BOOKS: PHYSICS

Boltzmann's Science, Irony and Achievement

Leo P. Kadanoff

Ludwig Boltzmann (1844–1906) was largely responsible for bringing both atomic and statistical concepts into the practice of physics. But, as this scientific biography by physicist and writer David Lindley makes clear, Boltzmann's triumphs were equivocal and his message flawed.

Boltzmann's Atom
The Great Debate That Launched a Revolution in Physics
by David Lindley
Free Press, New York, 2001. 272 pp. $24, C$35.50. ISBN 0-684-85186-5.

Atoms were probably an old idea even to the ancient Greeks. Nonetheless, a correct analysis of atomic motion could not occur until the mid-19th century, after concepts of heat and of energy conservation had been developed within mechanics. *Boltzmann's Atom* takes us into the scientific world in which physicists, especially Boltzmann and James Clerk Maxwell, began to build upon the existing kinetic theory and to ask whether the observed properties of gases could be fit into a mechanical view of the world.

The German-speaking universities of his period provided Boltzmann with the opportunity for a single-minded focus on atoms in motion. Fund-raising, job-seeking, and teaching all exerted only limited demands on his time and efforts. With the development of his experimental talents precluded by his poor eyesight, Boltzmann became one of the world's first theoretical physicists. In his mind, he built a world of little hard balls bouncing against one another. Through almost limitless effort and excellent analytic work, he developed a mathematical view of the behavior of that world.

Even as late as the 1870s, when Boltzmann was at his most creative, there was hardly any direct experimental evidence for atoms. Indirect evidence existed (provided, for example, by Dalton's law of combining proportions), but many philosophers of the period found such evidence to be insufficient. In particular, the physicist Ernst Mach had developed a philosophy of science that heavily discouraged theorizing by demanding direct experimental evidence for all scientific concepts. This point of view would place Boltzmann's atoms outside science. A substantial intellectual collision ensued.

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In describing the protagonists' lines of argument, Lindley develops the connection with today's discussions about string theory, a theoretical approach developed as a possible basis for understanding sub–sub-atomic level phenomena. Strings, however, are not directly observable. Their study forms a closed world, one much beloved by its creators. As the interest of theoreticians has moved away from things observable, the previous coordination between theory and experiment has much diminished, thereby making both seem less valid and relevant.

Looking back, Lindley sees that Boltzmann's work was most radical not in its use of atoms but rather in its movement toward statistical concepts. One cannot construct a fully deterministic theory of many particles in motion. To treat such many-particle systems, one must use a probabilistic approach and thereby give up elements of accuracy, specificity, and determinism. As pointed out by Lindley, and previously by Thomas Kuhn, Boltzmann was extremely reluctant to wed concepts of probability and those of mechanics. Yet he needed to join them to obtain explanatory power for his theories. A new—and quite revolutionary—point of view was required for his development of the Boltzmann dynamical equation. This change in perspective was even more necessary for his famous "H-theorem," an attempted mechanical proof that entropy always increases. While Boltzmann denied and evaded probabilistic arguments, more subtle and flexible minds saw that a specified and deterministic mechanics would require entropy to decrease sometimes. Boltzmann's research could not be correctly interpreted within the framework he had brought together.

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Advocate for atoms. Boltzmann's efforts to explain the second law of thermodynamics in statistical terms led him into heated debates on physics and the philosophy of science.

Something had to give. Neither Boltzmann's approach nor the second law of thermodynamics can possibly describe any and every mechanical system. A more Olympian view is necessary to bring the second law within physics. One can say that this law is true most of the time, that it is true "on the average," or that it is a property only of "likely configurations." One can also make ad hoc assumptions of "molecular disorder" as a supplement to the mechanics of Newton. These choices are possible, but ugly. More mathematical and perhaps more elegant formulations are also available. Boltzmann's equations are in the most part derivable as a property of a properly prepared collection of systems. Or, as suggested by Harold Grad, the equations might apply, not to anything real but to an imaginary, homogenized broth of infinitely many infinitesimally small atoms. I like this alternative formulation. Under it, statistical physics is not a part of finite mechanics but a generalization of mechanics to systems with infinite numbers of degrees of freedom.

Lindley's careful and thoughtful exposition brings us to several ironies. Boltzmann's straight-ahead approach got the equations quite right, but their meaning quite wrong. Mach was wrong about atoms and wrong in demanding that science only include the immediately visible, but right in demanding a different philosophic outlook for kinetic theory. Boltzmann was right about atoms but utterly wrong in believing that atoms provided a necessary basis for thermodynamics. The second law does not require atoms. Thermodynamics would be equally correct if the basic constituents in the world were atoms, or quantum fields, or even strings. Conversely, nothing in string theory can change the predictions of thermodynamics or even of the "standard model" of particle phenomena. Thus we should note with some sadness that any incisive experimental check of string theory will require techniques and approaches not presently in view.

Within Boltzmann's lifetime, Gibbs, Einstein, and Planck, aided by deeper and perhaps more philosophical insights, utterly transformed kinetic theory once more, and

thereby developed modern statistical mechanics. Einstein and Planck constructed the basis for proving the existence of atoms and for undercutting classical mechanics. Correspondingly, under the influence of modern string theory, maybe the physics of our own day is also ready to undergo a radical transformation. Some of the fundamental constants and natural laws seem to be losing their solidity. "Constants of nature" are in part being replaced by "running couplings," varying with distance and perhaps other environmental elements. The very structure of our laws of nature might be the accidental result of falling into one among a huge class of possible ground states. Perhaps we will soon face a major restructuring of our view of the physical world, even one comparable to the quantum revolution that started one century ago.

Scientifically, after Boltzmann's great work in the 1870s, the remainder of his life was postscript. Toward the turn of the century, he moved away from theoretical physics and began to work on the philosophy of science. This shift was partially an attempt to defend and discuss the point of view that he had developed many years before. The attempt was not successful, and its failure perhaps contributed to his eventual despondency and suicide.

In the above, I have mostly given Lindley's story. His rendition is not always flattering to Boltzmann, who is presented as creative but intellectually limited. A different story is told in Carlo Cercignani's recent biography, *Ludwig Boltzmann: The Man Who Trusted Atoms* (Oxford University Press, 1998), which offers a detailed description of Boltzmann's science in his own time and follows his contributions into recent work. Cercignani describes a towering individual with a very deep mind, who had magnificent achievements, and who has been underappreciated by posterity. Lindley does not paint such a larger-than-life figure. *Boltzmann's Atom* does not reach for the scientific scope and detail of its predecessor, but it is nonetheless quite satisfying. Appropriate for a nonspecialist yet scientifically cultured audience, Lindley's well-crafted account gives a believable, human-scale picture of Boltzmann and his science.

NOTA BENE: EXHIBITS

Microbial Resolution and Reality

Growth and Form Biomedical Images—Awards and Interpretations
Denna Jones, Curator

The Wellcome Trust, Two10 Gallery, London. 22 February to 4 May 2001. www.wellcome.ac.uk/en/1/misexhtwo.html

Sucked into the foyer of the Wellcome Trust's headquarters on Euston Road in London by a set of revolving doors, visitors are confronted by three immense square dishes containing what at first sight appear to be leopard skin rugs. These resolve into a mesmerizing patchwork of subtly colored fungal colonies, the progenitors of which originated in samples of London air captured by artist Rachel Chapman. Entitled *Breathe*, the piece (part of which is shown here) not only dramatically conveys the unseen horrors of air we inhale, but also its aesthetic potential. It is far and away the most arresting piece in the exhibition *Growth and Form*, which juxtaposes 22 scientific images selected from the Wellcome Trust's Biomedical Image Awards 2001 with work by nine contemporary artists and designers inspired by biological research.

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Unfortunately, the Two10 Gallery is cramped and its space is interrupted by pillars and a stairwell. Thus, for some of the larger pieces it is hard to judge their merits at arms' length. Apart from such obstacles, the impression left by the images inevitably depends on the visitor's background and interests. For me, an erstwhile microbiologist, several of the artworks imparted an awkward sensation, whereas the uninterpreted micrographs were far more successful and the beauty of their reality spoke for themselves. You can judge for yourself on the exhibit's Web site.

Some of the art pieces are thought-provoking. For example, *Nine Landscapes* by Rebecca Birch comprises tiny paintings on canvas. The pictures are ostensibly meant for microscopic examination, but when inspected by microscope they disappear into the topography of the paint surface. This idea is echoed in the video presentation *Minutiae* composed by Mat Tizard. Here, the artist compiled a series of scanning electron micrographs of various organisms at a range of magnifications. After overcoming the post-modernist trick of reading the descriptors backwards and realizing that viewing the video required standing in the stairwell, the effects of loss and recovery of resolution at the extremes of magnification were absorbing.

Other pieces were simply irritating to me as a scientist, mostly because they are unadventurous departures from reality and inappropriately borrow jargon. Sally Gould's *We All Fall Down* consists of an ironic assembly of the kind of white ceramic tiles that used to line Victorian hospital wards; sections of botulism-toxin motifs had been fired into the surface of the tiles. Annoyingly, the artist comments that "the new glaze reacts with the original glaze, like a virus attacking the body." *Germlights*, by Sue Withers, positions two dozen glowing paintings within translucent domes, where they look like three-dimensional renderings of microbiological cultures within Petri dishes. Although they make an attractive assemblage, they are poor cousins to the real things. And, contrary to the artist's expectations expressed in the catalog, to me they did not succeed in evoking sensations of either beauty or disgust.

Despite feeling irritated by several of the artworks, I was attracted to Serge Negre's *Fungteria*, a series of platinum prints depicting patterns formed by the fungus *Aspergillus flavius* growing inside old books. Their modest sepia record of subtle forms needed no other message or explanation.

Through its sponsorship of contemporary arts and artists, the Wellcome Trust is making a valiant attempt to bridge the current gap between art and science. Perhaps some of my disappointment comes from the enterprise trying too hard to find inspiration in objects that need no filter to tell the observer they are beautiful or provocative.

—CAROLINE ASH