Book Review

Hacking Matter,

Wil McCarthy (Basic Books, 2003) 224 pp, ISBN 0-465-04429-8; $16.00 (paperback)

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In the late twentieth century and the early years of the twenty-first, chemistry has emerged as the architectural science par excellence, as chemists have developed exquisite techniques for manipulating atoms and molecules into a bewildering variety of structures ranging from complex macromolecules to new materials to molecular machines. What is common to all their achievements to date, however, is that they begin with, and are limited to, the naturally occurring elements (or perhaps more accurately, atoms as we conventionally understand them).

What if it were possible to transcend this limitation, to create not simply new materials from pre-existing atoms, but to create a whole new class of atoms, whose characteristics could be designed and altered at will, and to use them in turn to develop entirely new materials, whose properties could likewise change virtually instantaneously in response to external conditions?

Is this merely science fiction or science fantasy? Perhaps not, according to Wil McCarthy. In his book, Hacking Matter, which carries the intriguing subtitle “Levitating Chairs, Quantum Mirages, and the Infinite Weirdness of Programmable Atoms,” McCarthy, described on the book jacket as “a novelist” (his most recent novel is The W ellstone, Bantam Books, 2003), “science columnist for the SciFi channel” and “Chief Technology Officer for Galileo Shipyards, an aerospace research corporation” argues that quantum dots have the potential to allow chemists to escape from the constraints of the Periodic Table by providing a gateway to a virtual philosopher’s stone of fully programmable matter, which he calls Wellstone. You can find his website at www.wilmc-carthy.com/fact.htm.

The basic idea behind quantum dots is fairly straightforward. They are spatially confined electrons, the basic theory of which is understandable to anyone familiar with the particle in the box model from elementary quantum mechanics. Electrons confined to a small region of space exhibit quantized energy levels, similar to electrons confined in atoms by electrostatic attraction to the nucleus, although the spacings and degeneracies of the various energy levels differ from those in atoms. A single confined electron constitutes, in effect, a "quasi-hydrogen atom," while additional electrons give rise to "atoms" of higher atomic number. The ability to confine electrons spatially began with the development of the P-N-P semiconductor junction, essentially a logic gate that allows electrons to flow into a region of space, but not out, making possible the work that McCarthy describes in Hacking Matter. This capability has allowed researchers to build up a new periodic table of these quasi-elements. In addition to novel properties, what distinguishes these new "elements" is their plasticity: "transmutation" is, in principle, simply a matter of removing or adding electrons – the counterpart of ionization in naturally occurring atoms. Moreover, energy level gaps, hence color and other properties, can be "tuned" by changing the size of the containing region, forming the basis of the "programmable matter" in McCarthy's subtitle. Its elaboration occupies the rest of the book.

The major difficulty impeding the practical use of quantum dots, as laid out in McCarthy's first two chapters, is that the potential wells had to be attached to solid substrates – analogous to being able to study single atoms, but not bulk matter. The breakthrough came with the discovery that electrons can be trapped within CdSe nanoparticles, making quantum dots available for study in the bulk liquid and solid phases. In his third chapter, McCarthy recounts how controlling the number of electrons per nanoparticle allows the creation of artificial atoms exhibiting a range of intriguing properties, including fluorescence, intermittent flashing, and tunable photoconductivity, index of refraction, photodarkening, and photoreflectivity.

In succeeding chapters, McCarthy discusses the potential for incorporating quantum dots into materials for energy storage and release, and for adjusting thermal conductivity (Chapter 4), as well as for potentially unusual magnetic and mechanical properties (Chapter 5).

As might be expected of someone writing not for scientists but for a general audience (albeit a scientifically literate one that will not be put off by the occasional sentence like " ... photon-photon interactions have such a low cross section that you don't have to worry about it for optical quantum states. A photon that's in a quantum superposition is therefore going to be a lot more stable at room temperature."), McCarthy's style is fluid and entertaining. He presents little technical detail, so it is not always easy to tell, without consulting the numerous references assembled in the first appendix, where the dividing line is between fact, extrapolation, and fantasy. Moreover, as an engineer, McCarthy naturally looks beyond the basic science to the development of practical products, and it is sometimes difficult to know how close to reality his extrapolations are. McCarthy's imagination (and his prose) takes flight in the last few chapters ("The Point and Click Promise", "The Programmable City" and "The Future Tense", where he envisions the enormous potential of Wellstone, a fully programmable form of matter (his patent for which appears in an appendix), imagining humanity spreading out into the universe in a triumphant new wave of colonization and concluding, " ... with programmable matter at our command, we may find it trivial to construct lighter and more capable spacecraft, even as we wallow in an energy glut of unprecedented proportion. ... When we do settle the planets, it may not be as overgrown cavemen, dressed in skins of airtight fabric and hurling metal spears at the sky. Instead we may stride there as a budding new race of Titans, with the gifts of Prometheus cradled lovingly in our open hands. And from there, my friends, the stars themselves await." A bit florid, perhaps, reminiscent of the fifties sci-fi style, but Hacking Matter is still an enjoyable read.