Atomism versus Continuum

Newton had memorably produced a light spectrum (ca. 1670) by directing sunlight through a prism, producing "a confused aggregate of rays induced with all sorts of colors" instead of discrete lines. Twenty-five years after Newton's death, Scottish natural philosopher Thomas Melvill (1726-1753) reported observations of discrete spectra resulting from heated sodium within the salt molecules held in a flame. Joseph von Frauenhofer (1787-1826) observed discrete dark lines in the solar spectrum, later explained by the presence of sodium in the outer layers of the sun. These were the beginnings of experimental optical spectroscopy. As discussed in the section *The Fall of Classicality*, the radiating power of a substance seen in its emission spectrum could be shown to equal its absorbing power as seen in its dark line absorption spectrum, as first quantified by Kirchhoff in 1859. He was able to derive from these results *Kirchhoff's Law*, the crucial property of blackbody radiation that eventually led Planck to discover the quantum of action in 1900. Pais points out that, by the time Bohr entered the picture, Kayser's handbook of spectroscopy already contained 5000 pages, a tremendous backlog of spectral information, which lacked fundamental interpretation [9, p. 141]. Bohr's remarkable success in developing his quantized atomic theory in 1913 began with the case of the hydrogen atom. The hydrogen spectrum was first detected by Anders Ångström (1814-1874) in 1853 and within a few years the frequencies of four of the lines of the hydrogen spectrum were identified and measured.

The view had been generally widespread in the 19th century that continuity was a dominant aspect of the description of the natural world, tracing back at least to Aristotle's definition [353]:

> *The continuous is a species of the contiguous; two things are called continuous when the limits of each, with which they touch and are kept together, become one and the same.* [Metaphysics XI.12]

However, Aristotle also anticipated discontinuities in nature:

> *Nor, again, can there be anything between that which suffers and that which causes increase; for that which starts the increase does so by becoming attached in such a way that the whole becomes one. Again, the decrease of that which suffers decrease is caused by a part of the thing becoming detached. So both that which causes increase and that which causes decrease must be continuous; and if two things are continuous there can be nothing between them.* [Physics VII.2]
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> *It is evident, therefore that between the moved and the mover – the first and the last – in reference to the moved there is nothing intermediate*. [Physics VII.2]

> *Nor again is there anything intermediate between that which undergoes and that which causes alteration.* [Physics VII.2]
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> *And this is evident from what happens in respect of sensation; for the same thing never appears sweet to some and bitter to others…* [Metaphysics XI.6]

Continuity here is being used as adjacent in time. It appears that what is being described are actually discontinuous processes since they are extremities and are adjacent. It may be that had Aristotle been alive when quantum mechanics was founded, he might have associated Planck's quantum of action with these discontinuities and concluded that because particles are quantized and divisible, that this would require their entire absorption into the measuring device upon measurement in order to meet the requirement of "becoming attached in such a way that the whole becomes one." This would be akin to accepting wave function collapse.

Some two millennia following the beginnings of atomism with the Greeks, the mid-18th and early 19th centuries saw the first stirrings of quantitative formulations of atoms, Figure 5.6, with Daniel Bernoulli (1700-1782) and James Joule (1818-1889) followed by the full development of the kinetic theory of gases by Rudolph Clausius (1822-1888), James Clerk Maxwell (1831-1879), and Ludwig Boltzmann (1844-1906). At the turn of the 19th century, Antoine Lavoisier (1743-1794) initiated the notion of chemical elements and determined that chemical compounds occur in proportion to their weights. On the basis of an atomic picture, John Dalton (1766-1844) explained that elements are identical and that materials can be viewed as built up from atoms. Guy-Lussac (1778-1850) went further and formulated the law of volumes for reacting gases, which provided the context in which Avogadro (1776-1856) was able to state that all gases contain an equal number of particles at equal volume, temperature and pressure, *Avogadro's Number* $N_A = 6.022 \times 10^{23}$. The 1840's saw the crucial formulation of the law of conservation of energy by Joule, Hermann von Helmholtz (1821-1894) and Robert Mayer (1814-1878). Clausius demonstrated the equivalence of heat and mechanical work, namely the First Law of thermodynamics, which more generally is the principle of conservation of energy. However, he found that thermodynamics required an additional concept: heat cannot of its own accord pass from a colder body to a warmer one, the Second Law of Thermodynamics. An equivalent statement of the Second Law is the impossibility of constructing a perpetual motion machine of the second kind: an apparatus that without violating the conservation of energy nevertheless transforms heat into mechanical work with 100% efficiency. For a system composed of atoms, Maxwell's thought experiment involving a demon, “a very observant and neat-fingered being,” showed how the Second Law might be violated and later led to insights into the role of information in physical systems. Statistical mechanics began with the work of Maxwell and Boltzmann and gave a statistical interpretation of transport and thermal equilibrium involving the vital relationship between entropy and the probability of the state of a gas. It was developed by J. Willard Gibbs (1839-1903) into a form general enough to address all classical systems. All of these developments were essential precursors to Planck’s discovery of the quantum of action in 1900. The theories which dominated quantitative physics were all based on the continuum world picture: Newton’s equations of classical mechanics, Maxwell’s equations of electromagnetism, and Einstein’s special relativity. The dramatic transition to the discontinuities of quantum theory began in physics and eventually spread to chemistry and biology.

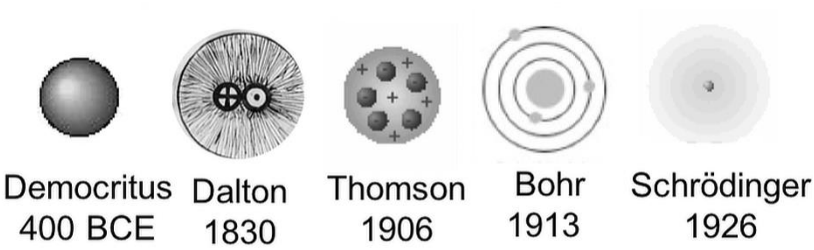

Figure 5.6: Evolution of the conception of the atom.