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MONTE JOHNSON AND CATHERINE WILSON

Lucretius and the history of science

The central aim of the *DRN* was to demolish religious belief and banish superstitious fear. To that end Lucretius, following Epicurus' largely lost *On Nature*,[1] 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' (2.1090–2). By way of accomplishing its aim, the poem addressed a range of scientific subjects: nutrition, perception and mental illness; cosmology, the seasons and eclipses; thunder, clouds, and the magnet; the emergence and evolution of animal and vegetable life; contagion, poisoning and plague.

Reintroduced into a Christian culture in which metaphysics and natural philosophy were dominated by a theory of providence and bolstered by 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 seventeenth century. Thanks in large measure to their compelling presentation in Lucretius' poem, Epicurean ideas 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

[1] For Lucretius' use of Epicurus see chs. 1 and 5 above.

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 being regularly invoked in scientific contexts as late as the nineteenth century, with his influence formally acknowledged well into the twentieth.

The undeniable influence of Lucretius' poem raises philosophical questions on the extent to which ancient ideas – about the discreteness of matter, the plurality of worlds, and the spontaneous adaptation of living things – are continuous with our own ideas about atomism, multiple universes and evolution. Readers should find it helpful to consider the continuities and differences on the basis of the intervening history of science.

Some knowledge of Epicurus, Lucretius and the existence of a pagan philosophy which held that all things including earth, air, fire and water (i.e. the elements), plants and animals, originate from atoms persisted in the medieval era.[2] There is mention of Lucretius in a work of William of Conches (*c.* 1090–*c.* 1154). Though William did not have access to the *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 *Dragmaticon philosophiae* the interlocutor 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:

> When the Epicureans said that the world 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.[3]

This compromise between Epicureanism and creationism, unlikely as it seems prima facie, was to have profound resonance throughout the development of the new philosophy and the scientific revolution.

Among the first scientists in the modern era to use Lucretius' text was the humanistic physician Girolamo Fracastoro (1478–1553).[4] In *On Contagion and Contagious Diseases* (1545) he developed a theory of contagion, 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 for words encapsulating

[2] See H. Jones 1989: 136–41. For knowledge of Lucretius generally in the Middle Ages see ch. 12 below.

[3] William of Conches 1.6.8–9, transl. Ronca and Curr 1997, modified.

[4] For Fracastoro's engagement with Lucretius see further pp. 191–2 below.

Fracastoro's idea to have been fabricated and interpolated into subsequent editions of Lucretius. These in turn were quoted in later medical texts on disease and 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 and scents were represented by Lucretius as types of particles, with specific effects (*DRN* 6.769–839), and this scheme was readily adopted by early modern chemists and physicians. The German physician Daniel Sennert (1572–1637) regarded the phenomena of fascination, plague and poisoning as proceeding from corpuscles or corpuscular effluvia. Walter Charleton (1619–1707) explained sympathies and antipathies in terms of a flow of atoms between the impassioned parties. 'Corpuscularians' – the term reflected agnosticism about the ultimate indivisibility of the particles and the existence of the void, and it implied dissociation from orthodox Epicurean atomism and thus from atheism and hedonism – were not applying a modern scheme to phenomena long deemed mysterious, but simply following Lucretius, who had explained dreams, ghosts, plagues and poisoning by the action of corporeal atomic effluvia.

Giordano Bruno (1548–1600) was the first philosopher in the modern period to revive the cosmological ideas of atomism.[6] Lucretius appears often in his writing, although Bruno was by no means an orthodox Epicurean. In *De l'infinito* (1584) the picture of an infinite plenum contained in an infinite void is attributed to Democritus and Epicurus. In his Frankfurt trilogy of Latin poems a kind of vitalistic atomism is elaborated as the explicit foundation of a cosmology embracing infinite worlds, and *De immenso* (1591) is devoted to the plurality and mutability of worlds.

This central Epicurean doctrine immortalised by Lucretius (*DRN* 2.1023–89) was consistent with the Copernican theory that the sun was merely another star, but it contradicted the Aristotelian teaching that our earth stood at the centre of the universe. It raised disturbing questions for Christians concerning the importance of the earth, its inhabitants and its allegedly sacred history. Fantasies of interplanetary travel and the discovery of new worlds nevertheless appeared throughout the seventeenth century, including John Wilkins's *Discovery of a World in the Moon* (1638), Pierre Borel's *New Discourse Proving the Plurality of Worlds* (1657), Cyrano de Bergerac's *States and Empires of the Moon* (1657), Bernard de Fontenelle's *Conversations on the Plurality of Worlds* (1686) and Christiaan Huygens's

[5] See Andrade 1928: xix n. 2.

[6] For Bruno's engagement with Lucretius see further pp. 192–5 below.

Cosmotheoros (1698). Leibniz took up the topic in his *New Essays* (written *c.* 1704). Contemporary astronomy takes the plurality thesis for granted, and few modern Christians appear to be troubled by the possibility that intelligent and morally meaningful life might exist in realms unvisited by the historical Jesus.

In *De minimo* (1591) Bruno treated the atom 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 a related form of vitalistic atomism expounded in his *Monadology* (1714).

Leibniz's return to vitalism came in response to the spectacularly successful revival of materialist atomism, in which the poem of Lucretius played an important part. But Lucretius was only one stream of influence on the development of corpuscular theories of matter in the early modern period. Others included the works of Aristotle (who directly opposed the atomism of Democritus), Hero's *Pneumatica*, and various sources in alchemy, iatrochemistry and metallurgy. Throughout the sixteenth century, natural philosophers worked on the problem of chemical mixtures, initially in response to the ancient controversy about whether in a mixture what is mixed retains its identity in the new substance, or rather takes on a 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 the atomist Sebastian Basso (*fl.*1550–1600), who discussed Lucretius in his *Natural Philosophy against Aristotle* (published 1621).

Bernardino Telesio (1509–88) had advanced a radically empiricist, anti-Aristotelian natural philosophy in *De rerum natura juxta propria principia* (1565; complete edn 1586). Telesio's influential views had been adopted at the academy of Cosenza; Francis Bacon (1561–1626) called him 'the first of the moderns' but took aim at him in a late essay, *De principiis atque originibus* (*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 stated there that 'to me the philosophy of Democritus seems worthy to be rescued from neglect', echoing his earlier remark in the *Cogitationes de natura rerum* (written 1605): 'the Democritean doctrine of atoms is either true, or useful for demonstration'.[7] In the *Novum organon* (1620) Bacon recommended Democritus' method of

[7] Bacon 1857–74: III, 84; III, 15.

'dissecting nature' as against the Aristotelian method of 'abstraction',[8] and he appealed to the atomic doctrine in the later essay *Of the Dense and Rare* (1623), a subject well suited to atomistic treatment.

Bacon's enthusiasm for ancient atomism was nevertheless tempered and ambiguously expressed.[9] He rejected key tenets of Lucretian atomism such as the void and the swerve, the latter because he was committed to the view that all matter is ordered by divine providence. Although he described the formation of the cosmos out of chaos in terms of atoms, he rejected Copernicanism and the cosmology of infinite worlds. And his view of matter in the *Novum organon* relied as little on the atomic conception of matter as on what he called the 'abstract' Aristotelian one: 'People do not stop abstracting nature until they reach potential and unformed matter, nor again do they stop dissecting nature until they reach the atom. But even if these things were true, they could do little to improve people's fortunes.'[10] Bacon denied that rigid atoms in a vacuum were the 'true particles', replacing them with '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 to Lucretius in particular.[11] The concept of material texture would later influence the first modern chemist, Robert Boyle.[12]

Daniel Sennert, professor of medicine at Wittenberg and a follower of Bruno's, had noted in an early work:

> 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 seventeenth century, in no small part due to Sennert's own defence of atomism in his *Thirteen Books of Natural Philosophy* (1618). He pointed out that silver atoms retain their individuality even after being combined with gold, reduced to invisibility with nitric acid and passed through a paper filter.[14] This

8 Bacon 1857–74: I, 168–9.

9 For Bacon's engagement with Lucretius see further pp. 155–8 and 251–2 below.

10 Bacon 1857–74: I, 178. 11 So Gemelli 1996: 196–7. 12 See Clericuzio 1984.

13 Sennert 1660: 446; the work quoted, the *Epitome philosophiae naturalis*, was first published in 1600; the section on atomism from which the above quotation was taken was included in the 1618 edition.

14 See Michael 2001.

experiment 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.

Descartes (1596–1650), whose interest in the new physics was sparked off by Beeckman, formed the ambition of displacing the natural philosophy textbooks of the Aristotelians with his own system of the world. He drew not only on Galileo's Democritean 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 *Principia philosophiae* (1644). In the *Principia* (2.23) 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 denied however that there are atoms – least particles – on the grounds that their existence conflicts with God's power to do anything we can imagine. While mechanical statues were interesting to Descartes and his contemporaries, and while machine-animal analogies are not uncommon in baroque literature, Descartes's 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, as Lucretius posited in *DRN* 4, account for some forms of sensation, dreaming and memory at least in animals. This less than original hypothesis was famously softened by Descartes's 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 retained the Lucretian notion that from a chaotic state of distributed matter, planetary systems or 'vortices' form spontaneously and their numerous earths bring forth plants, animals and even men.

Sometimes known today as 'the French Bacon', and famous now 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 his *Investigations into the Tenth Book* *of Diogenes Laertius* (1649), to which was appended his synoptic *Treatise on Epicurean Philosophy*. 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, observing in the *Syntagma*:

> 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 when the Epicureans said that the world consisted of atoms they were correct. But it must be regarded as a fable when they said that these atoms were without beginning and flew to and fro separately through the great void, then massed themselves into four great bodies.' 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.[15]

The words approved by Gassendi and here attributed to Aneponymus are those of William of Conches, the medieval philosopher quoted above. The view advanced is recognisable to the reader of the *Timaeus*, in which Plato presents his own version of atomism in the context of a creationist account of the formation of the world and 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 world-view, developed by Gassendi, then Robert Boyle and Isaac Newton, among others. Gassendi's system preserved the notion that the entanglement, motion and interaction of invisible corpuscles are the basis of all

[15] Gassendi 1972: 398, transl. Brush, modified.

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'.[16] A virtue of atomism was that, unlike Aristotelianism, it was compatible with the prevailing voluntarist theology; atomism requires neither eternal forms 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 corporeality and mortality of the soul, responding to no less than twenty-seven arguments against immortality drawn from Lucretius,[17] though his objections to Descartes's *Meditations* might well lead the reader to wonder how much importance he attached to the incorporeal human soul, by contrast with the corporeal souls he thought men shared with animals, and whose powers included cognition, language and experience.

Following closely on the continental developments was the growing interest in atomism in England. In the early years of the seventeenth century, Henry Percy, the 'wizard Earl', patronised an informal group of English Copernicans and atomists, including Thomas Hariot, whose scientific manuscripts were later studied by the mathematician Charles Cavendish.[18] Charles, his brother William Cavendish and his sister-in-law, the writer Margaret Cavendish, were at the centre of an important intellectual circle in Paris in the 1630s known as the 'Cavendish circle', which included Thomas Hobbes.[19] 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 own materialistic system in terms of human ideation, not fundamental ontology, even in his *On Body* (1655), as Locke was later to do. But Hobbes nevertheless maintained that all was body, including God. Margaret Cavendish 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 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-Gassendo-Charltoniana* (1654). Other English philosophers influenced by Cartesian and Gassendist corpuscularianism included Sir Kenelm Digby, the author of *Two Treatises*, 1645 (on the nature of bodies and on the nature of the mind),

16 Osler 2003. 17 M. R. Johnson 2003.

18 For the Percy circle see further Kargon 1966: 5–17 and p. 251 below.

19 For the Cavendish circle see further Kargon 1966: 40–2 and Clucas 1994.

20 See Rees 2000.

and John Locke, the author of the influential *Essay Concerning Human Understanding* (1690).[21]

Hobbes's enthusiasm for materialism did not help to polish the image of Lucretius, still regarded as the proponent of a dangerous and mostly unacceptable philosophy even in England. Robert Boyle (1627–91), in his essay *On the Usefulness of Experimental Natural Philosophy* (1663), repeated the old story that Lucretius' poem was written 'in one of the fits of that frenzy, which some, even of his admirers, suppose him to have been put into by a philtre given him by his either wife or mistress Lucilia'.[22] Under the title of an unpublished essay 'Of the Atomicall Philosophy' Boyle had written: 'These papers are without fayle to be burn't.' They were not, enabling us to read his observations:

> 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.[23]

Boyle expounded corpuscularianism in his *Origin of Forms and Qualities according to the Corpuscular Philosophy* (1666) and in numerous other works, including the *Considerations about the Excellency and Grounds of the Mechanical Hypothesis* (1674) and the *Inquiry into the Vulgarly Received Notion of Nature* (1686), 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.[24]

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

[21] For Locke see further pp. 275–6 below. [22] Boyle 1999–2000: III, 255.

[23] Boyle 1999–2000: XIII, 227. [24] Boyle 1999–2000: VIII, 104.

any experimental basis. One cannot say that physical or chemical phenomena really rendered the existence of atoms 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, seventeenth-century arguments for and observations cited in favour of corpuscularianism were inconclusive, and that its reappearance 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 argument, observation and evidence.[25]

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 'contrivance', one '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'.[26] He named his version of the mechanical philosophy 'Anaxagorean', in 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 implied that the cosmos, and plant and animal life, had emerged spontaneously.[27] 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.[28]

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

[25] Meinel 1988: 193. [26] Boyle 1999–2000: XI, 299–300.

[27] The term 'Anaxagorean' appears in the suppressed sections of the *Inquiry into the Vulgarly Received Notion of Nature*.

[28] So Anstey 2002.

repulsed than other atheist and mortalist versions of Aristotelianism and pagan naturalism. 'Libertines', he says, 'own themselves to be so upon the account of the Epicurean or other Mechanical Principles of Philosophy',[29] and they fail to pay due regard to Aristotle, Scotus, Aquinas and Augustine. He complained of being taken for an Epicurean himself. Yet one cannot say that Boyle showed much deference to Aristotle or to 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 was not conversant 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 they were far from being an embarrassing pseudo-scientific preoccupation; Newton was in the process of developing an atomistic chemical theory of matter.[33] His physics is also recognisably atomistic. Among 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 as 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 Lucretius' discussion of the motion of atoms in the void.[36] And eventually, in the last query of the second edition of the *Optics* (1718), Newton published his belief that all things are composed of atoms:

> it seems probable to me, that God in the Beginning form'd Matter in solid, massy, hard, impenetrable, moveable Particles, of such Sizes and Figures, and with such other Properties, and in such Proportion to Space, as most conduced to the End for which he form'd them; 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

[29] Boyle 1999–2000: VIII, 237. [30] Boyle 1999–2000: II, 354.
[31] Transcribed in McGuire and Tamny 1983. [32] See J. Harrison 1978 at H990.
[33] See Figala 1992. [34] See Newton 1962: 309–11; Cohen 1964.
[35] Turnbull *et al.* 1959–77: III, 338.
[36] Newton 1962: 312–17; McGuire and Rattansi 1966.

> 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.[37]

This is one of the most influential pieces of writing in the history of science. And it occurred amidst what is essentially a paraphrase of certain arguments in *DRN* 1.540–98, fusing Lucretian doctrine with creationism and voluntarist theology. One 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. Theirs were the first attempts to quantify atomic phenomena. The mathematicisation of the atomic theory is notable in some sections of Newton's optical and chemical writings and in his *Mathematical Principles of Natural Philosophy*, which contain a mathematical derivation of Boyle's gas law: Newton assumed the existence of particles in his derivation, but refrained from mentioning the atomic hypothesis in this essentially mathematical work. Newton's results had in turn a major influence on John 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 very notion of matter. Leibniz and Berkeley were not content with attacking the logical coherence of the notion of the 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 argument 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 devoid of all qualities except size, shape and mobility, Leibniz drew the remarkable inference that the elements of things must be alive and infinitely complex.[39]

[37] Newton 1718: 375–6 (Query 31), emphasis added.
[38] C. Wilson 2003: 104–8. [39] See further C. Wilson 1982.

Immanuel Kant (1724–1804) was perturbed by Leibniz and heavily influenced by Newton. He openly acknowledged his debt to Lucretius in offering a nebular hypothesis concerning the formation of the planets and solar system.[40] 'I will not deny', he admitted,

> 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 Heaven*, 1755)[41]

Despite his favourable attitude towards Lucretian cosmology, 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). Kant argued in the finale of his critical writings, the 'critique of teleological judgement' (Part 2 of *The Critique of Judgement*, 1790), that science required, conceptually, a teleological framework for the explanation of life, regardless of the basically unknowable nature of things. But atomistic and anti-teleological ideas were attracting a favourable reading in the rapidly developing life sciences. David Hume's *Dialogues Concerning Natural Religion* (first published 1779) contained a paraphrase of Lucretius' selection principle,[42] arguing that currently existing species of animals are those which, unlike their counterparts, had apt combinations of organs and were thus able to survive and reproduce, and this notion was common amongst the *philosophes*. Erasmus Darwin wrote a substantial Lucretian didactic poem, *The Temple of Nature* (1803), and his earlier *Zoonomia* (1794–6) explicitly endorsed the theo-mechanical version of atomism.[43] Lucretius did not technically elaborate a theory of evolution, since he held plant and animal species to be fixed.[44] 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 Erasmus' grandson, Charles Darwin, who became embroiled in theological controversies reminiscent of those of the seventeenth century.

[40] For Kant's engagement with Lucretius see also pp. 177–83 and 284–5 below.
[41] Transl. Hastie 1900: 24.
[42] Compare *Dialogues* Part 8 with *DRN* 4.823–57; 5.772–877.
[43] For Erasmus Darwin see further pp. 291–2 below.
[44] Campbell 2003: 6–8.

Historians have described a general 'victory of discreteness' in regard to the discovery of cells and genes, entities which, along with Darwinian evolution, are the bases of the modern life sciences. Lucretius represented the material units of heredity in a way that arguably anticipated later accounts. But the greatest victory for discreteness 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 led 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'.[45] 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 acquainted with 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 (partially quoted above) from the *Optics*.[46] Dalton's mechanical atomism was perceived as successful in explaining the behaviour of heat and gas. He realised that gases combine to form compounds in definite ratios, and he inferred from this that they must consist of discrete particles, thus robustly joining 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, celebrated for his work on electromagnetism and the kinetic theory of gases; Maxwell 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'.[47]

Despite the affirmation of Maxwell, and despite Dalton's earlier claim that atomism was a universally accepted chemical fact, several doctrinaire empiricists rejected atomism. Towards the end of the nineteenth century Ernst Mach had advanced a form of positivism according to which only things directly perceived are real, everything else being a convenient heuristic for scientific thought, if not a figment of the imagination. Mach had many important disciples; they constitute the last bastion 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'.[48]

[45] Dalton 1808: 141.

[46] For the relevant parts of the notebook see Roscoe and Harden 1896: 124.

[47] Maxwell 1873: 437.

[48] Duhem 2002: 93–4.

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.[49] This is ironic because the discovery of subatomic particles seems to explode the idea of the indivisible atom. The recollections of the artist Wassily Kandinsky show how startling was this new conception of nature:

> 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.[50]

Kandinsky's language here suggests Lucretius' mention of 'the walls of the world fleeing at the destruction of the world' and of how 'the walls of the world part' (*DRN* 1.1102; 3.16–17). Kandinsky, like Lucretius and later Newton, decided that the division of the 'atom' implied there were no atoms, and anything could be destroyed or transformed into any other thing.

Of course, Kandinsky need not have worried that science was 'destroyed'. Physicists have acquired extensive knowledge of various 'elementary' particles with the help of electrolysis, accelerators, cathode ray tubes and other procedures and devices. There are now many ways to detect 'atoms': scintillation screens, Geiger counters, cloud chambers, photographic emulsions and scanning-tunnelling microscopes. As Erwin Schrödinger, the Nobel Prize-winning scientist, observed, 'The great atomists from Democritus down to Dalton, Maxwell, and Bolzmann would have gone into raptures at these palpable proofs of their belief.'[51] 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 a hypothesis to a fact. Niels Bohr could state by 1929 that 'every doubt regarding the reality of atoms has been removed'.[52] Several models of the atom as a complex entity were advanced in the late nineteenth and early twentieth 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 Ernest Rutherford, Bohr's 'planetary model' in which electrons orbit the nucleus. Though the model is now discredited, a version of it remains 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

[49] Weinberg 1983: 3. [50] Kandinsky 1955: 16; transl. Holton 1993: 105 n. 19.
[51] Schrödinger 1954: 87. [52] Bohr 1934: 18.

the ancient theory. Lucretius, as was often noted, had called attention to the behaviour of dust motes in a sunbeam (*DRN* 2.114–28); the motes, he understood, must be moved by even tinier, invisible particles. It was on the basis of J. J. Thompson's work on the electron and Perrin's on Brownian motion that one of Mach's followers, Wilhelm Ostwald, virtually the last scientist to reject atomism, recanted.[53]

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 observes, 'atomism has performed this task all through its long history, the task of facilitating our thinking about palpable bodies.'[54] Nowadays children are taught that an atom is composed of 'elementary particles' – that it has a central nucleus, composed of protons and neutrons and surrounded by electrons. Werner Heisenberg, who preferred Plato's version of atomism to Lucretius', stated that '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, meson'.[55] A so-called 'standard model' now offers to explain nature in terms of sub-subatomic particles – six quarks, six leptons and some 'force carrying particles', such as photons. Although there are major differences between this kind of model and what we find in the poem of Lucretius, Schrödinger was not wrong to say that 'all the basic features of the atomic theory have survived in the modern one up to this day'.[56] Similar thinking led the physicist Richard Feynman to remark:

> If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, what statement would contain the most information in the fewest words? I believe that it is the atomic hypothesis (or the atomic fact, or whatever you wish to call it), that all things are made of atoms – little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another. In that one sentence, you will see, there is an enormous amount of information about the world, if just a little imagination and thinking are applied.[57]

What persists through all versions 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

53 See Holton 1978: 82–3. 54 Schrödinger 1954: 87.
55 Heisenberg 1958: 69. 56 Schrödinger 1954: 83. 57 Feynman 1963: I, 2.

Aristotle; the *pneuma* of the Stoics; any of the ethers and universal mediums that have been posited by those horrified by the vacuum. Although more recent fundamental ontologies based on fields, waves and strings appear promising, particles remain as indispensable to contemporary science as they were to Lucretius.

To summarise, 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 seventeenth century. Over the following three centuries the theory of atoms was converted 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 to understand some limited aspects of the natural world in atomistic terms for ethical purposes towards an effort – whether amoral or humanitarian – to remodel the world by manipulating its constituent atoms. 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 human beings from the compulsion to engage in repetitive, pointless religious observances. Acquiring power over nature and redirecting natural processes to serve human ends was not the aim of ancient philosophers; that branch of inquiry and practice belonged to magic and mechanics, 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 the mature Bacon was ill-disposed. The resulting ambition is expressed in Descartes's claim that through the application of the new philosophy we may 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

Robert Boyle, 'the father of modern chemistry', very concisely and persuasively articulated reasons for applying atomistic ideas to modern scientific questions in his essay *Considerations about the Excellency and Grounds of the Mechanical Hypothesis*, 1674. Andrade 1928 is another working scientist who, in a comprehensive overview, described the many contributions of Lucretius specifically to the history of science. But Lucretius' influence on science is, for obvious reasons, difficult or impossible to isolate from the revival of Democritean and Epicurean atomism, and thus the best histories discuss the revival of atomism generally. For the late medieval and early modern period see Lüthy, Murdoch and Newman 2001, an anthology which includes a complete and up-to-date bibliography. See also the important Meinel 1988 regarding the relationship between atomism and experimental science. The best general histories of materialism and atomism are Lange 1866, Lasswitz 1890, more recently Kargon 1966 (focused on English atomism) and Pullman 1998 (much wider in scope and written by a physicist). For the influence of ancient atomism on chemistry see Partington 1939, and of Lucretius specifically on the life sciences, Campbell 2003. Lennon 1993 deals generally with the philosophical debates between 'Epicurean' atomists and their Platonist opponents in the seventeenth century.