IN RETROSPECT

A New System of Chemical Philosophy

Philip Ball reflects on the work of John Dalton, father of modern atomic theory.

Visual metaphors are often essential in science when you can't see what you're studying. The English chemist John Dalton, born 250 years ago, illustrated his atomic theory using wooden spheres (pictured), drilled with holes for pins that enabled them to be linked into clusters. But there are hazards to such mental props. By the 1880s, students were so familiar with the spheres that one (taught by prominent advocate of atomic theory Henry Enfield Roscoe) declared: "Atoms are round bits of wood invented by Mr Dalton."

Today, the atoms Dalton proposed in his seminal *New System of Chemical Philosophy* (1808) are routinely revealed by microscopy and crystallography. They are corralled in electromagnetic traps, pushed around like marbles using scanning probe microscopes, even manufactured and monitored one at a time in superheavy forms using particle accelerators. No one mistakes them for bits of wood.

Neither did Dalton. He articulated the ancient idea that matter is built from fundamental particles in a way that aligned it with the quantitative principles of chemical reaction elucidated in the late eighteenth century. Those macroscopic rules, he said, stemmed from the systematic combination of microscopic bodies: solid, massy and hard, as Isaac Newton had put it in a phrase Dalton was fond of quoting.

Yet in a sense, even by the 1880s, atoms were still not much more than Dalton's model spheres. Because they remained unobserved, several leading scientists refused to accept their reality, among them physicist Ernst Mach and chemist Wilhelm Ostwald. Some considered atoms no more than an heuristic convenience: a crutch that the mind could use to make sense of chemical transformations. That is why, despite Roscoe's misgivings that Dalton's wooden balls might mislead students, the balls had a valuable role. They showed how visualizing an entity can help to cement the concept even while direct

John Dalton, painted in 1835 by Thomas Philips.

evidence is elusive. It is a risky strategy to assert the physical reality of something not yet observed (will dark matter really be particulate?). But without such an image, a theory can seem little more than metaphysics.

It is traditional to locate Dalton's *New System of Chemical Philosophy* as a step — perhaps the greatest — in a long road to modern atomic theory that began with the ancient Greek atomists Leucippus and Democritus in the fifth century BC, and ended with the nuclear atoms proposed by Ernest Rutherford and Niels Bohr in the early twentieth century, then quantum theory and scanning probe microscopes. The "philosophy" in Dalton's title signified something closer to a scientific theory than to the abstract reasoning

it tends to connote today. Yet his book also represents an important juncture for the philosophy of science. It spoke to whether science should be based on empiricism or explanatory hypothesis — a question that had exercised Newton and Robert Boyle in the seventeenth century. There was nothing new in Dalton's idea of atomistic matter; the question was whether to treat this as a useful conjecture or as a reality. Antoine Lavoisier, whose work on the proportions of chemical combination was crucial to Dalton, had no time for such questions. Lavoisier insisted that meditating on "ultimate particles" was metaphysical — and fruitless.

So how did Dalton, a modest teacher educated in Cumbrian village schools and excluded from Oxford and Cambridge for his Quakerism, take an imaginative leap that eluded distinguished professors? Even if we admit some of the fairy dust of "genius" into an explanation, we shouldn't discount Dalton's wide reading — from Boyle and Newton to Claude Louis Berthollet and Humphry Davy. He

also paid careful attention to the quantitative details of experiments by the likes of his friend, Mancunian chemist William Henry, and Lavoisier. Dalton presented his atomistic theory to the Manchester Literary and Philosophical Society, of which he was secretary, between 1803 and 1805. Some of his papers were published in the society's memoirs, but he was urged to present them as a book, as he put it, in "the interests of science, and his own reputation."

The *New System* is one of those foundational books that doesn't say what you might think it should. It is mostly not about atoms at all. The first 140 pages or so of Volume 1 dwell on heat and its effects,

The spheres that Dalton used to demonstrate atomic theory.

IAN DIGNALL/ALAMY

MANCHESTER MUSEUM OF SCIENCE & INDUSTRY/SSPL

A New System of Chemical Philosophy

JOHN DALTON

R. Bickerstaff: 1808.

whereas Volume 2 is a detailed account of inorganic chemical compounds. Dalton's atomic theory is confined to the five-page final chapter of the first volume. Here, he explains that the fixed stoichiometries of chemical reactions — so much of element A combines with so much of B — can be rationalized by supposing that the constituent atoms unite into “compound atoms” of simple ratios, such as 1:1 or 1:2. The point is most famously and eloquently made in a plate that shows sketches of these unions. An “atom” of water comprises one atom each of hydrogen and oxygen; an atom of ammonia is a 1:1 union of hydrogen and nitrogen (Dalton uses Lavoisier's term, “azote”, for nitrogen).

The proportions are wrong — chemist Jöns Jakob Berzelius corrected many in the following two decades. And in 1813, he proposed an alphabetical representation (for example, H^2O [sic]) in place of Dalton's pictorial balls. Dalton, with the conservatism common to trailblazers, declared this “horrificing”, saying that the symbols “cloud the beauty and simplicity of the atomic theory”. His displeasure might have contributed to a stroke in 1837.

The *New System* is not a new theory of chemistry. Among other things, it offers no explanation for why atoms react. Roscoe put his finger on it when he said that the significance of Dalton's theory was his proposal that each type of atom has a unique mass. That made sense of the quantities in which elements were found to combine, and offered the first general and fundamental distinction between one element and the next — what eventually became embodied in the idea of atomic number.

Yet it is the idea of atoms as the indivisible units of matter that stuck in the mind, because readers could see them on the page. Dalton didn't intend his pedagogical diagrams of atomic unions — “compound atoms”, or molecules as we'd now say — to be taken too literally. There's no inkling in his book of molecular shape; the arrangements of atoms in binary, ternary and other unions are purely notional, and when Dalton draws “water particles” packed into the crystalline forms of ice, they too are spheres.

All the same, visual representation of atoms was surely the precondition for the emergence of a concept of molecular structure, with atoms in fixed spatial relationships, in the mid-nineteenth century. Something of this kind would surely have appeared whether or not Dalton had “invented” atoms as wooden balls — but that innovation was more eloquent than its inventor anticipated. ■

Philip Ball is a writer based in London. His latest book is *The Water Kingdom*. e-mail: p.ball@btinternet.com

Books in brief

Reductionism in Art and Brain Science: Bridging the Two Cultures

Eric R. Kandel COLUMBIA UNIVERSITY PRESS (2016)

The sea-slug studies of Nobel-prizewinning neuroscientist Eric Kandel — which reveal the link between memory and synaptic connection — are models of reductionist science. In this intriguing treatise, Kandel finds methodological similarities in abstract art. By reducing image to colour, form or line, artists such as Piet Mondrian stimulated the brain's “top-down processing” in the viewer, encouraging ‘active seeing’. Kandel deconstructs this intricate dance between perceiver and perceived by way of recent neuroscience findings and deft analyses of seminal artworks.

Weapons of Math Destruction

Cathy O'Neil CROWN (2016)

While working as a Wall Street analyst during the 2008 crash, data scientist Cathy O'Neil realized how maths can fuel social problems. Her propulsive study reveals many models that are currently “micromanaging” the US economy as opaque and riddled with bias. These algorithmic overlords can taint policing and court sentences with racial profiling, and exacerbate unemployment rates in poor communities. In an era when many people uncritically applaud the power of big data, O'Neil argues for the dark side of the deluge to be tackled through algorithm audits, transparency and legal reform.

Citizen Scientist: Searching for Heroes and Hope in an Age of Extinction

Mary Ellen Hannibal THE EXPERIMENT (2016)

In this inside story on citizen science and biodiversity loss, Mary Ellen Hannibal meshes interviews with front-line scientists such as James Estes (*Nature* **533**, 318–319; 2016) with her own stints monitoring California wildlife. Inspired by the likes of marine biologist Ed Ricketts (*Nature* **516**, 326–328; 2014), she records starfish die-offs, meets the geeks who track deforestation, and plans a web-based supercommunity of citizen scientists to counter what many are calling the sixth great extinction. A cogent call to action.

A Brief History of Everyone Who Ever Lived: The Stories in Our Genes

Adam Rutherford WEIDENFELD & NICOLSON (2016)

Fifteen years ago, the first sequence and analysis of the human genome was published (E. S. Lander *et al.* *Nature* **409**, 860–921; 2001). A monumental surge in genetics followed. Science writer and broadcaster Adam Rutherford rides that tide and traces its effects, first focusing on how genetics has enriched and in some cases upset our understanding of human evolution, then examining the revelations of recent findings, such as deep flaws in the concept of race. Although digressive in the chapters on deep history, Rutherford unpeels the science with elegance.

Trillion Dollar Baby

Paul Cleary BITEBACK (2016)

Norway's government pension fund could hit US\$1 trillion in just four years. In this crisp economic history stretching back more than four decades, journalist Paul Cleary charts how this middle-income Scandinavian country ensured that 90% of the cash flow from vast oil discoveries accrued to its government. But despite its record of pragmatic fair-mindedness, Norway's eagerness to excavate environmentally sensitive reaches of the Arctic shows how its forward planning fails when it comes to climate change. **Barbara Kiser**