namics of Newton. Modern mathematics began with Cantor's set theory and Peano's space-filling curve. Historically, the revolution was forced by the discovery of mathematical structures that did not fit the patterns of Euclid and Newton. These new structures were regarded by contemporary mathematicians as "pathological." They were described as a "gallery of monsters," kin to the cubist painting and atonal music that were upsetting established standards of taste in the arts at about the same time. The mathematicians who created the monsters regarded them as important in showing that the world of pure mathematics contains a richness of possibilities going far beyond the simple structures that they saw in nature. Twentieth-century mathematics flowered in the belief that it had transcended completely the limitations imposed by its natural origins.

Now, as Mandelbrot points out with one example after another, we see that nature has played a joke on the mathematicians. The 19th-century mathematicians may have been lacking in imagination, but nature was not. The same pathological structures that the mathematicians invented to break loose from 19th-century naturalism turn out to be inherent in familiar objects all around us in nature. We do not have to look far to find them. Human tissue, as Mandelbrot notes, "is a bona fide fractal surface. . . . *Lebesgue-Osgood monsters are the very substance of our flesh!*"

Unfortunately Mandelbrot's book is fractally written. The main theme is clear and important; some of the digressions are unimportant and unclear. There are many illustrations, all of them computer-generated mathematical structures rather than pictures of natural objects. Some of these computer print-outs are beautiful, some are illuminating, some are obscure and poorly explained. There is a factual error in the caption to plate 167. The dimension of the Sierpiński carpet shown in the picture is 1.8927, not 1.2618.

The reviewer particularly enjoyed chapter 11, a dense cluster of historical anecdotes. Mandelbrot has an affinity for eccentric characters, and his historical scholarship is meticulously exact. One of his finest discoveries is a book called *Two New Worlds*, published in 1907 by Edmund Fournier D'Albe and containing the first description of a fractally clustered universe. "It is," Mandelbrot says, "the kind of work in which one is surprised to find anything sensible. One fears attracting attention to it, lest the more disputable bulk of the material be taken seriously." Mandelbrot the scientific maverick finds in Fournier D'Albe a kindred spirit, while Mandelbrot the historian, in a fine display of irony, describes D'Albe's book in words that could also be used to describe his own.

FREEMAN DYSON
Institute for Advanced Study, Princeton, New Jersey 08540

Formative Processes

Self-Organization in Nonequilibrium Systems. From Dissipative Structures to Order through Fluctuations. G. NICOLIS and I. PRIGOGINE. Wiley-Interscience, New York, 1977. xiv, 492 pp., illus. $27.50.

Physical scientists have long been fascinated by biological problems. Many of the tools of modern biology, for example, centrifugation, electrophoresis, x-ray crystallography, and microscopy, were developed by physicists. Moreover, many physical scientists have metamorphosed into biologists and have made and are making fundamental contributions in many branches of biology.

Less well known than these contributions are the efforts of physical scientists to study the mechanisms underlying the control and development of spatial and temporal patterns in biological systems by appealing to underlying physical chemistry or by drawing on analogy between physical and biological processes. Books relevant to this approach were written over 50 years ago (*1, 2*), and there has been continual, though limited, interest in it ever since.

Over the past decade, a large research group centered in Brussels and consisting of Ilya Prigogine and his co-workers has been pursuing problems of self-organization in chemical and biological systems. This book summarizes advances made by the Brussels school and provides extensive references to related research. It is an interesting and important contribution to the scientific literature.

The book deals with "dissipative structures," their mathematical analysis, and their application to self-organizing processes. In an open system, which is free to exchange mass or energy or both with the surroundings, ordered structures can arise that require continued energy flow through the system in order to be maintained. The authors call these "dissipative structures." A well-known example in the physical sciences is Bénard cells, hexagonal convection cells formed when a shallow dish of water is heated from below.

The book is divided into five parts. Part 1 gives a brief discussion of equilibrium and nonequilibrium thermodynamics. Parts 2 and 3 develop mathematical techniques for the study of dissipative structures, with deterministic methods discussed in part 2 and stochastic methods discussed in part 3. Parts 4 and 5 deal with the application of the techniques to concrete problems, part 4 with control mechanisms in chemical and biological systems and part 5 with evolution and population dynamics. Throughout the book the writing is clear, there are numerous examples and diagrams, and the typography is excellent.

The main expository method used by the authors is to pose mathematical models for self-organizing processes and to analyze the models by available theoretical techniques, principally linear stability theory and numerical integration of nonlinear differential equations. "The primary objective in studying a model," the authors write, "is to discover the types of qualitative behaviour compatible with some fundamental laws, such as the laws of thermodynamics and chemical kinetics" (p. 93). Underlying this view is the assumption that as the mathematical model becomes more realistic, and probably more complicated, qualitative features of the equations will remain unchanged.

The "main object" of the book is the application of the techniques to concrete problems. This material constitutes less than a third of the book. Mathematical models are presented for a wide range of topics, including feedback inhibition in biochemistry, prebiotic evolution, and nest building by termites. Coverage of the applications tends to be superficial. Take, for example, the case of a mathematical model of nest building by termites. The model predicts that for certain ranges of parameters in the model a regular, spatially periodic array of termite nests will arise. Unfortunately, the authors do not develop the example further to show that the parameters adopted are biologically meaningful. Further, no comparisons are made between the observed spatial patterns of termite nests and the patterns predicted by the theory. Thus, a plausible theory of nest building is presented, but the power of the quantitative approach is not developed or utilized to test the theory critically. In other cases the ground is somewhat firmer. For example, for the oscillating Belousov-Zhabotinsky reaction, the kinetics have been studied and rate constants for the reaction have been derived. However, even here the hypothesized kinetics do not yet make possible a clear understanding of the varied geometrical configurations adopted by the reaction.

Readers not familiar with the chemical literature may receive the impression that all self-organizing processes in chemistry may be classified as dissipative structures. This is not the case. In the last century, a periodic precipitation phenomenon was discovered. Periodic precipitates called "Liesegang rings" can be generated in a variety of ways. One way is by saturating a filter paper with a dilute solution of a salt A and then placing a drop of a concentrated solution of a salt B, which forms a precipitate with A, in the center of the filter paper. As B diffuses out, a precipitate is formed in one of a variety of geometric patterns, for example concentric rings or spirals (*1*). Other self-organizing processes that occur during phase separation are well known, and elegant mathematical treatments, which use deterministic and stochastic methods similar to those developed in the text, are available (*3*). Because these structure-forming processes are of interest in chemistry and biology, reference to this earlier work and a discussion of its significance should have been included.

The book will be of interest to physical scientists seeking a recent review of work on self-organizing processes in chemistry and biology. In addition, many mathematicians will find that the models pose sharp problems concerning the behavior of nonlinear differential equations. Although the authors indicate which sections of the book should be read by experimental chemists, biologists, or sociologists interested primarily in applications, much of the material in the recommended sections requires a sophisticated mathematical background, which many potential readers will not have.

The authors point out that many of the topics covered in the book are still the subject of active research. The book should help to focus and sharpen analysis of these topics, and should also contribute to the growing recognition that processes of self-organization are amenable to both theoretical and experimental study. These processes will be a rich source of problems for many years to come.

LEON GLASS
Department of Physiology,
McGill University,
Montreal, Quebec H3C 3G1, Canada

References

1. E. S. Hedges and J. E. Meyers, *The Problem of Physicochemical Periodicity* (Arnold, London, 1926).
2. D. W. Thompson, *Growth and Form* (Cambridge Univ. Press, Cambridge, England, 1917); A. J. Lotka, *Elements of Physical Biology* (Williams and Wilkins, Baltimore, 1924).
3. W. A. Johnson and R. F. Mehl, *Trans. Am. Inst. Min. Metall. Eng.* **135**, 416 (1939); E. N. Gilbert, *Ann. Math. Stat.* **33**, 958 (1962); J. W. Cahn and R. J. Charles, *Phys. Chem. Glasses* **6**, 131 (1965).

An Infamous Element

The Chemistry of Mercury. C. A. McAuliffe, Ed. Macmillan of Canada/Maclean-Hunter Press, Toronto, 1977. viii, 288 pp., illus. $34.95.

In retrospect, the protagonist of this story always has been a villain. Yet around the middle of the 17th century John Woodall wrote in praise of mercury:

> The perfect cure proceeds from thee,
> For Pox, for Gout, for Leprosie,
> For scab, for itch, of any sort
> These cures with thee are but a sport.

This reflected the prevailing medical opinion. In Europe in the years between 1500 and 1900, mercury and some of its compounds were credited with curative powers, particularly in the treatment of syphilis, a scourge that ravished prince and pauper alike. Two types of mercury "therapy," rubbing and tubbing, became part of the Mother Goose collection our children still read today ("Rub-a-dub-dub, three men in a tub . . ."). The toxicity of the most obviously toxic mercurial compounds was recognized, however, as another verse of later vintage shows:

> Auntie Jane gave Baby Nell
> What she thought was calomel.
> But, alas, what baby ate
> Was pure corrosive sublimate.
> A dreadful error, I confess—
> One atom and one baby less.

But it remained for Alfred Stock to establish in the early 20th century that mercury vapor is a dangerous hazard. It was the mercury pollution scandals of recent years that led to the present sharp decline in the utilization of mercury and in the commercial production of its compounds.

Mercury—so aptly named quicksilver—has always fascinated people. We no longer share the belief of Thomas Dover, the "quicksilver doctor," that mercury cannot be harmful because it has no sharp corners or edges, but who can resist being intrigued by the sight of a globule of mercury rolling across a table top? Moreover, mercury and its compounds are still with us in everyday life—in thermometers, in dental amalgams, in mercury-vapor lamps, and so on. Mercury still finds industrial applications, such as the mercury cell used in the electrolytic preparation of chlorine and caustic soda. In university laboratories, research on the inorganic and, especially, the organic chemistry of mercury continues at a brisk pace. An up-to-date book on mercury chemistry is therefore useful and welcome.

The Chemistry of Mercury contains short accounts of four aspects of the subject. A 40-page history of mercury by W. V. Farrar and A. R. Williams is the opening chapter. In ten short sections the authors discuss diverse topics, including mercury in the ancient world, in China, and in alchemy, the mercury industry, mercury in the development of the "new chemistry," mercury-nitrogen compounds, mercury in industry and in pharmacy, organomercurials, and mercury as a poison. This chapter makes fascinating reading, and one wishes it could have been longer. (For a whole book on the history of mercury, but with emphasis on matters medical rather than chemical, the reader is referred to L. J. Goldwater's *Mercury: A History of Quicksilver*.)

The remaining three chapters of the book are devoted to recent advances in the chemistry and biochemistry of mercury and its compounds. The coordination chemistry of mercury, very broadly defined, is discussed by W. Levason and C. A. McAuliffe, mainly from a structural point of view. The coordination chemistry of organomercurials is not included, which is unfortunate since the subject is not covered in the organomercury chapter. Levason and McAuliffe's chapter is the only one of the four that deals with inorganic aspects of mercury chemistry, and it is regrettable that the authors restricted their coverage to bonding and solid state structure, omitting any discussion of the preparation, reactivity, and synthetic applications of inorganic mercury compounds. The important subject of mercury(II) in solution is summed up in a paragraph of only eight lines. Although mercurials with novel substituents, such as $Hg(SCF_3)_2$, $Hg(SeCF_3)_2$, $Hg[N(CF_3)_2]_2$, $Hg[ON(CF_3)_2]_2$, $Hg[N(SiMe_3)_2]_2$, and $Hg(NSF_2)_2$, are mentioned, an account of their interesting chemistry and their use in synthesis is not given. Nor does the discussion of compounds in which mercury is bonded to other metals cover their reactivity and applications. Even though one can criti-