Lucretius and the History of Science

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The central aim of DRN was to demolish religious belief and banish superstitious fear. To that end, Lucretius, following Epicurus' lost On Nature, referred the production of all effects to the motion and interaction of atoms and denied all providential regulation of the universe: "Nature is her own mistress and is exempt from the oppression of arrogant despots, accomplishing everything by herself spontaneously and independently and free from the jurisdiction of the gods."[1] By way of accomplishing its aim, the poem addressed a range of scientific subjects, from nutrition, perception, and mental illness, to cosmology, the seasons and eclipses, thunder, clouds, and the magnet, the emergence and evolution of animal and vegetable life, and contagion, poisoning, and plague.

Re-introduced into a Christian culture in which metaphysics and natural philosophy were dominated by a theory of providence and bolstered by a raft of Platonic-Aristotelian arguments against materialism, Lucretius' poem produced both fascination and alarm. The theses that reality consists exclusively of atoms and void, that atomic interactions are purposeless and reflect no plan, that there are no immaterial spirits, and that the gods do not care about humanity and produce no effects in the visible world, were purged of some features, and variously absorbed and reworked into the so-called "new philosophy" of the

[1] DRN ii.1090.

17th century. Thanks in large measure to its compelling presentation in Lucretius' poem, Epicureanism effectively replaced the scholastic-Aristotelian theory of nature formerly dominant in the Universities. In place of continuous matter imbued with forms, qualities, and active powers, immutable species differentiated by their unique, individual essences, and a single cosmos, in which order descended from higher entities to lower ones, the moderns came to acknowledge a phenomenal world of largely fleeting appearances and transitory entities, behind which there existed only tiny particles, deprived of all characteristics and powers except shape, size, and movement, in constantly changing configurations and combinations. Both the atomic reality alleged to underlie the appearances and the self-sufficiency of nature forcefully asserted by Lucretius exercised a powerful influence on modern science and his name was still invoked from time to time as late as the nineteenth century, with his influence formally acknowledged well into the twentieth.

Some knowledge of Epicurus and Lucretius and the existence of a pagan philosophy that held that all things, including fire and water (i.e., the elements), as well as plants and animals, originate from atoms persisted in the medieval era.[2] There is direct notice of Lucretius in a work of William of Conches (c. 1090-c. 1154). [3] Though William did not have access to DRN, he mentions Lucretius, and he drew on Cicero, Virgil, Priscian, Isidore of Seville, and possibly Seneca for his knowledge of his doctrines. In his Dialogue on Philosophy, the interrogator says, "It seems to me, you are secretly falling back on the opinion of the Epicureans, who said that the world consists of atoms." To which, William's philosopher replies:

[2] Jones 1992: 136ff. Cross-ref to Reeve.

[3] William refers to Lucretius and iterates DRN 2.888 at I.6.10.

> No philosophical doctrine is so false that it does not have some truth mixed with it, though obscured by the addition of some falsehood. When the Epicureans said that the earth consists of atoms, they were correct. But it must be regarded as a fable when they said that those atoms were without beginning and “flew to and fro separately through the great void”, then massed themselves into four great bodies. For nothing can be without beginning and place except God.[4]

Among the first of the scientists in the modern era to use Lucretius’ text was the humanistic physician Girolamo Fracastoro (1478-1553). In On the Sympathy and Antipathy of Things (1545) he developed a theory of contagious disease, proposing that some sicknesses are the product of exhalations of seeds or tiny living bodies. Although for Lucretius these contagious seeds are lifeless, the idea is Lucretian enough that words encapsulating Fracastoro’s idea were fabricated and insinuated into subsequent editions of Lucretius. These in turn were quoted in later medical texts on disease and histories of bacteria until the late nineteenth century.[5]

Eventually other occult properties involving action-at-a distance or mysterious communication or transmission were explained by natural philosophers in terms of minute bodies (“corpuscles”). Effluvia such as smokes, steams, fumes, vapours, scents were represented by Lucretius as types of particles, with specific effects.[6] The German physician Daniel Sennert (1572-1637) regarded fascination, plague, and poisoning as proceeding from corpuscular effluvia or corpuscles. Walter Charleton (1619-1707) explained sympathies and

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[4] William of Conches I.6.8-9.

[5] “Obnoxia cuncta putrori / Corpora, putrores insecta animata sequuntur.” See Andrade 1928: 2:xixn2.

[6] DRN vi.780f.

antipathies in terms of a flow of atoms between the impassioned parties. "Corpuscularians"—the term reflected agnosticism about the potential divisibility of matter and the existence of the void, and implied dissociation on the part of its adherents from atheism and hedonism—were not applying a modern scheme to old phenomena. Rather, they followed Lucretius, who had explained dreams, ghosts, plagues, and poisoning by the action of atomic corporeal effluvia.

Giordano Bruno (1548-1600) was first in the modern period to revive the cosmological ideas of atomism. Lucretius appears often in his writing, although he was by no means an orthodox Epicurean. In On the Infinite Universe and Worlds (1584), the picture of an infinite plenum contained in an infinite void is attributed to Democritus and Epicurus. In a trilogy of Latin poems, a kind of vitalistic atomism is elaborated as the explicit foundation of the infinite cosmology. In On the Threefold Minimal and Measure (1591), the atom is regarded as a physical minimum corresponding to the geometrical minimum of the point, and the ontological minimum of the unit or monad. But Bruno rejected the void in favour of a vital ethereal medium responsible for the motion and arrangement of the atoms, holding that the atoms have no gravity and hence cannot spontaneously move. A similar problem dogged atomists throughout the seventeenth century, and encouraged Leibniz to invent another form of vitalistic atomism in his Monadology (1714).

Throughout the sixteenth century, natural philosophers worked on the problem of chemical mixture, initially in response to the ancient controversy about whether in a mixture what is mixed retains its identity in the new substance, or instead takes on a completely new form. J. C. Scaliger (1484-1558) argued on the side of Aristotle that the mixed substance takes on a new form, and in this was later opposed by Sebastian Basso (1550-1600). Basso directly discussed some ideas found in Lucretius in his Natural Philosophy against Aristotle (published 1621).[7]

Bernardino Telesio (1509-1588) meanwhile advanced a radically empiricist, anti-Aristotelian natural philosophy in On the Nature of Things According to Proper Principles (1563). Telesio's views were influential, having been adopted at the academy of Cosenza; Francis Bacon (1561-1626) referred to Telesio as "the first of the moderns." Bacon took aim at him, however, in a late essay, On Principles and Origins According to the Fables of Cupid and Coelum (c. 1612), rejecting Telesio's system in favour of the atomistic philosophy of Democritus, citing many passages from Lucretius, but referring to them as the words of Democritus. Bacon there plainly says: "to me the philosophy of Democritus seems worthy to be rescued from neglect,"[8] echoing his earlier remark: "The Democritean doctrine of atoms is either true, or useful for demonstration" (Meditations on the Nature of Things, 1604). In the New Organon (1620), Bacon frequently recommends Democritus' method of "dissecting nature" as over against the Aristotelian method of "abstraction,"[9] and he appeals to the atomic doctrine in the later essay History of the Dense and Rare (1623), a subject well suited to atomistic treatment.

Bacon's enthusiasm for ancient atomism was nevertheless tempered and its expression highly ambiguous. Bacon rejected key tenets of Lucretian atomism, such as the

[7] But Lucretius was only one stream of influence on the development of corpuscular theories of matter in the renaissance and early modern periods. Other influences included the works of Aristotle (who directly opposed the atomism of Democritus), alchemical literature and the medical alchemical literature of Peracelsianism, the medical and metallurgical arts, and other ancient works, especially Hero's Pneumatica.

[8] In Ellis and Spedding: 650.

[9] I.LI.

void and the swerve, the latter because he was committed to the view that matter is ordered by divine providence. Although he used the myth of Cupid to tell a story about the formation of the cosmos in atoms out of chaos, Bacon rejected infinite cosmology and Copernicanism. And his view of matter in the New Organon makes as little use of the atomic conception of matter as what he calls the “abstract” Aristotelian one: “Men do not cease to abstract nature until they reach potential and unformed matter, nor again do they cease to dissect nature until they come to the atom. Even if these things were true, they can do little to improve men’s fortunes”.[10] Bacon denied that rigid atoms in a vacuum were the “true particles”, which he thought composed “schematisms” resulting from the “texture” of pneumatic matter. At the same time, the concept and even terminology of the textura owe much to ancient atomism in general and Lucretius in particular.[11] The concept of material texture would later influence the first modern chemist, Robert Boyle.[12]

Daniel Sennert noted in the first quarter of the 17th century that: “everywhere amongst Philosophers and Physicians both Ancient and Modern mention is made of these little Bodies or Atomes, that I wonder the Doctrine of Atomes should be traduced as Novelty . . . All the Learnedest Philosophers . . . have acknowledged that there are such Atomes, not to speak of Empedocles, Democritus, Epicurus, whose Doctrine is suspected, perhaps because it is not understood.”[13] Atomistic ideas were indeed steadily gaining acceptance throughout the century, in no small part due to Sennert’s own defence of atomism in his Thirteen Books of Natural Philosophy (1618). In On the Agreement and Disagreement of the Chemists with

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[10] I.LXVI.

[11] Gemilli 1996:196-7.

[12] Clericuzio 1984.

[13] Sennert 1659:446.

Aristotelians and Galenists (1619) and Physical Remarks (1636) he provided the first real experimental evidence for atoms, showing that silver atoms retain their individuality, even after being combined with gold, reduced to invisibility with acid, and passed through a paper filter.[14] This argument would in turn be widely cited by other proponents of atomism, such as J.C. Magnenus in his Democritus Revived, or, On Atoms (1648). The Dutch physicist Isaac Beeckman (1588-1637) was another working chemist who inclined towards atomism.

René Descartes (1596-1650), who benefited from his association with Beeckman, formed the ambition to displace the natural philosophy textbooks of the Aristotelians with his own system of the world. He drew not only upon Galileo's analysis of sensory qualities, rejecting the Aristotelian conception of matter as imbued with active "forms," qualities, and teleological principles, but directly on Lucretian cosmology. He elaborated a theory of the purely material animal and the self-forming cosmos in his suppressed treatise The World (written towards the end of the 1620s) and recapitulated his theories in his Principles of Philosophy (1644). In the Principles, the original object of creation is "extended substance"—matter that has no qualities apart from being measurable and extended. Corporeal substance, like Lucretian matter, is silent, uncoloured, and unscented, but its parts can be moved around relative to one another. And what seems to begin as an undifferentiated block of matter divides into a collection of an indefinite number of particles "although it is beyond our power to grasp them all" or even "exactly how it occurs." Descartes denies however that there are atoms—least particles—on the grounds that they conflict with God's power to do anything that we can imagine.[15] While mechanical statues were interesting to

[14] Michael 2001.

[15] II.20.

Descartes and his contemporaries, and while machine-animal analogies are not uncommon in baroque literature, Descartes' references to the "machines of nature," which can grow, react, reproduce, and generally display all the manifestations of life, and their operation, point to a specifically materialistic conception of life. The corporeal machine can, like the Lucretian account of Book IV, account for some forms of sensation, dreaming, and memory in animals. This bold hypothesis is famously softened by Descartes' superaddition of an incorporeal soul (in humans alone), and by the claim that God is the only source of power, force, or motion in the universe, being possessed of unlimited will and power by which he sustains the universe from moment to moment. Nevertheless, Descartes retains the Lucretian notion that from a chaotic state of distributed matter, planetary systems or "vortices" form spontaneously and that their numerous earths bring forth plants, animals, and even men.

Famous now chiefly for his criticisms of Descartes, Pierre Gassendi (1592-1655) was the most important reviver of ancient atomism in the early modern period. He undertook an ambitious project of editing, translating, and interpreting an important Greek source for Epicureanism in Investigations into the Tenth Book of Diogenes Laertius (1649), to which was appended the Treatise on Epicurean Philosophy, a concise encapsulation. Although Gassendi's views were well known to his contemporaries through his extensive correspondence, the final version of his philosophy was not published until after his death, in the Syntagma Philosophicum (1658). This work frequently quotes Lucretius at length, and includes a complete philosophy according to the traditional Epicurean division of Canonic (i.e. logic), Physics, and Ethics. Its mechanical accounts of natural phenomena are, like those of his rival Descartes, Lucretian in tenor.

Gassendi was not just a philologist seeking to explicate an ancient philosophy. He intended also to revive atomism as a physical theory and this required him to redeem atomism from the accusations of impiety and gross hedonism that had dogged it since late antiquity, through the influence of Cicero and the Fathers of the Early Church, especially Lactantius. Gassendi, unlike Descartes, admitted least particles. He denied however that they were eternal and uncreated.

> To present at last our conclusion that apparently the opinion of those who maintain that atoms are the primary and universal material of all things may be recommended above all others, I take pleasure in beginning with the words of Aneponymus. After his opening remark that 'There is no opinion so false that it does not have some truth mixed in with it, but still the truth is obscured by being mixed with the false', he then continues, 'For in their assertion that the world is made up of atoms the Epicureans spoke the truth, but in their assertion that these atoms had no beginning and they flew about separately in a great void, and then coalesced into four great bodies they were telling fairy tales'. I say I take pleasure from these words for one can draw the inference that there is nothing to prevent us from defending the opinion which decides that the matter of the world and all the things in it is made up of atoms, provided that we repudiate whatever falsehood is mixed in with it.[16]

The words approved by Gassendi and here attributed to Aneponymus are those of William of Conches, the medieval philosopher quoted above. The viewpoint being adopted is recognizable to the reader of Plato's Timaeus, in which the philosopher presents his own version of atomism in the context of a creationist account of the formation of the world, and

[16] Opera 1:279b-80a; trans. Brush 1972:398.

its elements, plants, and animals. This model for the reconciliation of theology with matter theory and this combination—both awkward and compelling—would become the dominant scientific worldview, developed by Gassendi, then Robert Boyle, and Isaac Newton, amongst others. Gassendi's system preserved the notion that the entanglement, motion, and interaction of invisible corpuscles is the basis of all phenomena, even if it rejected the classical atomists' denial of divine providence. The atoms cannot move by themselves, but they have "the power of moving and acting which God instilled in them at their very creation."[17] A virtue of atomistic explanations was thus that they worked well with voluntarist theology, unlike Aristotelianism, since atomism requires neither eternal nor necessary essences. Against Lucretius and Descartes, Gassendi accepted the appeal to final causes in explaining the parts and functions of plants and animals. He also rejected the doctrine of the thoroughgoing corporeality and mortality of the soul, responding to no less than twenty-seven arguments against immortality drawn from Lucretius,[18] though his objections to Descartes' Meditations might well lead the reader to wonder how much importance he attached to the incorporeal parts of the human soul, by contrast with the corporeal souls he thought men shared with animals and whose powers included cognition, language, and experience.

In the early years of the 17th century, Henry Percy the "wizard Earl" patronized an informal group of English Copernicans and atomists, including Thomas Hariot, whose scientific manuscripts were later studied by the mathematician Charles Cavendish. Charles, with his brother William Cavendish and his sister-in-law Margaret Cavendish, were the

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[17] Osler 2003.

[18] Johnson 2003.

centre of an important intellectual circle in Paris in the 1640s.[19] Thomas Hobbes's stay in Paris for three years beginning in 1634 introduced him to the thought of Gassendi, Galileo, and Descartes. Hobbes went on to present his system in terms of human ideation, not fundamental ontology, even in his On Body (1655), as Locke later would as well. But Hobbes nevertheless maintained that all was body, including God. Margaret Cavendish, an acquaintance of the early translator of DNR, Lucy Hutchinson, alluded to the atomic construction of worlds in her own cosmological poetry,[20] and she made little effort to award God a role in the management of the atoms. A more conciliatory figure was her supporter, Walter Charleton, who referred to the "pure and rich Metall" hidden amongst detestable doctrines in his Darkness of Atheism (1652). Charleton went on to expound and develop long sections of Gassendi in his Physiologia Epicuro-Gassendi-Charletoniana (1654). Other English philosophers influenced by Cartesian and Gassendist corpuscularianism included Kenelm Digby in Two Treatises (on the nature of bodies and on the nature of the mind, 1644) and John Locke in his influential Essay Concerning Human Understanding (1690).

Hobbes's enthusiasm for materialism did not help the image of Lucretius, and he was still regarded as the proponent of dangerous and mostly unacceptable philosophy even in England. This is indicated by the attitude of Robert Boyle (1627-1691), who, in his Requisite Digression concerning Those that Would Exclude the Diety from Intermeddling with Matter (1663) repeats the old story that Lucretius' poem was written "in one of the fits of frenzy, which some even of his admirers suppose him to have been put into by a philtre given him by

[19] Kargon 1966: 40ff.

[20] Poems and Fancies and Philosophical Fancies (1653).

either wife or mistress Lucilia".[21] Under the title of an unpublished essay "Of the Atomicall Philosophy" Boyle had written, "These papers are without fayle to be burn't". But in it he argued that:

> The atomical philosophy invented or brought into request by Democritus, Leucippus, Epicurus, & their contemporaries, tho since the inundation of Barbarians and Barbarisme expelled out of the Roman world all but the casually escaping Peripatetic philosophy… is so luckily revived & so skillfully celebrated in diverse parts of Europe by the learned pens of Gassendus, Magnenus, Descartes, & his disciples our deservedly famous countryman Sir Kenelme Digby & many other writers especially those that handle magnetical and electrical operations that it is now grown too considerable to be any longer laughed at, & considerable enough to deserve a serious inquiry."[22]

Boyle expounded atomism in his <u>Origin of Forms and Qualities according to the Corpuscular Philosophy</u> (1666) and in numerous works, including the <u>About the Excellency and Grounds of the Mechanical Hypothesis</u> (1674) and the <u>Inquiry into the Vulgarly Received Notion of Nature</u> (1678), in which he described nature as "the system of the corporeal works of God," consisting only of corpuscles moved according to laws imposed by the creator. If an angel were to work any change in the world, Boyle said, it would have to do so by setting matter in motion.[23]

Why was the theory of nature Lucretius presented so appealing? Boyle suggested both that his experiments with the transformation and reintegration of chemical substances

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[21] <u>Works</u>: ?:??

[22] <u>Works</u> 13: 227-235.

[23] <u>Works</u>: 8:104.

and the simplicity of the corpuscularian hypothesis recommended it. The doctrine of emergent qualities that atomism entailed perhaps appeared newly credible as a result of expanded experience with chemical transformations and with optical instruments. Yet, methodologically Boyle seems to have interpreted his results—including his experiments with the air pump—in corpuscularian terms rather than effectively deriving the theory on any experimental basis. One cannot say that physical or chemical phenomena really rendered their existence more likely. Rather the situation was reversed: the experimental philosophers sought specifically an ancient metaphysics upon which to declare their practices grounded in order to convey on them the dignity of philosophy, elevating chemistry from a merely mechanical practice. Meinel has argued that by the standards of any era 17th century arguments for and observations cited in favour of corpuscularianism were inconclusive, and that its re-appearance and persistence in early modern science had as much to do with the charm of Lucretius' presentation, and its appeal to the senses and imagination, as it did with arguments, observation, and evidence.[24]

Boyle furthered Gassendi's project of detaching the science of atomism from its atheistic and hedonistic associations through his promotion of "natural theology". He insisted repeatedly that atomistic mechanism implied the existence and activity of a "Machine so Immense, so Beautiful, so well-contrived, and, in a word, so Admirable as the World cannot have been the effect of mere Chance, or Tumultuous Justlings and Fortuitous Concourse of Atoms, but must have been produced by a Cause exceedingly Powerful, Wise, and Beneficent." [25] He named his version of the mechanical philosophy "Anaxagorean," in

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[24] Meinel 1988:193.

[25] Works 11: 299-300.

order to distinguish it from classical atomism, and also from the Cartesian version which, though it introduced God as the cause and maintainer of corpuscular motions, nevertheless held that the cosmos, and plant and animal life, had emerged spontaneously.[26] According to Boyle's doctrine of Anaxagorean mechanism, the frame of the world and its original plants and animals, or at least their "seeds or seminal principles", had been intelligently and beneficently designed and created, though thereafter, the laws of motion, the structure of objects, and the dispositions of seeds sufficed for the production of all, or almost all effects.[27]

This Anaxagorean system, one might think, reconciled religion and natural philosophy easily, provided one accepted the notion that the laws of nature could in some sense be prescribed to and obeyed by inanimate particles, and provided one was not troubled by the paradoxes of division and composition which militated against atoms. Yet Boyle was often troubled by his adoption of large parts of a pagan and arguably anti-theistic system. He believed himself to be living in an exceptionally dissolute age, and he considered the threat to religion and morals to be more serious and less easily defended against than other atheist and mortalist versions of Aristotelianism and pagan naturalism, such as those represented by Pomponazzi and Vanini. "Libertines," he says, "own themselves to be so upon the account of the Epicurean or other Mechanical Principles of Philosophy"[28] and they fail to pay due regard to Aristotle, Scotus, Aquinas and Augustine. He complained of being taken for an Epicurean himself.[29] Yet one cannot say that Boyle showed much deference to Aristotle or to

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[26] The term "Anaxagorean" appears in the suppressed sections of the Inquiry into the Vulgarly Received Notion of Nature.

[27] Anstey 2002:597-630.

[28] Works 8: 237.

[29] Works 2:354.

his scholastic followers. By contrast, there are hundreds of references to Epicurus and Lucretius in his writings. If Boyle was sincere in maintaining that he had read little of Lucretius and lacked conversancy with Epicureanism in 1663,[30] he made up for his neglect later.

Isaac Newton was interested in atomism from his student days, attempting proof "of a vacuum and atoms" in his Trinity notebook.[31] He was influenced by both Gassendi and Boyle, but he also read Lucretius directly, even inserting his own line numbers into Fabri's 1686 edition.[32] Recent research on Newton's alchemical researches has revealed that, far from being an embarrassing pseudo-scientific preoccupation, Newton was actually developing an atomistic chemical theory of matter.[33] His physics is also recognizably atomistic. In his unpublished scientific papers is a "fragment on the law of inertia" in which he attributes the first law of motion to the ancients, referencing Lucretius twice.[34] The notes of his disciple Gregory record him saying that "the philosophy of Epicurus and Lucretius is true and old, but was wrongly interpreted by the ancients as atheism."[35] In a draft version of the Mathematical Principles of Natural Philosophy (1687) in which he set out to deal with the mechanical cause of gravity, Newton introduced the subject through an elaboration of

[30] Works 2:354.

[31] Transcribed in McGuire and Tamny 1983.

[32] See Harrison 1978 at H990.

[33] Figala 1992.

[34] See Hall and Hall 1962:309-311; cf. Cohen 1964.

[35] Correspondence 3:335/338 in Turnbull 1959-77.

Lucretius' discussion of the motion of atoms in the void.[36] In the last query of the Optics (1704) Newton published his belief that all things are composed of atoms.

> It seems probable to me, that God in the beginning formed Matter in solid, massy, hard, impenetrable, moveable particles, of such sizes and figures, and with such other properties, and in such proportion to space, as most conduced to the end for which he formed them; and that these primitive particles, being solids, are incomparably harder than any porous bodies compounded of them; even so very hard, as never to wear or break in pieces; no ordinary power being able to divide what God himself made one in the first creation. While the particles continue entire, they may compose bodies of one and the same nature and texture in all ages: But should they wear away, or break in pieces, the nature of things depending on them would be changed. (Query 31, emphasis added)

This is one of the most influential pieces of writing in the history of science. And it is occurs amidst what is essentially a paraphrase of certain arguments in De Rerum Natura Book I,[37] except that that Lucretius has now been completely fused with creationism and voluntarist theology. One also sees here an extension of the line of thought articulated by William of Conches and later developed and propagated by Gassendi.

Magnenus, Charleton, Gassendi, Boyle, and Newton all attempted to estimate the size of the smallest units of given materials, having conducted experiments on various substances such as smoke, incense, dust, and flame. These represent the first genuine attempts to quantify atomic phenomena. The mathematicization of the atomic theory is notable in some

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[36] Hall and Hall 1962: 312f.; cf. McGuire and Rattansi 1966.

[37] i.e., DRN i.547f. and 603f.

sections of Newton's optical and chemical writings and in his Mathematical Principles of Natural Philosophy, which contain, among other things, a mathematical derivation of Boyle's gas law: Newton assumed the existence of particles in his derivation of the law, but refrained from mentioning the atomic hypotheses in this essentially mathematical work. Newton's derivation in turn had a major influence on Dalton and contributed to the eventual success of a mathematical atomistic chemistry.

The threat posed by the revival of Epicureanism even in an officially Christian framework seemed to some metaphysicians to demand a more radical attack on the notion of matter itself. Leibniz and Berkeley were not content with attacking the logical coherence of the notion a least particle, but denied that there could be any purely material particle. The young Leibniz had been excited by material atomism, which he had encountered in Hobbes and Gassendi, but then turned away from it in favour of what he considered to be an improved version of the theory of substantial forms. He was much engaged (in unpublished writings), however, with the Lucretian notion of creation by combination and was evidently taken with the notion of a plurality of worlds.[38] Leibniz accepted the Lucretian arguments that only the indivisible atom is indestructible and immortal, but he insisted in Platonic fashion that anything material is susceptible of division and destruction and that only soul-like entities with experiences and appetitions can function in the role of eternal substances. Where the classical arguments are intended to show that, in order to be the elements of things, the atoms must be relatively qualityless, Leibniz drew the remarkable inference that the elements of things must be infinitely complex.[39]

[38] Wilson 2003:104f.

[39] Wilson 1982.

Immanual Kant (1724-1804) was heavily influenced by Newton and Leibniz, and openly acknowledged his debt to Lucretius in offering the nebular hypothesis of the formation of the planets and solar system: “I will not deny,” he admits, “that the theory of Lucretius, or his predecessors, Epicurus, Leucippus, and Democritus has much resemblance with mine. I assume, like these philosophers, that the first state of nature consisted in a universal diffusion of the primitive matter of all the bodies in space, or of the atoms of matter, as these philosophers have called them. Epicurus asserted a gravity or weight which forced these elementary particles to sink or fall; and this does not seem to differ much from Newton’s attraction, which I accept” (*Universal Natural History and Theory of the Heavens*, 1755).[40] But despite this cosmological compatibility, Kant rejected “the mechanical mode of explanation” which he said, “has, under the name atomism or the corpuscular philosophy, always retained its authority and influence on the principles of natural science, with few changes from Democritus” (*Metaphysical Foundations of Natural Science*, 1786).

Even while Kant was misdoubting them, atomistic ideas attracted a favourable reading in the life sciences. David Hume’s *Dialogues concerning Natural Religion* (1779) contain a paraphrase of Lucretius’s selection principle,[41] arguing that the currently existing species of animals are those who, unlike their counterparts, had apt combinations of organs and were thus able to survive and reproduce, and this notion was common amongst the *philosophes*. Charles Darwin’s grandfather, Erasmus Darwin, wrote a Lucretian long didactic poem, *The Temple of Nature* (1802), and his earlier *Zoonomia* (1794-6) explicitly endorsed the theo-mechanical version of atomism. Lucretius does not technically elaborate a theory of

[40] Trans. Hastie 1900:24.

[41] Compare *Dialogues* part viii with DRN 4.823-57, 5.772-877.

evolution, since he holds plant and animal species to be fixed.[42] But he did develop the older atomistic idea that extinctions play a key role in determining what life is now present on earth, a view developed by Darwin, who became embroiled in theological controversies reminiscent of those of the seventeenth century.

Historians have described a general "victory of discreteness" in the nineteenth century, with reference to the discovery of cells and genes, discreet entities that, along with Darwinian evolution, are the bases of the modern life sciences. Lucretius represents the idea of material units of heredity in a way that arguably anticipates later accounts. Of course, the biggest victory for discreetness in the nineteenth century was the presentation of the first convincing experimental evidence for atoms themselves. In 1808, John Dalton asserted that "Observations have tacitly lead to the conclusion which seems universally adopted, that all bodies of sensible magnitude, whether liquid or solid, are constituted of a vast number of extremely small particles, or atoms of matter bound together by a force of attraction, which is more or less powerful according to circumstances" (A new system of chemical philosophy).[43] The origin of Dalton's theory of the chemical atom is a highly contested episode in the history of science. Whether or not Dalton was directly influenced by Lucretius, there are several clear indirect lines of influence. For example, he repeatedly copied Newton's derivation of Boyle's law into his notebook, and he wrote out Newton's Lucretian Query 31 from the Optics.[44] Dalton's mechanical atomism was perceived as successful in explaining the behaviour of heat and gas. He realized that gases combine to form compounds in definite ratios, and he inferred from this that they must consist of discrete particles,

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[42] Campbell 2003.

[43] Dalton 1808:141.

[44] The relevant parts of the notebook can be seen in Roscoe and Harden 1896:124.

combining in a robust way speculative atomism with a quantitative and empirical methodology. The case for chemical and physical atomism was further strengthened by the successes of James Clerk Maxwell, who continued to evoke the spirit and letter of ancient philosophy, referring as late as 1873 to "the atomic doctrine of Democritus, Epicurus, and Lucretius, and, I may add, of your lecturer".[45]

Despite the affirmation of Maxwell, and despite Dalton's earlier claim that atomism was a universally accepted chemical fact, many dogmatic empiricists rejected atomism, and it was still doubted in the early twentieth century. Ernst Mach in the nineteenth century expanded this viewpoint into a positivism according to which only things directly perceived are real, everything else being a convenient heuristic for scientific thought, or else an outright figment of the mind. Mach had many important disciples; they constitute the last holdout against atomism. As late as 1913 Pierre Duhem, announced that the atomic theory was "without a future". "Modern chemistry," he insisted, "does not plead in favour of the Epicurean doctrines." [46]

As the Nobel Laureate Steven Weinberg commented, it is somewhat odd that the atomic theory of matter did not win universal acceptance until the discovery of the constituents of the atom.[47] That is ironic because the discovery of subatomic particles seems to explode the idea of the indivisible atom. The artist Wassily Kandinsky captured how startling was this new conception of nature in describing how it helped him overcome writer's block:

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[45] Maxwell 1873:437.

[46] Duhem 1913:93-4.

[47] Weinberg 1983:3.

> A scientific event removed the most important obstacle: the further division of the atom. The collapse of the atom model was equivalent, in my soul, to the collapse of the whole world. Suddenly the thickest walls fell. I would not have been amazed if a stone appeared before my eye in the air, melted, and became invisible. Science seemed to me destroyed.[48]

Kandinsky's language here suggests Lucretius' mention of "the walls of the world fleeing at the destruction of the world" and "the walls of the world part".[49] Kandinsky, like Lucretius, and Newton later, decided that the division of the "atom" implied that there were no atoms and that anything could be destroyed or transformed into any other thing. Of course, Kandinsky need not have worried or rejoiced that science was destroyed. Scientists have developed far greater knowledge of various "elementary" particles with the help of electrolysis, accelerators, cathode ray tubes and other procedures and devices. There are now numerous physical methods of detecting "atoms": scintillation screens, Geiger counters, cloud chambers, photographic emulsions, and scanning-tunnelling microscopes. As Erwin Schrödinger has pointed out, "The great atomists from Democritus down to Dalton, Maxwell, and Bolzmann would have gone into raptures at these palpable proofs of their belief."[50] Atomism—understood as the theory of astonishingly small, active, and normally indivisible particles that underlie all appearances and change in the natural world—has moved from an hypothesis to a fact, as Niels Bohr, pointed out: "every doubt regarding the reality of atoms has been removed".[51]

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[48] Kandinsky 1955:16; cf. Holton 1993:105n19.

[49] DRN 1.1102 and 3.16-17.

[50] Schrödinger 1954:87.

[51] Bohr 1929/1934:18.

Several models of the atom as a complex entity were advanced in the late 19th and early 20th centuries, including J. J. Thompson's "plum pudding" model according to which electrons are embedded in a soup of positive charge, and, after the discovery of the nucleus by the resolute atomist Ernst Rutherford, Bohr's "planetary model" in which electrons orbit the nucleus (a caricature of which has become the logo of the "Atomic age").

Also worth mentioning here are the experiments of Jean Perrin on Brownian motion. In his Nobel acceptance speech of 1926, entitled "The discontinuous structure of matter", Perrin explicitly connected his work with the ancient theory. His success in discovering the cause of Brownian motion is a particularly interesting one, for it has long been noticed that Lucretius anticipated it with his description of the motes in a sunbeam[52]— the motes, like those studied by Brown and Perrin, must be moved by tiny, invisible particles. It was on the basis of J. J. Thompson's work on the electron and Perrin's work on Brownian motion that one of Mach's followers, Wilhelm Ostwald, virtually the last holdout against atomism, recanted his views, saying: "I am now convinced that we have recently become possessed of experimental evidence of the discrete or grained nature of matter, which the atomic hypothesis sought in vain for hundreds and thousands of years".[53]

Nowadays children are taught that an atom has a central nucleus, composed of protons and neutrons, orbited by electrons. Werner Heisenberg, who preferred Plato's version of atomism to Lucretius', said of these: "smaller units are nowadays called elementary particles, and it is obvious that if anything in modern physics should be compared with the atoms of Democritus it should be the elementary particles like proton, neutron, electron,

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[52] DRN 2.114-20.

[53] Ostwald, W. Grundriss der allgemeinen Chemie, 4th ed. (Leipzig, 1909); trans. in Holton 1978:82-3.

meson."[54] So we have now even detected the existence of sub-subatomic particles. A so-called "standard model" now offers to explain nature in terms of six quarks, six leptons, and some "force carrying particles" such as the photon. But sub-atomic particles behave quite differently than their ancient and early modern forerunners. Still, the Nobel prize-winning scientist Erwin Schrödinger has argued that atomism has retained its appeal since the time of Democritus because it is a means of "bridging the gulf between the real bodies of physics and the idealized geometrical shapes of pure mathematics." "In a way", he says, "atomism has performed this task all through its long history, the task of facilitating our thinking about palpable bodies".[55] What persists through all changes of atomism is the idea that macroscopic bodies and their qualities are ultimately composed of countable entities that do not possess most macroscopic qualities, and that retain their identity and characteristics throughout the changes we observe. The alternative is a concept of matter as infinitely divisible: the four elements of Empedocles and Aristotle, the pneuma of the Stoics, any of the ethers and universal mediums that have been posited by those horrified by the vacuum and the void. Although more recent alternatives involving fields, waves, and strings, appear promising as alternatives to atomism, particles remain as indispensable to contemporary science as they were to Lucretius' poem.

The Lucretian conception of nature as "accomplishing everything by herself spontaneously and independently and free from the jurisdiction of the gods" was a major driving force in the Scientific Revolution experienced in Western Europe beginning in the early 17th century. Over the following three centuries, the theory of atoms was converted

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[54] Heisenberg 1958:69.

[55] Schrödinger 1954:87.

from a poetic fancy to a well-confirmed empirical hypothesis, the charm, consoling power, and provocation of Lucretius' poem contributing in no small measure to this result. In every field of inquiry, from chemistry and physiology to meteorology and cosmology, the Lucretian rejection of teleology, immaterial spirits, and divine and demonic intervention into the lives of men and the phenomena of nature provided an explanatory ideal, even when it was scorned as inadequate to the phenomena or rejected as a threat to morals, politics, and religion.

There are nevertheless profound differences between ancient and modern materialism. With Boyle's and Hooke's experiments on air, the corpuscular theory assumed a quantitative and experimental dimension that would become the motor of the extraordinary successes of the physical sciences in the nineteenth and twentieth centuries. A subtler difference was occasioned by the move away from the attempt simply to understand some limited aspects of the natural world in atomistic terms towards an effort to remodel the world by manipulating the atom. The ethical significance of Lucretius' natural philosophy resided in its potential to remove, or at least reduce the fear of death and anxiety over the consequences of offending the gods, and to free men from the compulsion to engage in repetitive, pointless religious observances. Acquiring power over nature and redirecting natural processes to serve human ends was not an issue for older philosophers; that branch of inquiry and practice belonged to magic and mechanics and not to science. The classical atomist regarded the atomic reality underlying the appearances and changes of the visible world as screened off from human perception and manipulation. By contrast, the moderns integrated materialism into a methodological theory of control, in which the transformation of nature and the application of technology was a guiding concern. If nature is purely corporeal, if all effects arise from the motion and arrangement of particles, and if human beings demonstrably can change arrangements and impart motions (as their success in carrying out chemical transformations shows), the possibility of generating effects is unlimited. This marrying of a Baconian programme of power over nature with a corpuscularian theory in the Royal Society programme of useful works was perhaps based on an accident: the publication in 1651 of Bacon's earlier atomistic writings, representing an ontology towards which he was at best ambivalent. It is in any event expressed in Descartes' view that through the new philosophy we might become "masters and possessors of nature." Lucretius' poem, by contrast, offered a contemplative view, reverential in its treatment of the spontaneous cycles of renewal and decline in nature, and at the same time deeply pessimistic in its estimation of the worth of much human exertion and agency.

Further Reading

Lucretius' influence on the history of science is, for obvious reasons, impossible to isolate from the revival of Democritean and Epicurean atomism, and thus the best histories treat these together. For the late medieval and early modern period the following anthology, with a comprehensive bibliography, in indispensable: C. Lüthy, J.E. Murdoch, and W.R. Newman, <u>Late Medieval and Early Modern Corpuscular Matter Theories</u> (Leiden, 2001). See also the important article: C. Meinel, 'Early seventeenth century atomism. Theory, epistemology, and the insufficiency of experiment' in <u>Isis</u> 79 (1988): 86-103. T. Lennon in <u>The Battle of the Gods and Giants; The Legacies of Descartes and Gassendi, 1655-171</u> (Princeton, 1993) deals generally with the debates between Epicurean atomists and their Platonist opponents in the 17th century. The best general histories of materialism and atomism are: F.A. Lange, Geschichte des Materialismus (Iserlohn, 1865. English translation of 3rd German edition by E.C. Thomas: The History of Materialism. London, 1925); and K. Lasswitz, Geschichte der Atomistik vom Mittelalter bis Newton (2 Vols. Hamburg and Leipzig, 1890). See more recently: B. Pullman, The Atom in the History of Human Thought (trans. A. Reisinger: Oxford, 1998). Focusing on the English natural scientists is R. Kargon, Atomism in England from Hariot to Newton (Oxford, 1966). For the influence of ancient atomism on specific sciences, the following may be profitably consulted. For chemistry: J. R. Partington, 'The origins of the atomic theory' in Annals of Science, 4 (1939), p. 245-82. For the life sciences, see the introduction to the magisterial commentary by G. Campbell, Lucretius on Creation and Evolution: a commentary on De Rerum Natura 5:772-1104 (Oxford, 2003).

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