Prigogine writes on time irreversible and reversible

From Being to Becoming: Time and Complexity in the Physical Sciences

I. Prigogine
Freeman, San Francisco, 1980. $25.00 cloth, $12.50 paper

Reviewed by Erwin N. Hiebert

Ilya Prigogine was born in Moscow several months before the revolution. A professor of physics and chemistry, he currently apportions his time between the Free University of Brussels and the Center for Statistical Mechanics and Thermodynamics at the University of Texas in Austin. He received the 1977 Nobel Prize in chemistry for his contribution to irreversible thermodynamics, notably to the theory of dissipative structures. Prigogine's latest volume deals mainly with the "revolutionary" developments in which time, as "the forgotten dimension," enters into the real and complex, very large and very small, irreversible systems that are far from equilibrium. These contrast with equations in classical and in quantum dynamical descriptions that are invariant with respect to time, that is, in which the fundamental laws are seen to be symmetric in time.

The belief that time or time's arrow plays an indispensable role in natural phenomena was generated over a century ago almost concurrently in physics, chemistry, biology and sociology, in each with quite distinct meanings. Inspired by the much ventilated second law discussions that followed the work of J. C. Maxwell, Kelvin, L. Boltzmann, M. Planck, J. W. Gibbs, H. Poincaré, P. Ehrenfest, and A. Einstein, among others, Prigogine first analyzes the physics of dynamics, Hamiltonians, ergodic systems and ensemble theory in quantum mechanics. Then, from a strictly phenomenological point of view, he extends and reconstructs the domain of irreversible thermodynamics that such investigators as Raymond Defay, Th. De Donder, Pierre Van Rysselberghe, S. R. Groot and Lars Onsager had begun to stake out in the 1930s.

Large-scale eddies in Jupiter's atmosphere illustrate the emergence of ordered structures from the complex nonlinear interaction in *Being and Becoming*, reviewed here.

As used in Prigogine's title, "being" represents the restricted geometric concept of time that applies to the trajectories of classical dynamics and the probability amplitudes of quantum theory ($t \longleftrightarrow -t$). This static view of time is deeply rooted in Western science as the prototype of theoretical physics. By contrast, "becoming" represents the dynamic, evolutionary, time concept current in statistical physics and chemistry and in biology ($t \longleftrightarrow -t$). Here time no longer represents a simple parameter but is an "operator" by which irreversible processes are characteristically treated from a functional point of view.

Although Prigogine demonstrates that the concept of irreversibility is indispensable for describing complex dynamical systems within the framework of classical and quantum dynamics proper, the real thrust of his argument is that irreversibility essentially comes into its own where classical and quantum mechanics end. Thus while irreversibility plays a fundamental and constructive role in physics, it is absolutely central in chemistry. On the biological level, where nature presents human beings with "over-creativity" and where there is no terminus to historical evolution, irreversibility is revealed with conspicuous clarity everywhere.

The new and somewhat unexpected feature in Prigogine's nonequilibrium analysis is exhibited in processes that lead to new types of configurations called "dissipative structures." Prigogine uses this term to designate those new coherent states that are far from equilibrium and where the application of probability theory, as implied in the counting of numbers of complexions, breaks down. At some critical value, for example in the spatial pattern of convection cells in a heated liquid, certain fluctuations are amplified and a new molecular order appears that "basically corresponds to a giant fluctuation stabilized by the exchange of energy with the outside world. This is the order characterized by the occurrence of what are referred to as 'dissipative structures'." These structures are most sensitive to the "global" features of the system, for example, the size and form of the system, and the boundary conditions imposed on the surfaces of the system.

Oscillating inorganic chemical reactions discovered in the late 1950s provided the model for characterizing oscillations or fluctuations at all levels of biological organization from the molecular to the supercellular. More generally, the studies in chemical kinetics stimulated the analysis of systems in which instabilities are induced by suitable perturbations. These are macroscopic systems in which fluctuations and probability description play an essential role, but where it can be expected that in the neighborhood of alternative paths, the system has to "choose" one of the possible branches that appear at the bifurcation point. The examples cited are taken mainly from studies on chemical kinetics, nonequi-

FRANK ARMSTRONG

PRIGOGINE

librium phase transitions, time-symmetry breaking and other critical oscillatory fluctuations.

This is an imaginative and provocative work that surely will stimulate lively scientific and philosophical debates for years to come. With great skill, clarity, mathematical and pictorial elegance, and with considerable persuasion, Prigogine explores and deepens some of his earlier ideas, now placed within a much broader spectrum of problems. Included are numerous pertinent discussions of oscillating systems composed of nonlinear differential equations and complicated processes involving the self-organization of systems: chemical kinetics in far-from-equilibrium reactions, thermal diffusion, the patterns of circulation in planetary atmospheres, fluctuations in the way a given ecological niche is understood to be exploited, the growth of populations and towns, oscillations in enzyme activity in metabolism, the movement of monocellular organisms from nutrient-poor to nutrient-rich media, the process of replication of polymers, cross-catalytic mechanisms, regulatory processes at the cellular level, and the aggregation process in slime mold formation.

The author's analysis demonstrates that the idea of time asymmetry stands in need of a radical reappraisal, not only in thermodynamics proper but also in relation to "the baroque of the natural world" and to complicated artificial systems and ecosystems. Prigogine explicitly emphasizes that his intention is not to reduce physics and biology to a single scheme but to define clearly the various levels of description and to present conditions that permit us to pass from one level to another.

Throughout this work Prigogine has accentuated the fact that we are living in a single world whose aspects, however diverse they may seem, must bear some phenomenological relation to one another. In many areas of the sciences no notable progress in the direction of reductionist unified theories has been accomplished. He writes: "The world is richer than it is possible to express in any single language. . . .Scientific work consists of elective exploration rather than a discovery of a given reality; it consists of choosing the problem that must be posed."

Accordingly, the problem of constructing a bridge from "being" to "becoming" is seen by Prigogine to be crucial. His solution is to introduce the formal device of a microscopic entropy operator that corresponds to unobservable idealizations. Further, his objective is to demonstrate how the usual formulation of classical or quantum mechanics becomes "embedded" in the larger theoretical structure that allows for the description of irreversible processes. Thus irreversibility becomes not some approximation added to the laws of dynamics but the focus for an enlargement of the theoretical structure.

Prigogine obviously is strongly attracted to a pluralism of scientific schemes in looking at the nature of things; in this case, in fact, to a complementarity between dynamical frameworks, where $t \longleftrightarrow -t$ holds, and in thermodynamic frameworks, where $t \longleftrightarrow -t$ is incorporated into the conceptual structure. According to Prigogine, both are equally fundamental and merit equal theoretical status. He concludes:

> *A posteriori*, it is difficult to imagine how the conflict between "being and becoming" could have been resolved in a different way. In the nineteenth century, there was a profusion of controversy between "energeticists" and "atomists," the former claiming that the second law destroys the mechanical conception of the universe, the latter that the second law could be reconciled with dynamics at the price of some "additional assumptions" such as probabilistic arguments. What this means exactly can now be seen more clearly. The "price" is not small because it involves a far-reaching modification of the structure of dynamics.

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Elements of Acoustics

S. Temkin
Wiley, New York, 1981. $27.95

Students of acoustics at the beginning graduate level will benefit greatly from this new text, derived from a course in acoustics taught for several years at Rutgers University by Samuel Temkin. Treating acoustics as a branch of fluid mechanics, he describes waves in fluids and gases, but not in solids. With this emphasis he presents a detailed treatment of sound absorption in fluid media, a subject to which he has made several important research contributions.

The emphasis of the book is on theory. Once he derives the wave equation, Temkin gives many examples of its solutions to boundary-value problems. Although this technique allows the analyst to recover the waveforms of all acoustical variables at all points within the boundary, only simple situations can be treated in this analytical way. However, acoustics is mostly an applied science, in which measurements are commonly required. An experimenter can seldom use the precision of a waveform if it requires a separable coordinate system. In fact, often the only interesting measure of a waveform that is of first order in the amplitude is the amplitude density distribution. More commonly needed are its quadratic measures, such as power, power spectral density and covariance. Sometimes fourth-order measures of a waveform are necessary to reveal the properties of an acoustical propagation path. Measurement and prediction of these "measurable" properties of acoustical waveforms are not subjects common in fluid mechanics, while they are in electrical engineering, for example. After a study of the "physics of sound," guided by this book, a student would need to study the "signals of sound" guided, for example, by the *Foundations of Acoustics* by Eugen Skudrzyk.

The first two chapters present an exceptionally clear basis for wave motion in fluids. Except for the lack of a generalization to solids, the first chapter is a clear statement of continuum mechanics. The author takes care to include body forces and both conservative and dissipative terms in the equations of motion, in order to establish foundations for later studies of the effects of viscosity and heat transfer.

The third and fourth chapters are an analytical exposition of wave propagation, including plane, spherical and cylindrical standing and free waves. Temkin also includes wave transmissions through plane interfaces, two- and three-dimensional waveguides, and horns. Befitting the foundations he established in the first two chapters, he covers very efficiently both waveform distortion and attenuation owing to finite amplitudes. In keeping with his emphasis on exact solutions to the wave equation, he omits high-frequency asymptotic solutions, such as optical diffraction theory or the Eikonal equation, even though these "ray theories" are very important to applications of acoustics.

The fifth chapter deals with sound