value of the critical mass; at one point he even stated that no attempt had been made in Germany to calculate the number. Nowhere, however, did Heisenberg acknowledge his enormously consequential error in estimating the value at tons rather than kilograms, leaving the carefully crafted impression that only precision had been lacking. Maintaining this convenient ambiguity after the war, Heisenberg could insist disingenuously to the *New York Times* (12 December 1948) that "our reasoning was just like that of your physicists," and continue to avow that his wartime fission work had been occupied exclusively with "technical developments, with a peacetime application."

In Heisenberg's facility at rationalizing uncomfortable truths, and in his unresisting posture toward the Nazi ascendancy, Rose discerns a sense of responsibility that is strange in its detachment from the horror that was unfolding around him. To comprehend Heisenberg's moral view of the world, with its peculiarly German emphasis on the virtues of "inner freedom" and unquestioning obedience to established authority, is the ultimate purpose of the book and the ten years of fact-gathering that went into it: "Heisenberg," Rose writes, "seems to have believed that all power was amoral—a common prejudice in German culture. But this politically immature attitude was dangerous in that it promoted moral and political cowardice. For if all power was amoral, then no political cause was good, and hence the Allied cause was hardly superior to that of Hitler. In the end, the only thing that mattered politically for Heisenberg was the German nation."

Maxwell's Demon: Why Warmth Disperses and Time Passes

Hans Christian von Baeyer
Random House, New York, 1998.
207 pp. $25.00 hc
ISBN 0-679-43342-2

Modern physics is haunted by the specters of two celebrated mythical creatures—Schrödinger's cat and Maxwell's demon. Each embodies one aspect of the logical pitfalls that arose when randomness entered the foundations of our science.

Most physicists, and much of the general public, are aware that the cat, after a run of more than 60 years, is still there to torment us. But we sometimes need to be reminded that neither has the demon, after more than 130 years, yet been fully exorcised. In *Maxwell's Demon*, Hans Christian von Baeyer examines the underpinnings of the second law of thermodynamics and its role in fixing the direction of time's arrow.

Some of the finest literature in the English language has been penned by authors for whom it was not a mother tongue—Joseph Conrad and Vladimir Nabokov come readily to mind. German-born theorist von Baeyer, although perhaps not quite in that league, is a prime candidate for best wordsmith among popularizers of physics, composing prose that is elegant, economical and, above all, civilized.

Although his *Maxwell's Demon* is targeted to the broadest possible lay audience, with nary an equation in 174 pages of narrative, it can also be read with profit by physicists, for whom it will provide a historical perspective as well as an outline of some of the current thinking on the topic. It also boasts extensive notes and a remarkably complete index.

The story of the second law begins in 1823 with Sadi Carnot. His insight—that a hypothetical reversible heat engine would be the most efficient possible, but still could never achieve 100% efficiency—was a remarkable exercise in abstract reasoning. But trapped within the caloric theory on which his analysis was based, and lacking an absolute temperature scale, he could not clothe this logical skeleton in quantitative flesh. Three decades later, Rudolf Clausius, armed with a mechanical model for heat and Kelvin's absolute scale, gave Carnot's ideas substance through the concept of entropy.

James Clerk Maxwell built his kinetic model of gases on these foundations. Though unable fully to incorporate entropy, he recognized its statistical underpinnings, and thus was the demon born—able to violate the second law by manipulating matter on the atomic scale. Ludwig Boltzmann completed the theory with his inspired interpretation of entropy as the logarithm of the combinatorial probability of the state of a system.

Over the years, there have been attempts to exorcise the pesky sprite by developing mechanical demons and showing why they fail. These attempts range from Marian von Smoluchowski's simple flap door in 1912 to Richard Feynman's ratchet and pawl in 1964. But all modern work on this topic is enlightened by the 1950s work of Claude Shannon and Léon Brillouin, who established the connection between entropy and "missing" information.

In the last part of his *Maxwell's Demon,* von Baeyer outlines some contemporary approaches to the problem. Wojciech Zurek, noted for his efforts to exorcise Schrödinger's cat through the mechanism of decoherence, has an audacious proposal for dealing with the demon: Redefine entropy by adding a term based on something called "algorithmic complexity," which is nearly vanishing in all practical cases. It is designed to replace probability theory with the still-developing complexity theory as the logical basis for the second law.

The story ends with accounts of attempts to exploit thermal noise as an energy source without actually violating the second law. Biochemist R. Dean Astumian has proposed that a variant of Feynman's ratchet could well be the engine that drives molecular transport in living cells, while physicist Albert Libchaber's optical thermal ratchet is a working physical model of just such a device.

In short, von Baeyer serves up some nourishing food for thought for the lay reader and the professional alike. For a fuller meal, the latter may also wish to consult some of the references cited by the author.

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Tracks to Innovation: Nuclear Tracks in Science and Technology

Robert L. Fleischer
Springer-Verlag, New York 1998.
193 pp. $49.95 hc
ISBN 0-387-98342-2

A moving charged particle can produce ionization that, in certain materials, results in permanent radiation damage. When these materials are etched, the resulting conical pit reveals the particle's trajectory by the cone axis orientation, its energy by the cone depth and its charge by the cone half-angle. P. Buford Price and Robert M. Walker, along with Robert L. Fleischer, developed the art and technology of nuclear track etching and then adapted this process to a surprising variety of applications. The three documented their work in *Nuclear Tracks in Solids: Principles and Applications* (U. California P., 1975). The reprise presented in Fleischer's *Tracks to Innovation* was motivated by his desire to illuminate what he calls "the interplay between science and technology." Since the experimental technique was refined at the General Electric Research Laboratory, where Fleischer worked for many years, he is in a particularly good position to realize this goal.

Fleischer's story begins with a medical need for ~5 μm filters to isolate cancer cells in human blood. This was realized by the irradiation of thin polycarbonate plastic with alpha particles from californium-252 and then etching the plastic until the pits became holes. This was General Electric's first nuclear-track-related product and it is now sold through a freestanding spin-off company Nuclepore, that is the leader in an industry, with current earnings well in excess of $50 million per year. Today, these filters are used not only to isolate cancer cells but also to capture microscopic marine organisms from seawater and particulate matter from the air and to separate yeast from beer. (With these filters, sea-urchin sperm have been shown to move overwhelmingly though membranes head first, not surprising, since sea urchins continue to exist.)

Radon monitors using track-etch techniques have been another commercial success, again stimulating the formation of a spin-off company, Terradex. These detectors work by capturing the radon's polonium daughters on a plastic surface that is in contact with a known volume of air for a known period of time. Etching the plastic reveals the pit density and thus the radon concentration, which, if significant, can place occupants of a building at risk of lung cancer.

Nuclear tracks can also elucidate the age of things. Micas created millions of years ago deep in Earth's crust and subsequently brought to the surface by some geological event will, by the density of uranium-235 fission tracks they contain, reveal their age. Likewise, decorative museum glass that incorporated potassium-40 at its creation have been dated to ages as recent as 20 to 100 years. Tracks in glass shards from the Olduvai Gorge in Tanzania have been essential in placing early humans at that site 1.75 million years ago.

The nuclear-track technique is not restricted to detecting highly electrically charged particles, or even real particles. In the MACRO (Monopole Astrophysics and Cosmic Ray Observatory) experiment located in a chamber under Italy's Grand Sasso Mountain, trays containing m^2 sheets of CR 39 plastic lie in wait for the passage of a magnetic monopole. A signal of a slowly moving particle registered in the surrounding scintillation detectors will be the occasion for these sheets to be removed and etched. The track of a (137/2)e Dirac magnetic charge would be unique, while the myriad usual singly electrically charged muons leave no tracks.

Fleischer's chronicle is useful in that it provides a window on the activity of an important industrial research laboratory, a side of physics with which few academics have even the briefest acquaintance. That said, I have some quibbles. The narrative is to me somewhat overwrought at times ("this book describes the marvelous simplicity . . ."); a more measured tone would have improved the presentation. The current fashion of introducing chapters with pithy aphorisms, courtesy of Bartlett, from never-read sources, is here both affected and annoying (". . . show the tracks of knowledge." Lucretius in *On the Nature of Things*). The space devoted to references—consuming about one-tenth of this slim volume—many of which appeared in the Fleischer–Price–Walker book, would better have been used for the retelling of anecdotes. Finally, if this book had been published by a university press in paperback, students could afford a copy. The cost, at approximately 25¢ a page, is an outrage.

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Foundations of Vacuum Science and Technology

Edited by James M. Lafferty
Wiley, New York, 1998. 728 pp. $135.00 hc ISBN 0-471-17593-5

In 1962, a second edition of the classic 1949 *Scientific Foundations of Vacuum Technique* (Wiley), by Saul Dushman, was published. The editor of that volume was James M. Lafferty; revisions were made by members of the research staff of General Electric Co. Subsequently, Lafferty was encouraged by the education committee of the American Vacuum Society and John Wiley & Sons to bring the story up to date in a new edition. Lafferty chose 15 vacuum specialists from the US, Canada, the UK, Italy and Germany to contribute to "a survey of fundamental ideas in physics and chemistry that would be useful to both scientists and engineers dealing with the use, production and measurement of high vacuum."

Foundations of Vacuum Science and Technology is the result. Because of the many advances in vacuum science and technology made during the past three decades, readers familiar with the earlier works will find much of the material to be new. It is to the editor's credit that he was largely successful in upholding the tradition of the original book and avoiding the main pitfalls of multiauthored volumes (variation in the styles of presentation and excessive overlap in the material covered).

The first two chapters begin at the beginning, with the kinetic theory of gases and the flow of gases through tubes and orifices. While the basic laws have not changed over the years, the subject matter has been expanded to include all flow regimes, from free molecular flow to atmospheric pressure. Three chapters are then devoted to vacuum pumps, including the old standbys—oil-sealed positive displacement pumps and diffusion pumps—as well as new types, such as liquid-ring pumps, dry pumps, turbo pumps, getter pumps and cryopumps. A chapter on leak detectors includes their enhanced capacity for quantitative measurements in everyday use.

We learn that the art of pressure measurement has benefited from many advances in the design and understanding of the limitations of ionization, thermal conductivity, viscosity and capacitance diaphragm gauges. The partial-pressure analyzer has provided knowledge of the gas composition in a vacuum system, useful for vacuum diagnostics or process monitoring; it was the invention of the quadruple mass spectrometer that made such measurements relatively simple.

Ultrahigh vacuum is now a mature procedure rather than the state-of-the-art technology it was 40 years ago. Pressures as low as 10^{-11} pascal have been measured in the laboratory, below the transition from ultrahigh vacuum to extreme high vacuum, 10^{-10} Pa. In the chapter on this truly rarefied regime, it is shown that progress has been made by extending vacuum techniques to their limit and developing an understanding of gas–surface interactions and diffusion in solids. (The editor reminds his readers that the pascal is the ISO (International Organization for Standards) unit of pressure. For those of us who may find old habits hard to break, I suggest remembering just one simple conversion factor: 10^5 Pa is about 1 bar (1 atmosphere). Since the bar is about 1000 torr, we can easily return to what still may be a comfort zone.)

The material on calibration and standards may be common knowledge to those involved in calibration and quality control. It should nonetheless be useful to the many who (in my experience) are not aware of the accuracy limitations of vacuum measuring instruments.

There are two possible audiences for this book: those who use vacuum primarily as a tool—a means to an end—in the conduct of an experiment or a process, and those who specialize in vacuum technology. I believe both