The Impact of Atomic Theory on Philosophy

By Mike McPhee

This may turn out to be a misleading title in that, over much of recorded history, atomic theory has been inspired by philosophy rather than the other way around. Certainly, in ancient times and even up to the Middle Ages, all scientists were philosophers – which is hardly surprising, since questions about the nature of matter relate directly to the nature of the Universe and the very nature of existence.

The concept of atoms as fundamental particles of matter was originally proposed in opposition to the dominant (and perfectly natural) conception of ‘continuous’ matter that could, in principle, be subdivided indefinitely. Under either conception, there was the related question of elements – a finite number of pure substances, which all others were some combination of. There were, and still are, some quite remarkable applications of what is called ‘atomism’ which we will see as we proceed.

Contrary to what we (myself included) were taught, the first atomic theory was developed in India in the 6th Century BCE. While scholars are divided as to whether these ideas became known in Greece, it is interesting to note that one Indian school of thought held that there were as many different kinds of atoms as there were elements; while another anticipated Democritus in saying that all atoms were of the same kind and produced different effects through diverse modes of combination. Later developments included the identification of four elements with specific properties and the futuristic idea that atoms with opposite properties combined under mutual attraction.

The Classical Greek atomism of Leucippus and his better-known student, Democritus, held that atoms were eternal and indestructible; further, that all physical properties and effects were due to different ‘packings’ of atoms. Plato elaborated on this by assigning different geometric shapes to atoms of the four elements: tetrahedral (fire), cubic (earth), octoehedral (air) and icosahedral (water). However, all these shapes could be broken up into triangles which could then be rearranged differently, thus providing a mechanism for observed physical and chemical changes.

These concepts were opposed by Aristotle, who argued that atoms didn’t make provision for changes in the ‘nature’ of substances, and atomism was all but lost in the West for 1500 years. However, Islamic scholars debated both positions from the 10th Century and their writings presumably reached Europe by the time its first universities were established. Prior to that, the field had been left to the much-maligned alchemists, who were really the first empirical chemists. While not initially concerned about whether matter consisted of atoms, these researchers were very interested in determining which substances were elemental and which were compounds. They studied all sorts of chemical reactions, both of synthesis (combination) and decomposition, noting which elements did or did not react with each other and how.

Though they largely had to do their work by trial-and-error, the alchemists developed many tools and techniques that are well-known to modern chemists; moreover, they contributed greatly to the medicinal and industrial processes that brought Europe out of the Dark Ages. Nor can their alleged quest to turn lead into gold be derided, given that they had seen reactions in which a piece of iron or lead placed in a solution of ‘blue vitriol’ developed a coating of copper – how were they to have known that the blue solution was really copper sulfate, rather than assume that the original metal had been turned into copper?
The Renaissance was marked by great advances in science and a critical attitude toward the once-canonised doctrines of Aristotle. The new atomists included Francis Bacon, Galileo Galilei, René Descartes, Isaac Newton and Robert Boyle – most of whom said little about atoms of matter but disputed long-held Aristotelian scientific principles.

Descartes resurrected Democritus’ arguments that particulate matter was all that physically exists and that ‘sensations’ such as taste and temperature were caused by those particles. Pierre Gassendi, a Catholic priest and natural philosopher, sought to mitigate the atheistic implications of this mechanistic philosophy.

By the mid-1700s, further progress had been made, particularly in the areas of instrumentation and measurement. In tandem with the philosophy of rationalism, the first modern atomic theory emerged when it became possible to measure such things as the composition by weight of hydrogen and oxygen in water. Antoine Lavoisier demonstrated that the total mass of substances was conserved in chemical reactions, even when one of more of the reagents or products was a gas. It was confirmed that all atoms of elements and all molecules of compounds were identical to one another, leading to the question of what the relative weights of those atoms were and whether they were all multiples of a fundamental unit.

In 1808, John Dalton summarised all that had been determined by earlier workers and himself: that atoms were indivisible and indestructible; that they combined in fixed ratios to produce ‘atoms’ of compounds; also that, in some cases, more than one compound of the same elements existed (eg, carbon monoxide and carbon dioxide). Dalton provided a list of elemental and compound masses, which he found to be multiples of one-half the mass of hydrogen. This was corrected by Amedeo Avogadro, who showed that hydrogen consisted of diatomic molecules, as did all the other known elemental gases. Thus, the base unit was indeed the mass of a hydrogen atom, though some elemental masses were not exact integral multiples of that – e.g., the relative mass of chlorine was 35.5 – and no attempts to measure them more accurately provided more satisfactory results.

In 1868, Dmitri Mendeleev was able to arrange the elements (66, by then) into a Periodic Table – in order row-by-row by their atomic weights and in columns of common physical and chemical similarities. These rows were called ‘periods’ because of the recurrent succession of properties, while the columns were called ‘groups’. This required Mendeleev to leave some blank spaces, which were later filled by new elements that were discovered once their likely properties could be predicted – indeed, a whole final column was added when the inert gases were extracted from liquid air. He also had to put certain pairs of elements in reverse order by atomic weight, so as to have them in the appropriate columns. While this was puzzling at the time, Mendeleev had stumbled on some fundamental atomic principles that would not be understood for another half-century.

Nor had the physicists been idle during this time, though they necessarily had different priorities. From the 17th Century, the aforementioned Robert Boyle and others had established mathematical relationships between the pressure, temperature and volume of gases, leading to the Kinetic Theory of Matter. Essentially, the heat and pressure of a gas were...
related to the kinetic energy of fast-moving particles, whose speeds varied with temperature and whose motion ceased entirely at Absolute Zero. Others had been working with electricity, providing chemists with the vital process of electrolysis, from which many compositions of compounds and elemental atomic weights were determined.

The physicists then turned to subjecting rarefied gases in vacuum tubes to high voltages, which caused them to emit light of specific wavelengths that were unique to each element. In the highest achievable vacuum, mysterious rays were seen coming from the negative terminal (i.e., the cathode), which were eventually identified as streams of negatively-charged particles. It was obvious that these were the constituents of electric current, so they were named ‘electrons’. The subsequent discovery of much more massive positive particles led to the conclusion that atoms of gas had been torn apart by the strong electric fields in the tubes – so atoms were not indivisible, after all.

In 1900, John Joseph Thomson – who had done much of the earlier research – proposed that atoms were spheres of a positive pith in which the electrons were embedded, which became known as the ‘plum pudding model’. Atoms of each element had a different number of electrons and a corresponding amount of pith, thereby explaining the different atomic weights. He would actually have preferred to have had large positively-charged particles with the electrons in orbit around them, but such positive particles would repel each other and classical theory predicted that orbiting electrons would quickly spiral into the centre. The more serious problem at the time was that the atomic weights were known to be 1 (hydrogen), 4 (helium), 7 (lithium), etc – yet it was clear from the coherence of the Periodic Table that there were no yet-to-be discovered elements between them.

It was left to Thomson’s student, Ernest Rutherford of New Zealand, to vindicate Thomson’s preferred atomic structure. The ‘plum pudding’ atoms were thought to be closely packed in solids, yet it had been shown that accelerated electrons passed through metal foils with minimal obstruction. In 1910, Rutherford devised an experiment in which such foils were bombarded by alpha particles – known by then to be helium atoms without electrons – and these, too, mostly passed through with varying degrees of deflection while some actually rebounded. Rutherford concluded that atoms were mostly empty space with their positive charges concentrated in a central nucleus and their electrons separated from them at considerable distances.

Subsequent work by Rutherford proved the existence of a fundamental positive particle, which he named the proton. How protons stayed together in an atomic nucleus was still unclear, but it was suggested that the ‘missing mass’ that was complicating the atomic weights consisted of neutral particles which somehow overcame the mutual repulsion of the protons. By then, it had been confirmed that atoms of the same element were not truly identical in that their masses differed slightly, though these were always integral multiples of the mass of hydrogen. These isotopes could be explained if the number of protons defined the element but the number of neutrons could vary. The neutron could not be detected directly, but its existence was finally proven by James Chadwick in 1932.

Similarly, the problem of how electrons could remain in stable orbits was only resolved theoretically when Niels Bohr proposed that only a finite number of orbital radii provided such stability. The radii and corresponding energy levels he proposed fitted well with the characteristic spectral wavelengths that had been observed earlier, which Bohr showed were photons of electromagnetic energy that were
released when an electron dropped from a higher to a lower orbit. Conversely, electrons could be raised from one orbit to another by absorbing a photon with exactly the right amount of energy.

Thus began the truly modern era of quantum atomic physics, which raised a serious philosophical problem for determinists, such as Einstein. The stable orbital radii and their energy levels were related by the squares of integral numbers, and other quantised parameters were related by simple integers. But how could numbers, which have no physical existence, constitute a causative physical agency? – this was an entirely new phenomenon, for all its compelling logic. Ironically, it had been Einstein who earlier proved the existence of photons – literally, particles of light – which constituted yet another blow to the classical physics of the 19th Century.

In 1924, Louis de Broglie reversed Einstein's equations for photons to formulate wavelike properties for particles. This proposal would have been rejected but for his proof that the circumferences of atomic orbitals corresponded to multiples of the wavelengths that electrons moving at the known orbital speeds would have. The Davisson-Germer experiment of 1928 accidentally produced diffraction and interference of electrons, something that can only happen to wavelike entities. Quantum theory began to regard matter and electro-magnetic energy as having both particulate and wavelike properties, difficult as that was to conceive.

This presented a challenge to philosophers, as it seemed as though abstract mathematics yielded deeper understandings of reality than human intelligence could formulate in concrete terms. That problem was exacerbated when Erwin Schrödinger proposed a wave equation that depicted electrons as merely a ‘cloud’ of locations of varying probability. This was too much for Einstein, who denounced the notion that ‘god plays dice with the Universe’. Nevertheless, this approach yielded results and, with further advances over the decades, remains to this day the ultimate means of understanding subatomic phenomena. Whether the Uncertainty Principle contributed to post-modernist philosophy, I would not be rash enough to guess.

I’d just like to close by commenting that, as with previous presentations, my research has led me to discover new aspects of a subject that I thought I already knew well. In this case, I found that atomists of all ages were regarded as atheists and heretics by the dominant thinkers of their times. This was particularly true for the Classical Greek and Islamic atomists, who went against the idealist philosophies of their times, but we have also seen the rejection of mechanism during the Renaissance. Even in modern times, various aspects of quantum theory have caused some upset even though the existence of atoms was universally accepted. As Unitarians, we should honour these people for their ceaseless quest for truth and understanding, even at the cost of ‘proving what we cannot believe’.

Schrödinger and his wave equation

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