has some traction. Things are not as they should be in terms of internal values in biomedicine. Repairs are certainly in order.

Surprisingly, though, Callahan offers no comment on one of the most potent threats to scientific integrity and values — the power of government-sponsored military and anti-terror research to undermine the integrity of science. This is not a new problem but recent events have raised its profile. In the United States and Europe, some of the greatest threats to key scientific values come from the desire of government to keep secret the work that it funds in the name of national security.

But having said that, do proponents of biomedical research really wield the research-imperative weapon in the way that Callahan maintains? Most biomedical researchers are keenly alert to the obligations to treat human and animal subjects respectfully and with dignity. They understand the tensions imposed by private funding on the ethos of their work. And they are open to listening to and taking seriously the objections of those who fret about where biomedical technology might take us. And so they should. Despite Callahan's hyperbole about the power of the biomedical research juggernaut, critics have scored some victories. The genetic modification of plants and animals is moving much more slowly than proponents would like; stem-cell, embryo and cloning research are being subjected to close scrutiny; and efforts to advance xenografting and the creation of artificial hearts have come more or less to a grinding halt for a variety of ethical and social reasons.

Callahan has written an important book. The research imperative may not be quite as invulnerable as he thinks, but it is certainly imperative that the case he makes against it be given the close and thoughtful attention that his book provokes. ■

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Characters from the dawn of chemistry

The Last Sorcerers: The Path from Alchemy to the Periodic Table
by Richard Morris
Joseph Henry Press: 2003. 296 pp. $24.99

John Emsley

Who was the last true alchemist? Probably Johann Frederick Böttger (1682–1719), who started out looking for the Philosopher's Stone and ended up finding a way to make porcelain. Who was the first real chemist? Probably Robert Boyle (1627–91). He also began as an alchemist but became a chemist when he turned his attention to the newly discovered phosphorus in the 1670s. This he investigated in a systematic way, and he published his findings not in the arcane language of the alchemists, but in plain English.

This approach showed how far from alchemy Boyle had come, although he still believed that transmutation — turning one metal into another — might be achieved. For this reason, he fell prey to a scam wrought by a Frenchman, George Pierre des Clozets, who wrote to Boyle telling him that he could join a secret society of alchemists — for a fee. The upshot was that des Clozets milked Boyle of large sums of money. It is the inclusion of this kind of anecdote that makes Morris's book such a fascinating read.

The Last Sorcerers is a collection of short biographies of key individuals who span the years that saw the end of alchemy and the emergence of chemistry. It starts with an excellent account of Paracelsus and ends with one about Niels Bohr. Along the way we meet such chemistry greats as Antoine-Lurent Lavoisier, Henry Cavendish, Joseph Priestley, Jöns Jacob Berzelius and Dmitry Mendeleyev. In every case, Morris writes with a nice blend of science and human interest. I kept hoping that Morris might find a common thread of personality to unite his characters — what drove such a diverse bunch of men to study chemistry? Nothing illustrates the contrast more than the discoverers of hydrogen and oxygen. The former was the richest man in England; the latter was hounded out of the country for his radical left-wing views.

Cavendish was so wealthy that the Bank of England held his money in a special account. But he was so unworldly that when the bank sent a representative to suggest that he invest some of the £90,000 (equivalent to about £20 million, or US$35 million, today) that had accumulated in his account, he sent the man away saying he didn't want to be "plagued" about it, so there it sat growing ever larger. All Cavendish needed was enough money to enable him to carry out his experiments in his private laboratory in Clapham, and indeed he so little understood money that he gave the man whom he had employed to catalogue his library a cheque for £10,000. Cavendish was a recluse and was terrified of women, yet he performed some remarkable experiments that changed the course of chemistry, most notably making, collecting and studying hydrogen gas.

Priestley did the same for oxygen, but he was a non-conformist preacher who was married and relatively poor. He wrote inflammatory pamphlets in support of the French and American revolutions, and was attacked not only by the press, but also by rioters in Birmingham, who burned down his house and laboratory.

Not all chemists were so badly treated; some were even admired and loved. When John Dalton died, aged 74, in Manchester in 1844, the city fathers had his body taken to the Town Hall, where some 40,000 citizens filed past it to pay their last respects. The following day his funeral procession was a mile long, with 100 carriages and tens of thousands of ordinary people following on foot.

The Last Sorcerers is well-written popular science, and as such deserves to be widely read. That it deals with chemistry's somewhat shady origins adds to its attraction. The fact that it also reveals the human side of some famous chemists adds even more to one's enjoyment. ■

John Emsley is an author of popular chemistry books, his latest being Nature's Building Blocks *(Oxford University Press).*

The bits that make up the Universe

Information: The New Language of Science
by Hans Christian von Baeyer
Weidenfeld & Nicolson: 2003. 258 pp. £16.99

Michael A. Nielsen

What is the Universe made of? A growing number of scientists suspect that information plays a fundamental role in answering this question. Some even go as far as to suggest that information-based concepts may eventually fuse with or replace traditional notions such as particles, fields and forces. The Universe may literally be made of information, they say, an idea neatly encapsulated in physicist John Wheeler's slogan: "It from bit". Others rather less boldly suggest that taking a point of view based on information theory may yield insights into existing theories such as statistical mechanics and quantum mechanics.

These are speculative ideas, still in the early days of development. Their most encouraging success is perhaps the resolution of the 'Maxwell's demon' paradox, a century-old riddle in the foundations of statistical mechanics. In James Clerk Maxwell's paradoxical thought experiment, a demon of extraordinary dexterity and visual acuity partitions an initially homogeneous gas into two parts, one part containing slow-moving molecules and the other part faster-moving ones. In the thought experiment, the gas is initially spread evenly through a two-chamber container with a connecting trapdoor that can be opened and closed by the demon. By carefully observing the velocity of molecules approaching the trapdoor, and opening or closing it as appropriate, the demon sorts the molecules so that fast molecules enter one chamber and slow ones end up in the other.

Virtual art

Art that draws you in

Computer-generated virtual reality is a new form of art only in terms of its medium, according to art historian Oliver Grau of the Humboldt University in Berlin, Germany. In his highly original book *Virtual Art: From Illusion to Immersion* (MIT Press, $45), Grau argues that artists have been using a variety of techniques to immerse observers within their works for millennia.

The earliest trick simply involved physically surrounding the viewer with images. The frescos covering all four walls in a room in the Villa dei Misteri at Pompei, Italy, created in about 60 BC, draw observers into a 360° depiction of the preparations for a cult ritual. Those adorning a room in Livia's Villa at Prima Porta, dating from about 20 BC, create a 360° illusion of a garden. Post-antiquity, the frescos in the Chambre du Cerf (Chamber of the Stag) at Pope Clement VI's palace in Avignon, France, from 1343, place the observer at the centre of a hunting scene.

Mathematical perspective was the visual trick of the Renaissance. It is epitomized by the sixteenth-century Salle delle prospettive (Chamber of Perspectives) at the Villa Farnesina in Rome, the walls of which depict a columned hall. Between the pillars of the portico appears a view looking out onto the city and to the hills beyond.

Peepshow boxes — the forerunners of the stereoscope and the head-mounted display — first appeared in the eighteenth century, and in 1787 Robert Barker patented his hugely successful process for producing panoramic views on circular canvasses in correct perspective for observers standing at the centre. The techniques of cinematography and computing simply extended the opportunities for artists to immerse observers in an illusory world, according to Grau.

C. DAVIES

Virtually there: computers allow viewers to immerse themselves in Charlotte Davies' *Osmose*.

In the 1990s, the developers of virtual reality began to hire artists to assist them. Among these was Charlotte Davies, whose *Osmose*, shown here, is a total immersion in the fabric of the living Earth — rocks, roots, trees and leaves. It is is a product of her relationship with the Canadian software company Softimage.

But digital artworks are vulnerable to extinction as the operating systems on which they are based become redundant. Grau is cooperating on an international, interdisciplinary level with art academies and research laboratories to document two decades of computer-based art, much of which already cannot be shown. He has, for example, built a database of virtual art, a cataloguing project that is part technological and part art-historical, and is intended to support preservation efforts. *Osmose* is one of hundreds of works that will become publicly accessible through this database in the coming months. **Alison Abbott**

The resulting system is more ordered than the original homogeneous gas, and so has lower entropy. Furthermore, by making the trapdoor sufficiently lightweight, the demon can operate it by expending an arbitrarily small amount of energy. Thus, a naive analysis suggests that Maxwell's demon reduces the total entropy of the system, violating the second law of thermodynamics.

This paradox was resolved in 1982, when physicist Charles Bennett, building on earlier work by others, notably Rolf Landauer, showed that this analysis fails to take into account an entropy cost associated with the information acquired by the demon when it observes the velocities of molecules approaching the trapdoor. The cost is an entropic price paid when the demon erases its record of these observations. Remarkably, when this cost is taken into account, the violation of the second law is found to be illusory and the paradox is resolved.

A more recent example of information taking a surprising central role in fundamental science is a bold idea known as the holographic principle. Roughly speaking, this states that the correct way to describe a region of space-time is not through a description of fields and forces in the bulk of the volume, as is conventionally done, but through a theory whose elements are defined on the surface of the region. The motivation for the principle comes in part from results about the thermodynamics of black holes suggesting that the information content of a black hole is proportional to its surface area, not its volume. Some researchers hope that the holographic principle will help lead to a quantum theory of gravity, much as Einstein's principle of equivalence helped to motivate the general theory of relativity.

These and other examples illustrate the intellectual ferment associated with the role of information in fundamental science. It is against this backdrop that Hans Christian von Baeyer's elegant popular book is set.

The book's most appealing feature is its focus on big questions. What is information? What role does information play in fundamental physics? Where else in science does information play a critical role? And what common themes link these areas? Von Baeyer approaches these questions from many angles, giving us a flavour of some of the most interesting answers currently being offered.

There is a nice balance between accepted science and speculative ideas. For example, the standard theory of information, proposed by Claude Shannon in the 1940s, is introduced early in the book. However, von Baeyer admits that Shannon's theory has some shortcomings, and provides a flavour of several other approaches to developing information theories, notably quantum information theory.

Von Baeyer discusses many fascinating topics in a tour that is broad but not deep, taking in genetics, bioinformatics, quantum computation, the foundations of quantum mechanics, and black-hole entropy. He faces, and on the whole overcomes reasonably well, the difficulty faced by popular science writers of needing to simplify without misleading. However, I did notice several unfortunate minor errors of fact.

In summary, von Baeyer has provided an accessible and engaging overview of the emerging role of information as a fundamental building block in science. ■

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