanical philosopher before the later 1660s, as his student notebook shows,[11] yet in his earliest chemical papers one finds hardly a hint of a particulate theory of matter.

Basic to this dichotomy of thought is the general problem of the appearance of "forms and qualities" in matter. According to the chemists, forms and qualities inhere in chemical substances, and in that sense the chemical thinking of the seventeenth century remained somewhat Aristotelian. However, the mechanical philosophers preferred to discuss matter as if odor, taste, color, crystalline form, and chemical reactivity did not inhere in the basic corpuscles. For most of the mechanical philosophers, the primitive particles were made of one stuff, "one catholic and universal

[10] Robert Boyle, *The Origine of Formes and Qualities, (According to the Corpuscular Philosophy,) Illustrated by Considerations and Experiments, (Written formerly by way of Notes upon an Essay about Nitre)* (Oxford: Printed by H. Hall Printer to the University, for Ric: Davis, 1666). Newton's references are to this first edition. A later version of the book may be found in Robert Boyle, *The Works of the Honourable Robert Boyle. To which is prefixed The Life of the Author,* 6 vols. (London: Printed for J. and F. Rivington, L. Davis, W. Johnston, S. Crowder, T. Payne, G. Kearsley, J. Robson, B. White, T. Becket and P. A. De Hondt, T. Davies, T. Cadell, Robinson and Roberts, Richardson and Richardson, J. Knox, W. Woodfall, J. Johnson, and T. Evans, 1772), *III,* 1–137.

[11] J. E. McGuire and Martin Tamny, *Certain Philosophical Questions: Newton's Trinity Notebook* (Cambridge: Cambridge University Press, 1983).

matter," as they so frequently argued, the corpuscles of which had only "primary" attributes such as extension, shape, impenetrability, motion, and perhaps weight. The philosophical problem of moving from the "primary" qualities of mechanical thought to the "secondary" qualities to which our senses respond and by which the chemist classifies his substances and distinguishes them from each other is a significant one, and one which Newton's contemporaries addressed at length.

Newton's later solution to the problem, as we know from the *Opticks*, was to postulate a hierarchical internal structure of parts and pores for chemical substances, the ultimate parts being the universal corpuscles of mechanical philosophy. In his solution, secondary qualities emerged from the internal structure and larger size of the complex hierarchies he envisioned, but not without the addition of certain "active principles," which to the orthodox mechanical philosopher were unacceptable. Even so, Newton's solution was not really adequate. It will eventually be instructive to examine his speculative structures anew in the context of the complex issues that engendered them, but that is beyond the scope of the present article, for we must first see just what those issues were.

NEWTON'S FIRST PHYSICALIST VIEWS

Newton's student notebook records his first encounters with the mechanical philosophy in sections entitled "Of the first matter," "Of atoms," "Of a vacuum and atoms," and "Of quantity."[12] The "Certain Philosophical Questions" he raised were centered in the seventeenth-century revival of atomism but were reflective of ancient controversies, and, although Newton examined his contemporaries' views critically, it is clear that he was engaged in these passages with the speculative and logical tradition going back to Leucippus and Democritus and not with natural manifestations of matter in the phenomenal world. The problems that concerned him were, for example, whether the first matter "be mathematical points, or mathematical points and parts, or a simple entity before division indistinct, or individuals, i.e., atoms." Concluding for

[12] Ibid., pp. 336–47.

atoms, he argued against the infinite divisibility of matter and shied away from the profound difficulties Aristotle had had with the idea of indivisible extension implied by atomism.[13]

Nowhere in his initial inquiries did Newton attempt to relate his indivisible particles to the sensory world, but we may safely assume that the distinction between primary and secondary qualities was already fixed in his mind. Walter Charleton's *Physiologia Epicuro-Gassendo-Charltoniana* restated the traditional Democritean/Epicurean doctrine, and Charleton was one of Newton's first sources. Atoms have *"Consimilarity of Substance,"* Charleton said; they also have magnitude or quantity, determinate figure, and gravity or weight. To those four properties, Epicurus had added resistance, but Charleton preferred to conflate resistance with gravity since both depended on the atom's solidity. These attributes, and only these, are primary and inseparable from the atoms; the qualities of compound bodies, i.e., secondary qualities, emerge only from the *"Concurse, Connexion, Position, Order, Number,* etc." of the atoms and are not essential characteristics of the atoms themselves.[14]

THE CHEMICAL CONCEPT OF MATTER

Contemporary chemists were not unaware of the revived corpuscular philosophy, but at least one of them had scant patience with it, dismissing the speculative tradition on epistemological grounds and opting for a radical empiricism that defined the parts of bodies by the direct "testimony of the senses." The chemical physician

[13] Aristotle, *Physica*, 231ᵃ21–231ᵇ18; cf. Lillian U. Pancheri, "Greek Atomism and the One and the Many," *Journal of the History of Philosophy, 13* (1975), 139–44; Friedrich Solmsen, *Aristotle's System of the Physical World. A Comparison with his Predecessors,* Cornell Studies in Classical Philology, ed. by Harry Caplan, James Hutton, G. M. Kirkwood, and Friedrich Solmsen, vol. *XXXIII* (Ithaca, New York: Cornell University Press, 1960), 199–204; McGuire and Tamny, "Commentary," in *Certain Philosophical Questions* [see note 11], pp. 49–60.

[14] Walter Charleton, *Physiologia Epicuro-Gassendo-Charltoniana: or a Fabrick of Science Natural, Upon the Hypothesis of Atoms, Founded by Epicurus, Repaired by Petrus Gassendus, Augmented by Walter Charleton,* with indexes and introduction by Robert Hugh Kargon (reprint of the London ed. of 1654; The Sources of Science, No. 31; New York: Johnson Reprint, 1966), pp. 111–12; Andrew G. Van Melsen, *From Atomos to Atom: The History of the Concept Atom* (reprint of the 1952 ed.; Harper Torchbooks/The Science Library; New York: Harper & Brothers, 1960); Robert Hugh Kargon, *Atomism in England from Hariot to Newton* (Oxford: Oxford University Press [Clarendon Press], 1966).

or "Naturalist," said Nicolas le Fèvre, will not rely "upon bare and naked contemplation" but will

> endeavour to bring his demonstrations under your sight, and satisfie also your other senses, by making you to touch, smell, and taste the very parts which enter'd in the composition of the body in question, knowing very well that what remains after the resolution of the mixt, according to the rules of Art, was that very substance that constituted it.[15]

The "resolution of the mixt" (a mixt being what we should call a chemical compound) was generally effected by some sort of fire analysis. Though fire analysis raised other problems, which we will consider below, one could hardly deny the efficacy of the procedure in producing substances that differed from the original mixt, and most of the chemists maintained the position that, since the new substances came "out of" the mixt, they must have been present in it before analysis and so must be the principles of which the body was composed. To le Fèvre, this chemical argument was vastly more meaningful than the speculative one, and he belabored some of the philosophical questions that had interested Newton at considerable length in order to make his point more explicit.

> But if you ask from the School Philosopher, What doth make the compound of a body? He will answer you, that it is not yet well determined in the Schools: That, to be a body, it ought to have quantity, and consequently to be divisible; that a body ought to be composed of things divisible and indivisible, that is to say, of points and parts: but it cannot be composed of points, for a point is indivisible, and without quantity, and consequently cannot communicate any quantity to the body, since it hath none in its self; so that the answer should have concluded the body to be composed of divisible parts. But against this also will be objected, If it be so, let us know, whether the minutest part of the body is divisible or no, if it be answered, Divisible, then it is instanced again, that it is not the minutest, since there is yet a place left for division: but if this minu-

[15] Nicolas le Fèvre, *A Compleat Body of Chymistry: Wherein is contained whatsoever is necessary for the attaining to the Curious Knowledge of this Art; Comprehending in General the whole Practice thereof: and Teaching the most exact Preparations of Animals, Vegetables and Minerals, so as to preserve their Essential Vertues. Laid open in two Books, and Dedicated to the Use of all Apothecaries, &c. By Nicasius le Febure, Royal Professor in Chymistry to his Majesty of England, and Apothecary in Ordinary to His Honourable Houshold. Fellow of the Royal Society. Rendred into English, by P. D. C. Esq; one of the Gentlemen of His Majesties Privy-Chamber. Part I. Corrected and amended; with the Additions of the late French copy* (London: Printed for O. *Pulleyn* Junior, and are to be sold by *John Wright* at the Sign of the *Globe* in *Little-Brittain*, 1670), p. 9.

test part be affirmed to be indivisible, then the answer falleth again into the former difficulty, since it returns to affirm it a point, and consequently without quantity; of which being deprived, it is impossible it should communicate the same to the body, since divisibility is an essential property to quantity.[16]

Le Fèvre was demonstrator in chemistry at the Jardin du Roi in Paris for a number of years in midcentury, then after 1660, chemist and apothecary to Charles II in London, becoming Fellow of the Royal Society in 1663. His chemical treatise was part of the French text tradition of the seventeenth century initiated by Beguin's *Tyrocinium chymicum* and culminating in Lémery's *Cours de chymie*. In its several editions, le Fèvre's treatise was perhaps one of the most significant chemical publications of the 1660s.[17] English editions of 1662 and 1664 appeared in time for Newton to have used them in compiling his dictionary of 1666–8, and in that case Newton would have been made vividly aware of le Fèvre's intensely chemical approach to matter theory, with its emphasis on the epistemological importance of the secondary qualities, for le Fèvre concluded his diatribe against the philosophers thus:

You see then, that Chymistry doth reject such airy and notional Arguments, to stick close to visible and palpable things, as it will appear by the practice of this Art: For if we affirm, that such a body is compounded of an acid spirit, a bitter or pontick salt, and a sweet earth; we can make manifest by the touch, smell, taste, those parts which we extract, with all those conditions we do attribute unto them.[18]

Based as it is on a naively realistic approach to matter, le Fèvre's position must have seemed reactionary to most mechanical philosophers, whose program emphasized the quantitative at the expense of the qualitative. Only the primary characteristics of matter were supposed to have objective existence; the subjective sensory qualities did not "really" exist in nature and were to be reduced to quantitative determinations of particulate magnitude, figure, configuration, and motion. The naive assumption that le Fèvre made – that color, taste, odor, etc., were the essential properties of sub-

16 Ibid., pp. 9–10.

17 Partington, *History of Chemistry* [see note 1], III, 1–48, esp. pp. 17–24; Hélène Metzger, *Les doctrines chimiques en France du début du XVII^e^ à la fin du XVIII^e^ siècle* (reprint of the 1923 ed.; Paris: Librairie scientifique et technique Albert Blanchard, 1969), esp. pp. 62–82.

18 le Fèvre, *Compleat Body of Chymistry* [see note 15], p. 10.

stances – could have seemed to seventeenth-century mechanists only as a throwback to a discredited Aristotelianism. But in fact, the seventeenth-century mechanical philosophers did not have so clear a vision of the future development of science as they thought, and on their limitations Paneth has made a number of relevant observations from the chemist's point of view.[19]

Chemistry was, and to a certain extent still is, a subject in which interest focuses on the secondary qualities of substances. Though the early mechanists expected to reduce chemistry to physics in short order, that proved not to be possible. Even yet, an emphasis upon the qualitative characteristics of matter in its many forms pervades the discipline of chemistry in spite of the fact that most of the so-called secondary qualities have in the twentieth century been given quantitative particulate explication. Using their naive-realistic approach, the chemists slowly unraveled complex manifestations of matter to isolate the simple substances of which they were composed. Procedures for finding the "principles of bodies," that is, the simple elementary substances comprising them, were refined of course, but later characterizations of substances did not differ in any important way from that of le Fèvre. When sodium was first isolated in the nineteenth century, it was classed as a metal precisely because it had the same secondary qualities that had defined the metals since antiquity. Sodium chloride continued to taste like salt and hydrogen sulfide continued to smell bad, even as new nomenclature was devised to reflect their composition more accurately. Even at the beginning of the twentieth century, chemistry itself could still be defined as "bangs and stinks," yet by then it had discovered and organized into families almost all of the naturally occurring chemical elements – work all done, as Paneth has observed, on the basis of that naive, primitive conception of substance that insists on the primacy of secondary qualities.[20]

Given chemistry's subsequent successes, one can now hardly agree with the seventeenth-century mechanists who devalued the chemist's approach to matter, and, as far as one can tell from his chemical dictionary, Newton may at first have accepted the chemical concept at face value, without bringing the mechanists' cri-

[19] F. A. Paneth, "The Epistemological Status of the Chemical Concept of Element (I)," *The British Journal for the Philosophy of Science, 13* (1962), 1–14, and "The Epistemological Status of the Chemical Concept of Element (II)," ibid., 144–60.

[20] Paneth, "Chemical Concept of Element (I)," [see note 19], esp. pp. 1–9.

tique to bear upon it, for in his discussion of the fire analysis of several materials, he simply gives the substances into which each is resolved – substances defined by their secondary qualities.

Harts horne in sand yeilds Urinous spirit, volatile salt stinking oyle & flegme. Woods in a retort in naked fire yeild an acid spirit & fixt salt, & most of them an oyle espetially the heavy ones as box &c: Tartar yeilds a very little spirit more flegme, a great quantity of foetid oyle & a fixed Salt. Wood-soot yeilds an urinous spirit, a yellow oyle, & a white & very volatile salt.[21]

PARTICLES AND SUBSTANCES

Another objection to the position of the mechanical philosophers turns on the distinction they wished to make between primary and secondary qualities, for their arguments masked an arbitrary stopping point. As was realized in the eighteenth century, if the secondary qualities were not present in nature, then neither were the primary ones the seventeenth century had defined.[22] That never became an issue for the early mechanists, however, to whom the primitive particles with their primary qualities seemed surely to have objective existence. Their problem was to relate their postulated particles to sensory phenomena.

Since the particles were supposed to be devoid of secondary qualities and also too small to be perceived by the human sensory apparatus, the problem became one of transdiction – or transduction, as it is sometimes called: relating the perceived qualities of the sensory world to the qualities of the corpuscles that were, in principle, imperceptible. It was the problem first adequately solved by Dalton when he demonstrated that the relative weights of substances measured in the macrorealm could be ascribed to the microrealm as the relative weights of the individual particles of the substances.[23] But in the seventeenth century, two fundamentally

[21] Bodleian MS Don. b. 15, fol. 6^{v}.

[22] Paneth, "Chemical Concept of Element (I)" [see note 19]; *The Concept of Matter in Modern Philosophy*, ed. Ernan McMullin (revised ed.; Notre Dame, Ind.: University of Notre Dame Press, 1978).

[23] Henry Guerlac, "The Background to Dalton's Atomic Theory," in *John Dalton & the progress of science. Papers presented to a conference of historians of science held in Manchester September 19–24 1966 to mark the bicentenary of Dalton's birth*, ed. D. S. L. Cardwell (Manchester: Manchester University Press; New York: Barnes & Noble, 1968), pp. 57–91.

different approaches were put forward, and neither was capable of solving the problem.

The *matter* comprising all the particles was assumed to be the same, but traditionally the corpuscular systems allowed variety in size and shape. Especially in those systems with infinitely divisible particles, such as that of Descartes, it was inevitably a temptation for the mechanists to ascribe to the particles speculative shapes and sizes that would translate directly into the perceived qualities of bodies in the macrorealm. Good examples of this tendency may be found in Descartes's *Meteora,* where water has long, flexible particles and hot spirits have small, spherical or oval ones.[24] Descartes's matter was all the same in the beginning, but motion had reduced it to three varieties. It was to particles of the third of these – terrestrial matter – that Descartes assigned his ad hoc shapes and sizes.

Newton encountered Descartes's mode of explaining macroproperties by the sizes and shapes of the particles in his early explorations of mechanical thought and was skeptical from the first of some of Descartes's specific attributions. Raising the question "Whether fresh water consists of long bending parts and salt [water] of stiff and long ones," as Descartes had said in *Meteora,* Newton found six reasons for the falsity of the first suggestion and did not even bother to consider the second. But certain "branchy" types of particles seemed acceptable, as did the notion that "burning waters" must have "many such globuli as fire is made of . . . because they are most easily agitated and so heat and enliven men. . . ."[25]

Nor were other mechanical philosophers immune to that sort of thinking when the correlation between macro- and microspheres seemed "obvious" to them, the most notorious case being the attribution of the sharp taste and corrosive chemical action of acids to knifelike or needlelike particles. Even Boyle fell into the trap with acids, though he usually made the generalized "texture" of groups of corpuscles responsible for secondary qualities and did not specify the exact shape of individual particles. But in speaking of the change of sweet grape juice into vinegar he had this to say:

[24] René Descartes, *Oeuvres de Descartes publiées par Charles Adam & Paul Tannery,* 11 vols. (Paris: Librairie Philosophique J. Vrin, 1964–74), *VI,* 651–720; J. F. Scott, *The Scientific Work of René Descartes (1596–1650),* with foreword by H. W. Turnbull (reprint of the 1952 ed.; London: Taylor & Francis, 1976), pp. 65–9.

[25] McGuire and Tamny, *Certain Philosophical Questions* [see note 11], pp. 372–5.