Backstory to Atomism

Newton's ideas concerning the reciprocal actions of the particles of material bodies had inspired many physicists and chemists interested in the structure of matter. In particular, John Dalton was influenced by Newton's treatment of the interparticle relations rather than the particles themselves [343, p. 323]. Newton's theory of matter, called the *nutshell theory* by Joseph Priestley (1733-1804), consisted of hierarchically arranged particles and voids, the smallest of which were called *ultimate particles*. Newton's scheme only had a minor influence on science during the 18th century, but Dalton's borrowing of the interparticle relationships in Newton's scheme led to the first modern atomic theory. Newton's view of matter was influenced by Robert Boyle (1626-1691), incorporating both the indivisible particles of the ancient Greeks and Aristotle's *minima naturalia* which embody properties of the bulk. Dalton likewise would establish a link between the microscopic and macroscopic regimes [344]. Newton had a justification for *Boyle's Law* based on a repulsion of particles that would decrease as the square of the distance between them. Newton regarded his theory as a working hypothesis, but Dalton instead took Newton's corpuscular views of matter straightforwardly and, by never wavering, achieved remarkable success in a short time. If atoms in proximity repel each other, then Dalton took chemical combinations as having as few atoms as possible. Dalton had concluded that "the ultimate particles of all homogeneous bodies are perfectly alike in weight, figure, etc.," which recalls Newton's description that Dalton had transcribed into his notebook [344]:

> *See the print edition of The Quantum Measurement Problem for quotation.*

During the 18th century, Newton's view of matter had been forced to compete with the theory of Georg Ernst Stahl (1660-1734) in which matter comprises identical particles which are formed by atoms of one and the same basic material and from which molecules are formed. The Newtonian-Stahl ideas were revived during the last decades of the 18th century by the chemical revolution brought about by Lavoisier, giving birth to the molecular theory of Dalton, which was a crucial event in the genesis of modern atomism [343, p. 328]. Dalton's atomic theory first appeared in an 1807 book by Dalton's advocate Thomas Thomson and then in Dalton's *A New System of Chemical Philosophy* in 1808. As early as 1803, Dalton began deducing relative atomic weights. For example, he knew that water was comprised by weight of 87.5 percent oxygen and 12.5 percent hydrogen. Then if he *assumed* that water was a binary compound HO so that one atom of water and one atom of oxygen goes into each water molecule, then he could deduce that every oxygen atom weighs seven times as much as every hydrogen atom; e.g., O=7, if H=1. Or if water instead was H_2O, he could deduce that O=14. H=1 [345]. Dalton's chemical atomic theory gave a basis for giving relative *atomic weights* to chemical elements, where chemically indivisible units combined with each other in integer multiples consistent with the laws of stoichiometry. Dalton could deduce each of his atomic weights using more than one separate line of deduction, assuming a formula for the compound in each approach. Consistency among the results would give confidence in the chemical formulas. Although Dalton regarded these units as the actual constituents of matter, most chemists regarded them as a convenient scheme for developing their work. Dmitri Mendeleev (1834-1907), who developed the Periodic Table for predicting the existence and properties of new chemical elements, considered Dalton's atoms as being [344]

See the print edition of The Quantum Measurement Problem for quotation.

The influence of Dalton's work can be traced from 1803 to the present, and it enabled chemistry to have the status of the earliest robust area of science that had an impact on both fundamental issues and technology. Dalton's physician, Joseph Ransome, recalled a walk with Dalton (ca. 1820) in which Dalton explained that it had occurred to him that if Newton's ultimate particles were indestructible, then there must be many varieties varying in size and weight to account for so many known chemical elements and compounds. Then he emphasized, illustrating this with a piece of limestone picked up from the path, that since compounds are formed by one-to-one association with their elements, then the principle of multiple proportions must exist [345]:

> *Thou knows it must be so, for* ***no man can split an atom****.*
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Deductive thought experiments can have very long-lasting influence.

In the period of approximately 1860-95, comparison of Dalton's atomic hypothesis with spectroscopy experiments was hampered by the complexity of the internal structures revealed by experimental observations [346]. However, the kinetic theory of heat of Maxwell and Boltzmann, which was on an underlying molecular picture, began to allow more precise predictions, for example allowing specific calculated values for the mean free paths and relative diameters of various gas molecules as well as Avogadro's number. Gas laws began to be applied to liquids based on van der Waal's law of corresponding states [346]. Evidence for atoms and molecules continued to accumulate from the advances of both experimental and theoretical developments including cathode rays, radioactivity, the photoelectric effect, electron-photon scattering, leading up to the discovery of quantum mechanics.

However, atomism was still under debate in the late 19th century, when Maxwell would describe the state of atomism in an 1873 lecture [347]:

> *An atom is a body that cannot be cut in two. A molecule is the smallest portion of a particular substance…Do atoms exist or is matter infinitely divisible? The discussion of questions of this kind had been going on ever since man began to reason, and to each of us, as soon as we obtain the use of our faculties, the same old questions*

> *arise as fresh as ever. They form as essential a part of the science of the nineteenth century of our own era as that of the fifth century before it.*
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> .

In the 19th century, there were conflicting approaches for what is acceptable as a description of nature. Some insisted on eliminating hypothetical elements and only including directly measurable quantities. These included Ernst Mach (1838-1916), Wilhelm Ostwald (1853-1932), Pierre Duhem (1861-1916), and Gustav Kirchhoff (1824-87). Henri Poincaré's view was that the atomic hypothesis was not capable of being either proved or disproved. Alternatives to the discrete atomic approach were continuous formulations of matter such as hydrodynamics, the use of *equivalents* and volume elements, and the use of thermodynamic approaches based on energetics [346]. Others, such as Ludwig Boltzmann (1844-1906) and Heinrich Hertz (1857-94) were able to make progress by using the atomic hypothesis. The effort to discredit atomism was led by Ostwald and Mach. Ostwald had won the 1909 Nobel Prize for his research on catalysis and insisted that it cannot be explained in terms of atomic theory but instead results from transformations of energy. Ostwald's approach, which he first summarized in his 1887 lecture in Leipzig, became known as *energism* and held that energy and not matter was the basis of all natural processes. He was led to this view by studying Gibbs' (1839-1903) approach to statistical mechanics which he concluded did not require any concepts beyond changes in "volume elements" without assuming the existence of atoms [348]. Concepts such as atoms, molecules and ions were convenient fictions without basis. In Ostwald's 1895 lecture in Lübeck, "The Superseding of Scientific Materialism," he had summarized [349]:

> *…everything we know of the world is transmitted to us through our sense organs. In order that a sense organ should function, a transmission of energy between it and the external world is necessary and sufficient. Thus, the only direct knowledge we have of the external world is of its energy conditions. Everything beyond that is subjective addition.*
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Mach also dismissed atomism but criticized energism as being an abstract theory. His objections were partly philosophic ones and also being a physiologist, he emphasized the preeminence of sense data, Figure 5.4. He regarded the concept of *atom* as only a symbol for how sensations are manifested [348]:

> *See the print edition of The Quantum Measurement Problem for quotation.*

Mach admitted that the atomic hypothesis had served a useful purpose historically in the development of physics, but he insisted that this framework now needed to be dismantled. As Phillip Frank (1884-1966) recalled from his student days in Vienna with Mach in 1907 [346]:

See the print edition of The Quantum Measurement Problem for quotation.

In spite of their differences, Mach and Ostwald led a united front against atomism. At the 1897 meeting of the Academy of Sciences in Vienna, Boltzmann defended his kinetic theory of gases based in terms of atoms, when Mach abruptly stated during the discussion, “I don’t believe atoms exist.” Boltzmann later recalled that “The utterance ran in my mind” [348]. Regarding these statements by Ostwald and Mach, it should be kept in mind that in the 1890s, theoretical physics was still not a fully formed discipline [350]. Whereas what was in the process of becoming *theoretical physics* had previously been synonymous with *natural philosophy* and focused on seeking out the underlying causes of phenomena, it was now also becoming *mathematical physics*. Scientists such as Boltzmann and Planck would now separate theoretical physics from the philosophy and anthropomorphism of Mach [351]. As discussed in the section *The Fall of Classicality*, Planck had earlier been aligned with Mach against atomism. However, in his work leading to the discovery of the quantum, Planck had been drawn to accept Boltzmann’s statistical approach to the Second Law, coming to believe that atoms were as real as planets [352, p. 49].