BOOKS

A Life Devoted to the Enigma of Irreversibility

Ludwig Boltzmann: The Man Who Trusted Atoms

Carlo Cercignani
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Reviewed by David Ruelle

Heroes die, flowers fade, and time flies away irretrievably. These facts have inspired many poets. To physicists, they are a source of preoccupation because the elementary constituents of heroes, flowers, and the rest are known to obey time-reversible equations of motion. How is it that no arrow of time exists in the microscopic laws of evolution of matter, while the difference between past and future is so evident at the macroscopic level? There is a macroscopic quantity, entropy, that can only increase with time and describes the irreversible transformations of heroes and flowers. But since the direction of time is not visible in the microscopic equations, how does entropy inexorably increase in a macroscopic description?

Solving the enigma of irreversibility was the great enterprise to which the Austrian physicist Ludwig Boltzmann (1844–1906) dedicated his life. At a time when many scientists still doubted the existence of atoms, he took atoms seriously and was one of the founding fathers of statistical mechanics, which explains the properties of bulk matter in terms of their microscopic constituents.

Nonequilibrium statistical mechanics was Boltzmann's main field of interest. He resolved logically the paradox of macroscopic irreversibility by noting that, while the microscopic evolution is reversible, the initial conditions may be very special, so that the direction of time moving away from the initial condition is clearly perceptible. To make this idea quantitative, Boltzmann related the entropy of a macroscopic state to its "probability," for example, to how special its microscopic configuration is. Boltzmann also set up an equation (now known as the Boltzmann equation) as a kind of bridge between a probabilistic description of the collisions of atoms (or molecules) in a gas and a macroscopic description.

In modern language we may describe the increase in the entropy of a gas with time as follows: The very special initial condition means that the positions and velocities of the particles of the gas are highly correlated. Shocks between the particles do not destroy the correlations but let them diffuse, so that they are carried by particles that end up far from each other. These correlations can then be forgotten. We thus lose information, and the entropy correspondingly increases.

According to the Boltzmann equation (in the "Grad limit"), after two particles collide, they never see each other again. It is reasonable that entropy increases in this situation, as Oscar Lanford's rigorous treatment in 1975 showed. The case of a dense fluid in which the same particles collide again and again raises difficult questions that have yet to be resolved. A promising path of investigation uses the idea that microscopic dynamics has sensitive dependence on initial conditions (chaos), so that the system quickly forgets correlations.

Carlo Cercignani's *Ludwig Boltzmann: The Man Who Trusted Atoms* is not about recent developments in nonequilibrium statistical mechanics. It may be described briefly as a careful, in-depth discussion of Boltzmann's science and personality and of the world he lived in. Why should that interest us? Actually, Boltzmann's scientific ideas have retained immediacy because the development of nonequilibrium statistical mechanics has been slow (unlike that of almost every other branch of physics in the 20th century).

This singular quality of Boltzmann's science is associated with a fascinating, tragic personality. He was, as we would now say, manic-depressive, and he ended up hanging himself. How did he come to this extremity? What was the role of the ceaseless battles he fought with colleagues over atomism or the paradoxes of irreversibility? In a sense, he won these battles, but can one say that his suicide had no relation to his scientific life? We simply do not know the answer to these questions.

A depressive personality and a fine sense of humor often go together, and this was the case with Boltzmann. The author recounts Boltzmann's hilarious stories of how he managed to procure wine during a (pre-Prohibition) US trip, and how he nearly died after drinking bottled mineral water. Boltzmann's personality comes through quite convincingly in Cercignani's book, which has numerous quotations and a translation (as an appendix) of "A German Professor's Journey to El Dorado," an account of Boltzmann's trip to the US (PHYSICS TODAY, January 1992, page 44).

Cercignani is a scientist (in fact, a specialist in the Boltzmann equation), and this can be felt in his style. In an epilogue, he describes his book as "a sober exposition that tries to describe sound facts." It is obviously a work of love, and I would advise the reader to take time going through it. There are, for instance, sensitive descriptions of the intellectual atmosphere of central Europe in the late 19th century. There is also a long discussion of Boltzmann's ideas on the philosophy of science, where he appears strikingly modern: He used, for instance, Darwinian ideas to assess the human intellectual potential. It is refreshing to see the philosophy of science discussed not by a licensed hermeneutician but by a true scientist like Boltzmann, who is able to disregard formal details and go straight to the important ideas.

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From Hiroshima to the Iceman: The Development and Applications of Accelerator Mass Spectrometry

Harry E. Gove
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Harry Gove's excellent book, *From Hiroshima to the Iceman*, is a person-