More than the sum of their parts

Books written by scientists tend to be either convenient collections of already published work, or speculative excursions that allow the author to step back from detailed research to consider more 'philosophical' questions. Steven Weinberg's *Dreams of a Final Theory* made the case for the near completeness of our physical theories, but Roger Penrose, in a number of books, has argued essentially the reverse — that fundamentally new physics will be required to make any lasting marriage between general relativity and quantum theory.

Robert Laughlin's *A Different Universe*, however, goes off in another direction entirely, presenting an impassioned argument for a radical revision of what we mean by 'fundamental'. Most of us, I suspect, intuitively embrace the idea that the Universe has fundamental entities such as electrons and quarks, and that these go together in various ways to produce more-complicated and less-fundamental objects, from protons to superconductors to stars. The laws at higher levels rest on those below, and down lowest are the fundamental laws of physics. But this is the idea that Laughlin rejects, arguing that electrons, for example, are really no more fundamental than liquids or thunderstorms.

The notion seems almost crazy, but maybe it isn't. Any measurement of an electron's mass or charge ultimately depends on its immersion in a sea of vacuum fluctuations. So the observed character of the electron reflects not the simplicity of some isolated object, but a collective phenomenon deeply tied up with the nature of the Universe. Perhaps not coincidentally, Laughlin points out, the most accurate measurements of the electronic charge do not come from single-particle experiments, but through measurements of the Josephson and quantum Hall effects in condensed matter.

Laughlin is arguing for a shift in our application of 'fundamental' from parts to processes, especially to the process of 'emergence', and this naturally raises another kind of question. The notion that collectives are often more than the sum of their parts gets a lot of attention these days, but usually in a descriptive sense. Can we explain why this is true?

Why, for example, are chemistry and biology more than just applied particle physics? Obviously, molecules and cells and tissues have a coherence and persistence that brings their natural description to a level far above that of electrons and quarks. But it remains mysterious why such coherence and persistence emerges so readily in our world. Some, such as the philosopher Jerrold Fodor, think it will always be a mystery: "Why is there anything except physics? … I don't even know about how to think about why. I expect to find out why there is anything except physics the day before I figure out why there is anything at all."

WHY, FOR EXAMPLE, ARE CHEMISTRY AND BIOLOGY MORE THAN JUST APPLIED PARTICLE PHYSICS?

But this may be somewhat despairing. For example, many cellular automata once thought to be computationally irreducible — and hence beyond any kind of prediction — are in fact surprisingly predictable if considered in a coarse-grained sense. This is emergence of a kind, in this case of patterns out of a background of chaos, and in a very simple setting. It suggests that there might well be a basic mathematics to the process of emergence that could be pinned down in detail.

Laughlin is right that emergence is not just a concept, but a physical process. It therefore demands some explanation.

Mark Buchanan

Into the breach?

The US federal commitment to basic research in the physical sciences could double in the next decade. In the proposed FY07 Federal Budget, funding for the National Science Foundation is up by 7.9%, and the budget of the Office of Science — the largest funding source for the physical sciences — is increased by a whopping 14.1%. This sounds like good news, providing a much-needed infusion of research money in areas that have been languishing for years.

But there is great pressure on the overall budget, and this increase in support for the physical sciences has to come from somewhere — off the back, it seems, of the other sciences. Support for the National Institutes of Health (NIH) will decrease; student aid and support for higher education programmes at the Department of Education will be flat or cut; NASA will see its budget increase by only 1%, less than the rate of inflation.

Already these shifting priorities are creating tension. NIH officials are crying foul, and NASA has indicated that it will accommodate the anticipated budget reduction — at a time when they are undertaking a return to the Moon and a manned mission to Mars — by cutting science programmes. Among those facing cuts or delays are the next-generation space telescope, new probes of cosmic anisotropy and dark energy, and the Terrestrial Planet Finder mission. As these projects are also of great interest to the physics community, it is not clear what the net gain for physical sciences from the new budget really is.

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Besides, any rational increase in support for the physical sciences must take into account that the boundaries between disciplines are disappearing. Just as Harold Varmus, former head of the NIH, argued when the NIH budget was doubled and the physics budget cut, it is increasingly difficult to compartmentalize scientific progress. The tools of physics are important in biology, and biological systems are providing new phenomena for physicists to study.

One can hope that the upcoming negotiations will result in a budget that allows fundamental research to flourish across the board. But I wouldn't bet on it.

Lawrence M. Krauss