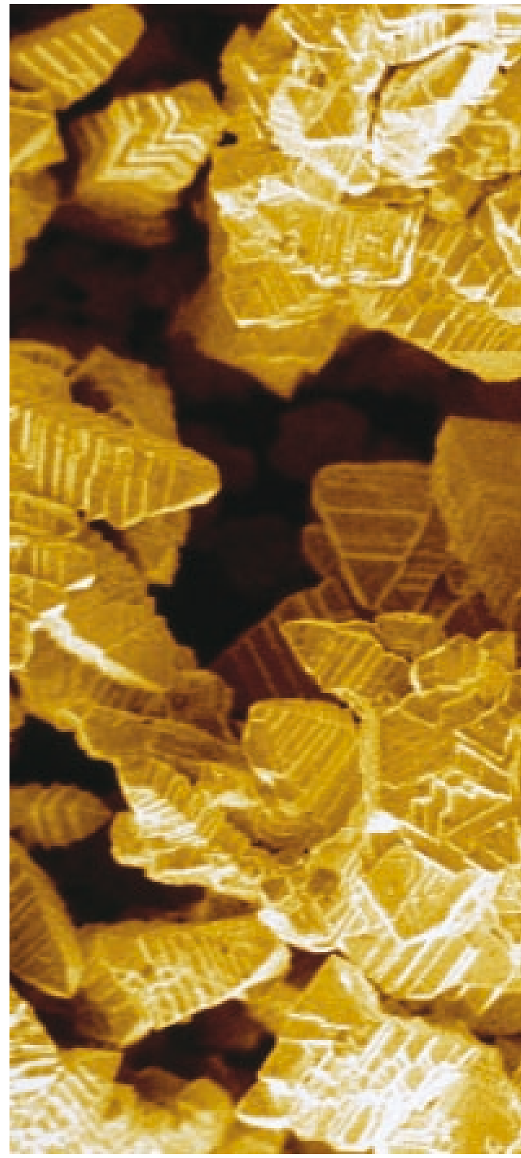
Is it time to get real?

Some say that science describes the world so well that we should accept that entities such as atomic particles really do exist. Others say that so many theories and entities have come and gone, why should we regard any of them as real? Don't panic, says **Eric Scerri,** there may be a better way to look at things



ARE you ever tempted to ask whether entities such as electrons, black holes or the Higgs particle really exist? As a chemist, I worry about what is real and dependable in my field. Is it the "entities" or the "theories" of chemistry and quantum mechanics that largely explain the periodic table? I also care because all of this goes to the heart of an old, important – and unresolved – debate about how to regard scientific discoveries.

There are two main camps in this debate: scientific realism and anti-realism. Scientific realism holds that if science has made great progress by invoking entities such as electrons, then we should take the next step of accepting that they really do exist, that the world described by science is the "real" world. Our present theories are too successful to have happened by chance: somehow we have latched onto the blueprint of the universe.

This is not to everybody's taste. Anti-realists accept the progress made by science but stop short of taking the additional leap of faith of believing in the materiality of things they cannot actually see. The anti-realist typically presents a counter-argument along these lines: so many past theories and theorised entities have come and gone (remember ether or phlogiston?), why should we ever regard any of them as "real"? It is difficult to say how many scientists belong to each camp – moreover, you may be a realist about some theories but an anti-realist about more abstract theories such as quantum mechanics.

Anti-realists also argue that their approach places them in a better position to adapt to change when a particular entity or theory becomes redundant. Not investing belief in a particular theory, they claim, allows them to move on to alternatives more easily.

Realists retort such an approach is cavalier, or even dangerous. Science progresses by creeping up on the truth about the world: if successive theories were to merely replace one another, that progress would be truly miraculous. The worry is that anti-realism could lead to a view that all theories are relative, and thus could threaten the very notion of scientific progress.. You might think this is just an argument for philosophers of science, but it is crucially important to how scientists present themselves and to how everybody else views the status of science.

Surely there is a way out of this impasse? In 1989, John Worrall, a philosopher of science at the London School of Economics, published the paper "Structural Realism: The Best of Both Worlds?" in the journal *Dialectica.* In it, he outlined structural realism, an approach he traced back to French mathematician Henri Poincaré, among others. For Worrall, what survives when scientific theories change is not so much the content (entities) as the underlying mathematical structure (form).

Worrall used examples from 19th-century optical theories to support this view. For example, in 1812 the French engineer Augustin-Jean Fresnel developed a theory about the nature of light, from which successful predictions were made. Fresnel believed that light waves were a disturbance in an all-pervading mechanical medium. But this theory was overtaken by James Clerk Maxwell's theory of electromagnetic radiation, in which light was seen as a disturbance in an electromagnetic field.

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Despite the defeat, Worrall and others argue Fresnel had the correct structure of light, if not the correct entity since some of his equations were successfully carried over into Maxwell's theory, and the behaviour of light in Maxwell's theory obeys similar laws to Fresnel's theory.

Worrall is backed by James Ladyman, a philosopher at the University of Bristol, and philosophers of physics such as Steven French

PROFILE
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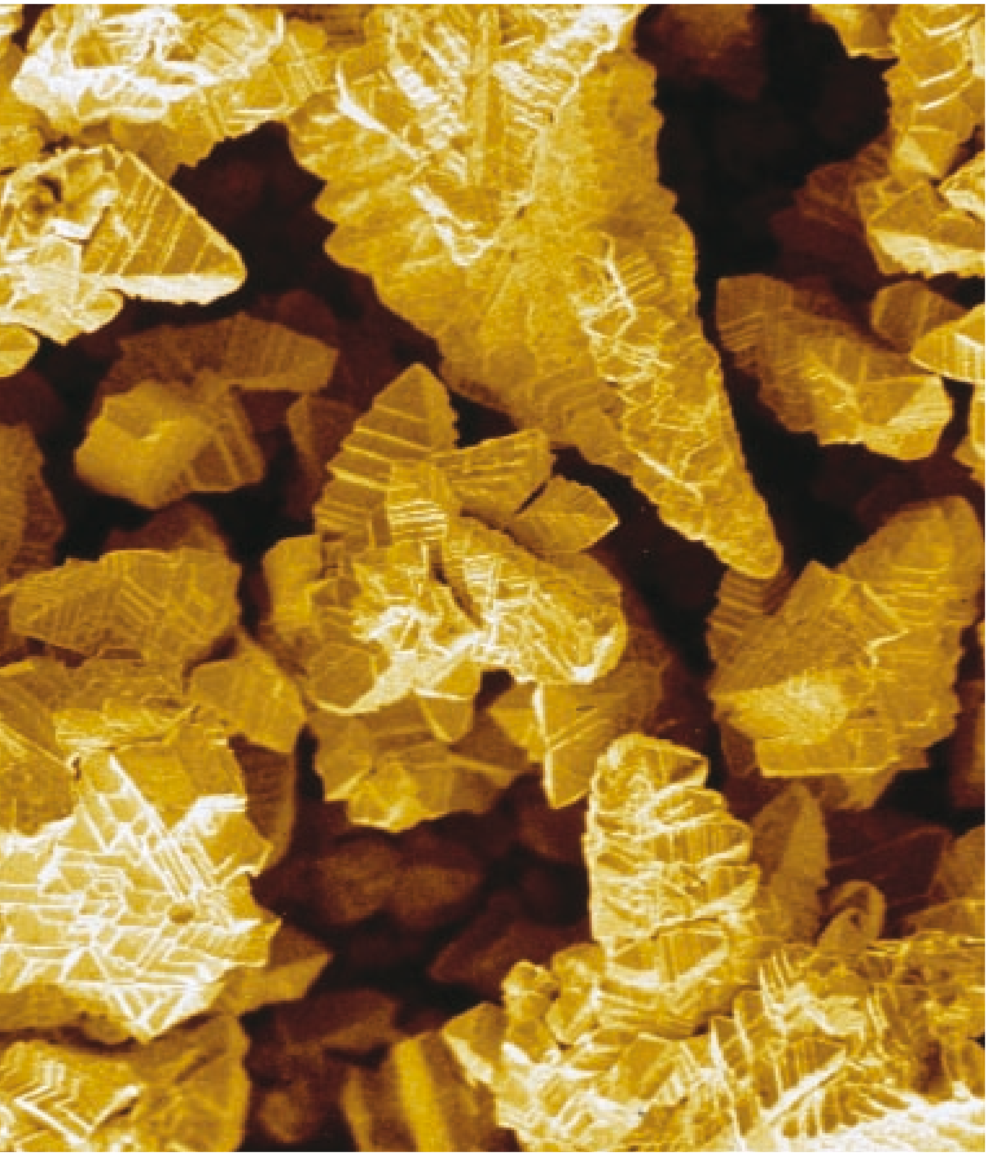

JIM ZUCKERMAN/ALAMY

The Midas touch: relativity theory has been used to explain gold's unique yellow colour

at the University of Leeds and Simon Saunders at the University of Oxford. Between them, they have extended the reach of structural realism to include the transition from classical mechanics to relativity, and from classical to quantum mechanics. The idea that particles are not the ultimate entities is not altogether new, but some critics have suggested that theorising about the quantum strings of string theory merely replaces one entity with another. Structural realism goes further by removing attention from any form of entity.

And in 2007, Ladyman and others published a provocative book entitled *Every Thing Must Go*. In it, they argued for abandoning a scientific ontology based on "things" such as particles, and for concentrating only on the fundamental mathematical structure.

It's fair to say that for structural realism to offer a serious way forward, it has to work for other areas of science, too. So I have been busy applying it to the periodic table. The table of the elements is a classification system for the behaviour of all chemical elements, and, in some cases, their compounds. Arranged according to increasing atomic number (the number of protons), the properties of the elements show approximate repetitions after regular but varying intervals (2, 8, 8, 18, 32, 32, and so on).

In 1869, when Dmitri Mendeleev published his periodic table, nobody knew about the substructure of the atom or that it contains protons, electrons and neutrons. This knowledge, which helps explain why the periodic table works as it does, came from quantum theory developed in the 1920s by Niels Bohr, Wolfgang Pauli, Werner Heisenberg and Erwin Schrödinger.

Broadly speaking, electrons occur in quantum shells. The number of outer-shell electrons governs the chemistry of an element and determines which column of the periodic table it falls into. Initially, Albert Einstein's theory of special relativity had little impact on chemistry, but now it is almost indispensable to chemists, especially in theoretical calculations on all manner of properties of atoms and molecules. For example, relativity theory has been used to explain why gold has its unique yellow colour, unlike all the other surrounding elements. And, by applying relativity as well as quantum mechanics to chemistry, new compounds have been predicted – including the novel fullerene molecule WAu_{12}, which contains tungsten.

What has survived and very probably will survive is the relationship between the elements that is embodied in the periodic table. This is literally the structure, or organising principle, of chemistry, rather than its content. But is the structure a mathematical one? This is by no means clear, and academics are trying to find out by studying the mathematics of the periodic table using group theory. My guess is that it will turn out to be so – watch this space.

Moving to modern biology, does structural realism have a role? In some ways, it has had a similar trajectory to chemistry. When Charles Darwin published his theory of evolution by natural selection in 1859, the theory lacked a physical mechanism on which selection acted. This was eventually provided by the discovery of DNA, which has played a similar role in biology to that of the electron in chemistry.

But DNA only takes things so far: to go deeper we need to take a mathematical direction. DNA determines the genetic code according to the sequence of bases A, T, G and C. This becomes a question of mathematical combinations, and the kinds of computation issues played out during the human genome project of the 1990s, and now in genomics.

Worrall's structural realism is on the right track – not just with physics, but chemistry and biology too. If I am right, he and his colleagues deserve real credit for offering a way out of this longstanding, bitterly fought over, utterly fundamental question. n