Obituary

Ilya Prigogine (1917–2003)

Ilya Prigogine died on 28 May in Brussels, after a long illness. Born in Moscow, he emigrated at an early age, as his family sought to escape the aftermath of the Bolshevik revolution. The family arrived first in Germany, then moved to Belgium — the country that became Prigogine's true homeland. He studied chemistry and physics at the Université Libre de Bruxelles, and obtained his PhD in 1939 under the tutelage of Théophile De Donder, a remarkable professor, who pioneered the development of modern physics in Belgium. Extending and deepening De Donder's work, Prigogine himself became a pioneer of the thermodynamics of irreversible processes.

Classical thermodynamics is the science of equilibrium: the concept of variation with time was viewed with suspicion; dissipative phenomena, such as friction, were considered a nuisance. Prigogine attacked the problem head-on, by introducing a quantitative concept of irreversibility. He produced a sound derivation of transport processes, relating the fluxes of energy and matter to the thermodynamic forces (such as gradients of temperature or density, or electric fields) that cause them. Irreversibility and entropy became the main themes of his subsequent work.

The next step was to consolidate these macroscopic notions by addressing their molecular basis. This subject had remained in the shadows since the last years of the nineteenth century with Ludwig Boltzmann's work on the kinetic theory of gases and a definition of entropy at the microscopic level. (It was even considered to be 'cursed' — Boltzmann committed suicide in 1906.) How could the irreversibility of real processes at the macroscopic scale be reconciled with the perfect time-reversibility of the (classical or quantum) law of motion for molecules? In the 1960s, surrounded by a small group of enthusiastic co-workers, Prigogine began to make crucial progress on this point, developing the first form of non-equilibrium statistical mechanics. (Another approach, developed independently by Nikolai Bogolyubov in the Soviet Union, turned out to be equivalent to Prigogine's.) As well as being quite a general formulation of the theory, there were other fruits of this endeavour, for it could be applied to a variety of systems, from gases and solids to plasmas.

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Pioneer of the thermodynamics of irreversible processes

Pushing the study further, to systems that are far from equilibrium, Prigogine and his increasingly numerous co-workers uncovered an extraordinary phenomenon. When the distance from equilibrium (measured by some appropriate parameter) reaches a certain threshold, the trajectory of a system meets a fork, or bifurcation. The system may then leave the trajectory along which it has evolved from equilibrium, and jump to a totally different one. If the system is pushed even further, more bifurcations may appear, and when the system is very far from equilibrium, it may behave completely chaotically (as, for example, the regular flow of a liquid may become turbulent). But, alternatively and unexpectedly, the system might reach a new, ordered state — what Prigogine called a 'dissipative structure'.

Such states are particularly striking in systems in which chemical reactions proceed alongside the effects of diffusion or external forces: ordered structures of different chemical composition appear, which may even propagate as 'chemical waves'. Two ingredients are vital if this is to occur: the 'open' character of the system (meaning that it can exchange matter and energy with the external world), and the nonlinear character of the equations governing the evolution of the system. These conditions arise, in particular, in living systems. Prigogine had thus created an important link between physics, chemistry and biology (even extending it to sociology and economics). His achievement was crowned with the award of the 1977 Nobel prize for chemistry — the pinnacle of a long list of awards, prizes and honorary degrees.

By the 1990s, Prigogine was again thinking about physics at the microscopic level. Substantial progress had been made by mathematicians and physicists in the study of nonlinear dynamical systems, and one of the most important features to be uncovered was the intrinsic dynamical instability of most 'non-integrable' systems (even very simple ones). As a result, Prigogine introduced the crucial idea that the usual method of defining the state of a system by specifying exactly the positions and momenta of all of its components (that is, a point in 'phase space') is not realistic, because a close, neighbouring state may evolve in a completely different way. Rather, the state should be described by an ensemble — a cluster of identical systems differing in their initial conditions. The latter may (but does not have to) be concentrated around a single point in phase space. The description of the system's evolution thus becomes statistical. In this way, the solutions of the equations are regularized (divergences are suppressed), and irreversibility appears as a welcome bonus in the theory.

Like his mentor De Donder before him, Prigogine was also a remarkable professor. In the United States, he was the founder and director of the Center for Statistical Mechanics at the University of Texas at Austin (later renamed the Ilya Prigogine Center for Studies in Statistical Mechanics and Complex Systems); in 1959 he was made director of the International Solvay Institutes for Physics and Chemistry in Brussels. His lectures were fascinating for students, as he preferred to leave out tedious details and instead include parenthetical perspectives on art, music and philosophy. His books for a general audience, such as *La Nouvelle Alliance* (with I. Stengers), *From Being to Becoming* and his last work, *La Fin des Certitudes*, were bestsellers around the world. He was a true humanist, in the widest meaning of the word, and attracted numerous disciples. His death closes an important chapter in the history of science.

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