Chapter 14
Atomism Vindicated?

Abstract After the experiments of Perrin on Brownian motion and of Zeeman, Thomson and others that revealed the existence of the electron there remained little room for doubt about the existence of micro-particles way below the dimensions of direct observation. To what extent is this achievement a vindication of atomism? It was not a vindication of the philosophical tradition that had sought an account of the ultimate structure of matter. The atoms of modern science have an inner structure about which much is known and some inner structure of the electron might well be revealed by the next generation of particle accelerators. Knowledge of atoms and electrons was acquired early in the twentieth century by argumentation that was experimental rather than philosophical and was arrived at by a route that owed little to the tradition of philosophical atomism. As the twentieth century progressed properties, such as half-integral spin, needed to be ascribed to micro-particles in a way that gives rise to nothing but headaches for those inclined to base an account of the ultimate structure of matter on some general philosophical principles. To view contemporary atomic theory as a vindication of Democritus is to seriously misconstrue the nature of science and its mode of argumentation.

14.1 Introduction

As we have seen, Perrin's experiments left no room for serious doubt that there are molecules. The connections between the kinetic theory and chemistry, and the need to include rotational modes of motion for molecules to cope with specific heats of gases, further led to the recognition that molecules are made up of atoms, one kind of atom for each chemical element. The experiments of Zeeman and Thomson, and a range of related experiments that followed in their wake, established that atoms have tiny negatively charged electrons as components, that molecules can become positively or negatively charged ions by losing or gaining electrons, that electrolysis and electrical discharges through gases involve the transfer of ions, that conductivity in metals involves the transfer of electrons and that electrons are in some way implicated in chemical combination and the production of spectra.

To what extent can such dramatic developments be regarded as a vindication of atomism? The answer depends much on what is intended by the term 'atomism'. If

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atomism is interpreted suitably vaguely, as claiming that the objects and materials of our experience are composed of discrete parts with properties that serve to explain the properties of the wholes they are parts of, then it was vindicated in a significant and uncontroversial sense by the time the first decade of the twentieth century had expired. But such an assessment needs to be qualified as soon as atomism is defined in more precise ways so that, for example, distinctions can be made between the kinds of atomism involved in the theories of Democritus, Sennert, Boyle, Newton, Dalton, Maxwell and Perrin.

The atoms invoked by Ancient Greeks such as Democritus and Epicurus and by seventeenth-century mechanical philosophers such as Gassendi and Boyle were construed as the ultimate and unchanging components of material reality. Some notion of reality that was regarded as evident or as the only intelligible notion led to the conclusion that atoms possess only the properties of shape, size and motion together with a property such as solidity or tangibility or impenetrability characteristic of matter in general. Twentieth-century atoms are nothing like those envisaged in these philosophical traditions and they and their properties were discovered by experiment rather than philosophical analysis. The modern atom has an internal structure, most importantly an electron structure. Electrons have a charge as well as a mass. I am confident that according to the notion of intelligibility that Boyle employed to dismiss Aristotle's 'real qualities' the charge on the electron is unintelligible. If this is not seen as sufficient to establish the qualitative difference between electrons, on the one hand, and atoms in the tradition of Democritus and Boyle, on the other, then I remind the reader that it was not far into the twentieth century that it became necessary to attribute to electrons a half-integral spin, a quantum-mechanical notion having no classical correlate, and to understand electrons as obeying Fermi-Dirac rather than classical, Boltzmann, statistics. (There are only three ways, not four, of distributing two electrons over two boxes.) Such properties are far from anything envisaged by Democritus and Boyle and cannot be reconciled with the notions of reality and intelligibility that informed their theories. What is more, it is precisely these novel kinds of properties that are fundamental for explaining the details of such things as atomic spectra, chemical combination and the conduction of electricity through metals. The twentieth-century science of atoms is a violation of and departure from atomism in the sense of Democritus, Epicurus and the seventeenth-century mechanical philosophers.

Another tradition that attributed the properties of observable wholes to the properties of their discrete parts was the one that invoked natural minima. Those minima possessed properties sufficient to characterize them as minima of the substances they were the least parts of. Minima of blood, water and gold differed from each other in precisely this way. The reductionist character of modern atomism places it closer to the Democritean ideal than the theory of natural minima. It is true that, in the modern theory, the atoms of each element are characteristic of, and peculiar to, that element. However, the properties of atoms responsible for chemical, optical, electrical and indeed macroscopic properties generally involve electron structure. In the medieval theory and its successors key properties of macroscopic materials reappear as the properties of natural minima. By contrast, in the modern theory macroscopic properties are *explained* by appeal to a narrow range of properties such as electron charge and spin. Substances do have least parts as Sennert and his medieval precursors supposed, but the properties attributed to those least parts and the explanatory role that they play in the modern theory differ vastly from anything they envisaged.

Modern atoms differ markedly both from atoms in the tradition of Democritus and the mechanical atomists and from natural minima. What is more, they are able to perform their explanatory role because of the ways in which they so differ. The potency of atoms as characterized in the modern theory, that enables them to perform their role as fundamental building blocks, stems precisely from the difference between them and miniature stones.

14.2 Did Philosophical Atomism Play a Productive Heuristic Role?

In the previous section I was concerned to spell out the distinction between the modern scientific atom and the philosophical notions of an atom that preceded it. However great the distinction, there remains the possibility that the philosophical version played a productive role in leading to the scientific one. I suggest that reflection on the story told in this book invites a sceptical response to any such proposal.

The path to solid evidence for the electron came very much from left field (as they say in the USA where I am writing the first draft of this chapter). The rotation of the plane of polarization of light by a magnetic field and the existence of line spectra that Zeeman investigated using improved spectroscopic techniques were nineteenth-century experimental discoveries. The electrical technology that was a crucial part of what made discharge tube phenomena possible stemmed from Volta's discovery of the battery late in the eighteenth century. I am not aware that the discovery owed anything to philosophical atomism. The same can be said of the invention of the mercury diffusion pump that made possible the production of pressures sufficiently low to make the experimental production of cathode rays possible from the late 1850s. The investigation of cathode rays and related experiments on discharge tube phenomena forced Thomson and others to the conclusion that cathode rays are beams of sub-atomic particles with charge as well as mass. No philosophical theory had anticipated, nor could possibly have anticipated, the quantum mechanical behavior of electrons that was to enable them to play their full explanatory role.

The kinetic theory of gases shows more promise as an example of a productive path from philosophical to scientific atomism. The explanation of the properties of gases by appealing to the motions and mechanical collisions of its least parts seems to come close to the kinds of explanation envisaged by Democritus and the mechanical philosophers. The mass and velocity that needs to be attributed to the molecules in the kinetic theory find a ready home in mechanical atomism. The perfect elasticity of collisions is not so easily accommodated, however. As we have seen, elasticity was a notion that troubled the mechanical philosophers. They saw it as necessary to explain it away but did not succeed in doing so to their own satisfaction. The problem was less acute from the point of view of Newtonian atomism insofar as rebounds could be attributed to short-range repulsive forces rather than to the perfect elasticity of the molecules themselves.

Aside from qualms about how elastic collisions can be accommodated in philosophical atomism, there is a more significant problem with seeing the kinetic theory as one of its fruits. My first point is that the kinetic theory was first successful as a theory of *gases*. Gases, as chemically distinct substances in the vapor phase some of which are components of air, were not anticipated by philosophy. Knowledge of their existence was an experimental discovery of chemists in the second half of the eighteenth century. The second point concerns the extent to which the kinetic theory was tied to and served to explain the gas laws. These, too, were experimental discoveries made in the second half of the eighteenth century. What is more they presupposed a precise and measurable notion of temperature, another innovation of the same period.[1] The idea that the heat of a body is associated with internal motions was a speculation that goes back at least as far as Francis Bacon early in the seventeenth century. But the transformation of that speculation into a reasonably precise theory with empirical support depended on experimental discoveries that owed little to philosophical matter theories, atomistic or otherwise.

Chemistry is the other field that might well be invoked as an illustration of a productive heuristic role played by philosophical atomism. Even if I am right to endorse Thackray's view that Newtonian atomism was unproductive as far as eighteenth-century chemistry is concerned, Dalton explicitly appealed to and employed it in his formulation of an atomic theory of chemistry early in the nineteenth century. However, my detailed study in Chapter 9 was designed to downplay the productive role played by that atomism. I argued that progress in nineteenth-century chemistry was more a precondition for rather than a result of the productive introduction of atomism into chemistry. I have most difficulty defending my position when confronted by historians such as Rocke and Klein who see the nineteenth-century advances as coming about by way of a chemical atomism, rather than physical atomism in the tradition of Newton or the mechanical philosophers. Even if my opponents are right here, the chemical atomism they endorse differed from philosophical atomism. The properties of chemical atoms were meant to be filled in as a result of chemical research rather than being specified in advance. Progress in nineteenth-century chemistry cannot be claimed as an example of philosophical atomism bearing fruit.

It needs to be stressed just how different the methods were that led, on the one hand to philosophical atomism, and on the other to the scientific atomism we take for granted today. The former drew on principles that seemed plausible or self-evident given the knowledge of the day and employed them to build and rationally defend an atomistic world-view. The path to the latter involved grappling with specific problems in the scientific knowledge of the day, framing new notions to help articulate responses to them and insisting that claims made in terms of the new notions passed stringent experimental tests. The pursuit of this latter method led to a radical undermining of the philosophical principles assumed by the former. For instance, the macroscopic/microscopic analogy employed in some form or other to defend philosophical atomism turned out to be highly problematic. It is not just a question of its content, knowing in what respects the microworld resembles the macroworld and just what properties can be projected from the one to the other. There is the question of its truth. It became evident, in the light of scientific advances, that the macroscopic/microscopic analogy is radically false. From the point of view of quantum physics and relativistic mechanics that inform modern atomism, the principles extracted from our knowledge of the macroworld by classical philosophical atomists constituted obstacles to be overcome. Rather than being a source of and inspiration towards a viable scientific atomism, philosophical atomism constituted a barrier to it that needed to be transcended.

To take features of atomism in contemporary science and point out how it differs from atomism in the ancient and mechanical traditions is to adopt a modern perspective. But I resist the charge that my stance is anachronistic. I have argued that the beginnings of the distinction between philosophical and scientific matter theories were already present in the seventeenth century. The methods that Boyle employed and articulated in the context of his pneumatics were the very ones that were to eventually lead to knowledge of atoms and, in so dong, undermine the fundamental claims of his mechanical philosophy. Not all, nor even most, of the reservations held by nineteenth-century chemists concerning atoms can be properly understood as positivistic prejudices. They made sense in the context of an increased awareness of the distinction between scientific and philosophical accounts of matter. By the time experimental science had developed sufficiently to dispel the qualms of those wary of atomism most of the principles underlying atomism in the tradition of Boyle and Newton had been undermined.

14.3 Twentieth-century Atomism a Victory for Scientific Realism?

The undeniable success of the atomic theory in the twentieth century is frequently invoked as a victory for scientific realism.[2] Positivists who held it to be impossible for science to gain knowledge of the world behind the appearances, and instrumentalists who held that scientific theories should be seen as useful instruments aiding our dealings with the world rather than as adequate descriptions of it, have been shown to be wrong. Whilst there is some important truth underlying such claims they need to be qualified to take into account the extent to which modern science has undermined what I will call the ‘billiard-ball realism’ that was implied by philosophical matter theories that have become outmoded.

Before I expand on my qualifications about seeing the triumph of atomism as a victory for realism, let me acknowledge the element of truth in it. There are extreme positivist or instrumentalist views, occasionally voiced by nineteenth-century critics of atomism, which are difficult to reconcile with the eventual success of scientific atomism. As Nyhof (1988, pp. 87–89) reports, Mach did occasionally express the extreme view that the world postulated by scientists as lying behind the appearances 'exists only in our understanding' and that, 'in our investigation of nature, we have to deal only with the connections of appearances with one another'. Duhem, (1962, p. 19) for his part, insisted that 'a physical theory is not an explanation. It is a system of mathematical propositions, which aim to represent as simply, as completely, and as exactly as possible a set of experimental laws'. The ultimate success of atomism in the physical sciences flies in the face of such assertions.

The construal of the success of atomism as running counter to extreme anti-realist views is altogether too easy and stands in the way of our learning what there is to be learnt from the story of atomism as told in this book. The success of atomism is hardly necessary to counter extreme positivism and instrumentalism. Knowledge of the physics and chemistry of gases such as oxygen and hydrogen, for instance, is sufficient to do that. This suggests that, if there is something valid about intuitions to the effect that the confirmation of atomism was especially significant as far as the realism issue is concerned, they are not captured by the mere recognition that that confirmation runs counter to extreme positivist or instrumentalist views. There are a number of less extreme views, versions of which can be found in the writings of the likes of Mach and Duhem, although I will not document that here.[3] The mechanical view of the world as portrayed by the mechanical philosophers and Newton, what I have dubbed 'billiard-ball realism', is not one that is sanctioned by experimental science and should not be assumed by experimental science. The assumption that all science can be reduced to mechanics, or, more generally, to physics, is something that needs to be supported by effecting such reductions rather than assuming it in advance in experimental research. There is no good reason to expect that the world lying behind the appearances conforms to common-sense intuitions based on familiarity with the world of appearances. I suggest that all of these theses are supported by the history of atomism as I have told it.

There is a question that I like to press, an answer to which forces a realist to formulate that position in a way that is more sophisticated than a mere denial of extreme positivism and instrumentalism as I have characterized them above. That question is, if the establishment of atoms constituted a victory for realism, why didn't the banishment of the aether constitute a defeat? A number of scientists in the latter part of the nineteenth-century sought a reality behind knowledge of chemical combination and the physics of gases and postulated atomic theories. They were ultimately successful in that endeavor. Maxwell and his followers sought a reality behind knowledge of optics and electromagnetism and postulated a mechanical aether. They were unsuccessful. If there is a deep structure underlying the electromagnetic field the current success of field theory does not depend on knowing what it is. The fluctuating displacements currents implicated in electromagnetic radiation, including visible light, are fluctuating electric fields that are not states of an aether or anything else. They are as alien to mechanistic intuitions as the half-integral spin of the electron and the non-classical statistics obeyed by those particles. If one is to get comfortable with such notions then one had better learn the relevant physics rather than engage in philosophical reflection.

There is a kind of realism I am willing to endorse because I believe it to be implicit in the practice of science. It involves two claims. The first of them is this.

The world is the way it is whether we know it or like it or not. This claim is best borne out by the failures of science rather than its successes. We cannot make the world conform to our conceptions or our wishes. My view is implicit in the acknowledgement that the claims of science need to be rigorously tested by experiment. The second claim in my version of realism is that science is indeed capable of revealing knowledge of the world. This claim is supported to the extent that science has proved to be progressive. A feature of my characterization of realism, which I suspect will be too weak to satisfy many self-proclaimed scientific realists, is that it does not include any substantive claim about what the world is like. A declaration like 'it is the job of science to discover the reality lying behind and serving to explain experimental knowledge' is too strong. Whether there is such reality is something that the world decides, not us. For all we know, there is no reality lying behind electromagnetic fields, and if it should transpire that there is, it will be advances in physics that establish this. From my point of view, versions of realism that implicitly or explicitly incorporate assumptions central to the philosophical versions of atomism with which we have been concerned with in this book assume too much, and it is such realist views that have been undermined by the success of scientific versions of atomism. I am keen to encounter any impression that the success of atomism somehow shows that philosophical atomism in its mechanical or Newtonian guises were on the right lines.

14.4 In the End is My Beginning

To all intense and purposes Perrin established that molecules exist and was able to determine their weights experimentally. After his experiments on Brownian motion chemists had no need for reservations when identifying chemical molecules figuring in chemical formulae with the molecules whose weights Perrin had measured. Further, chemists can use their chemical formulae to derive atomic weights from molecular weights. After Perrin, atoms and molecules could be counted as well as weighed. Philosophical speculations about the existence of discrete entities underlying and responsible for observable phenomena had become scientific truth. Our story has reached its conclusion.

Or has it? By 1910 at the latest, chemists could safely presuppose atoms and molecules with weight and understand the symbols in their formulae as referring to them. But the same query can be raised here as I raised in the context of Dalton's first proposal of his atomic theory. What kind of chemistry can one do armed merely with atoms and molecules with weight? The question does not lose its poignancy by virtue of the fact that, after Perrin, chemists had confident access to absolute and not merely relative ones. Nor is it of much relevance to chemistry to note that the kinetic theory yields an average value for the square of the velocity of molecules in a gas. Developing atomic chemistry to the extent that it could give an account of valency, explain chemical bonding and the stability of molecules, the periodic table and so on was, in the first decade of the twentieth century, a task for the future. Atomic physics, too, was just beginning. Explaining the details of spectra, metallic conduction, the photo-electric effect, the outstanding problems with the specific heats of gases, black body radiation, electron diffraction patterns and so on, not to mention a host of problems associated with radioactivity, all posed problems for the future. The beginning of the twentieth century in a sense marked the dawn of atomism rather than its successful conclusion. The tasks that lay ahead were tasks for the scientist rather than the philosopher. The relativistic and quantum mechanical pictures of the world that were to emerge were such as to pose nothing but headaches for the mechanistically-minded philosopher.

Because of the stringent way in which scientific knowledge is required to pass experimental tests, it is the best kind of knowledge that we have. As far as providing knowledge of the deep structure of the world is concerned, science has progressed in a dramatic way and proved itself capable of answering questions that were once supposed to be the province of philosophy. This does not render philosophy redundant. Many areas of philosophy, such as moral philosophy or philosophical logic, do not contest ground claimed by science in a way that some traditional metaphysics does. The best contemporary metaphysics takes the findings of science for granted and attempts to go beyond it, in an attempt, for example, to defend physicalism or a philosophy of perception. I presume that in this book I have been engaged in philosophy (as well as some history) but I have not been practising science. One of these days someone should write a book called *What is this thing called philosophy?*. But not me.

Notes

1. See Chang (2004) for a fascinating and instructive account of the experimental route to a workable notion of temperature.
2. See, for instance, Gardner (1979) and Nyhof (1988).
3. For a construal of Mach's opposition to atomism that differs from an extreme positivist one see Laudan (1976) and for a sympathetic account of Duhem's anti-realism see Worrall (1982).