is not a serious problem, for there exist adequate treatments in other books. There is not much discussion of the role played by molecules other than H_2 in interstellar studies. In my view, this is unfortunate, because much of the current observational effort is in this direction and often seems to be poorly connected to theoretical issues. Among the topics I would have liked to see discussed at greater length are: formation of molecules via charge-exchange process versus catalysis on the surface of dust particles, chemical fractionation, ionization equilibrium in molecular clouds, trapping of CO line emission in interstellar dust clouds, and interpretation of the large Doppler widths of interstellar molecular lines. Of course these topics are discussed in the literature, but inclusion of them here would have given the reader a better background for interpreting data.

The format of the book is attractive. The chapters and sections are well organized, and the figures are helpful (although relatively few in number). The index is well done, and there is a helpful list of symbols. Cross-references, which are plentiful, consist of citations of chapter, section, and subsection (not page). Unfortunately, none of these numbers appear serially at the top or bottom of the pages, so the reader must thumb through until his or her eye happens to light on the proper section.

In summary, *Physical Processes* will become the standard textbook in the field of theoretical studies of the interstellar medium, just as its predecessor was. Another generation of astrophysicists will be strongly influenced by Spitzer's approach to the field. And that is all to the good, for his mastery of the field is unparalleled.

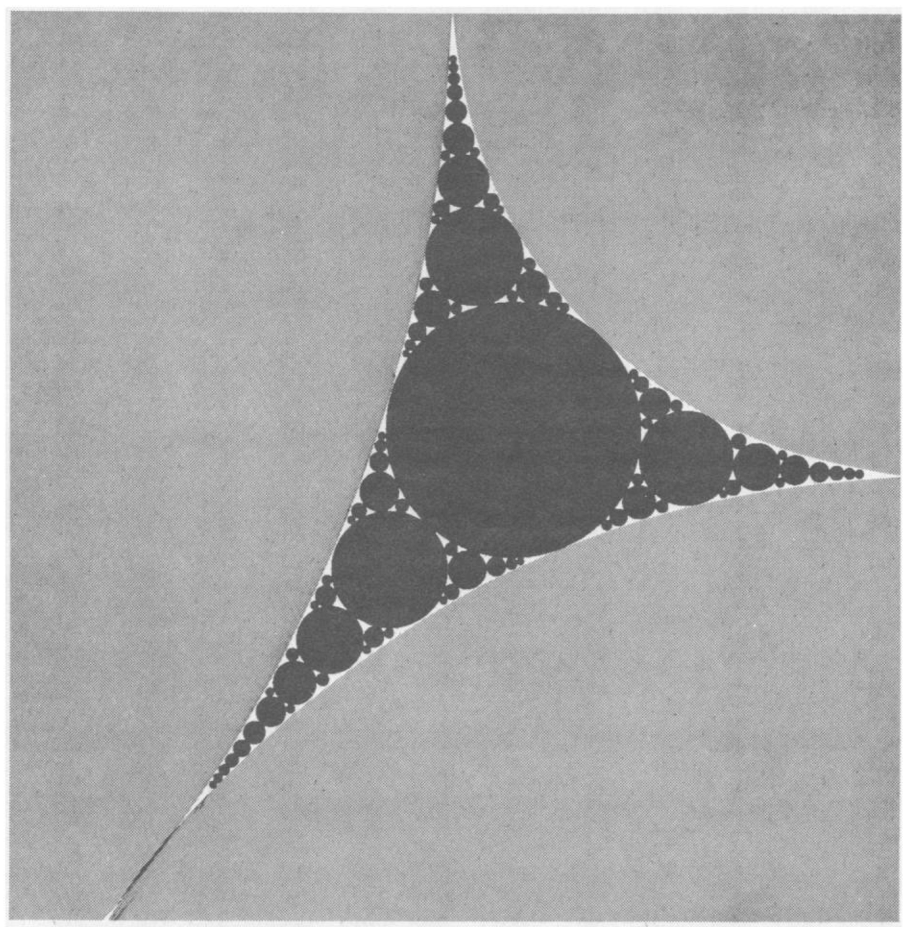
G. B. Field
Center for Astrophysics,
Harvard University,
Cambridge, Massachusetts 02138

Characterizing Irregularity

Fractals. Form, Chance, and Dimension. Benoit B. Mandelbrot. Translation and revision of French edition (Paris, 1975). Freeman, San Francisco, 1977. xviii, 366 pp., illus. $14.95.

"Fractal" is a word invented by Mandelbrot to bring together under one heading a large class of objects that have certain structural features in common although they appear in diverse contexts in astronomy, geography, biology, fluid dynamics, probability theory, and pure mathematics. The essential feature of a fractal is a fine-grained lumpiness or wiggliness that remains inherent in its texture no matter how thin you slice it. In an article in *Science* 11 years ago, "How long is the coast of Britain?," Mandelbrot pointed out that the concept of length is inappropriate to the description of a natural coastline. If you measure the length by following all the wiggles around the boundary of a map of Britain, the answer will depend on the scale of the map. The finer the scale, the more wiggly the boundary and the greater the measured length. To characterize the texture of the coastline in a manner independent of scale, you can say that it has a geometric dimension $D = 1.25$, intermediate between the dimension of a smooth curve ($D = 1$) and the dimension of a smooth surface ($D = 2$). The coastline is here showing the typical behavior of a fractal. In his book, Mandelbrot collects a great variety of examples from various domains of science and shows that they can all be described in the same way as the coastline of Britain by being assigned suitable "fractal dimensions." Important examples from human anatomy are our vascular system (veins and arteries) and the bronchiole structure of our lungs. In the vegetable world we have trees, in the world of geography we have river networks and archipelagoes, in astronomy we have the hierarchical clustering of stars and galaxies.

The cataloging of natural objects with fractal structure is only half of Mandelbrot's theme. The other half is the historical role that fractals played in the development of pure mathematics. A great revolution of ideas separates the classical mathematics of the 19th century from the modern mathematics of the 20th. Classical mathematics had its roots in the regular geometric structures of Euclid and the continuously evolving dy-



Apollonian gasket, dimension about 1.306951. "To construct a circle tangent to three given circles constitutes one of the geometric problems that tradition attributes to Apollonius of Perga. Begin with three gray circles tangent two by two, forming a circular triangle, and let the above construction be iterated to infinity. The black Apollonian circles (less their circumferences) will 'pack' our triangle, in the sense that almost every point of it will eventually be covered. The remainder will be called [an] *Apollonian gasket*. Its surface measure vanishes, while its linear measure, defined as the sum of the circumferences of the packing circles, is infinite. Thus the shape of the Apollonian gasket lies somewhere between a line and a surface. It enters in the theory of Smectic A liquid crystals." [From *Fractals*] 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