BIOLOGICAL CLOCKS AND HEARTBREAKING FAILURES

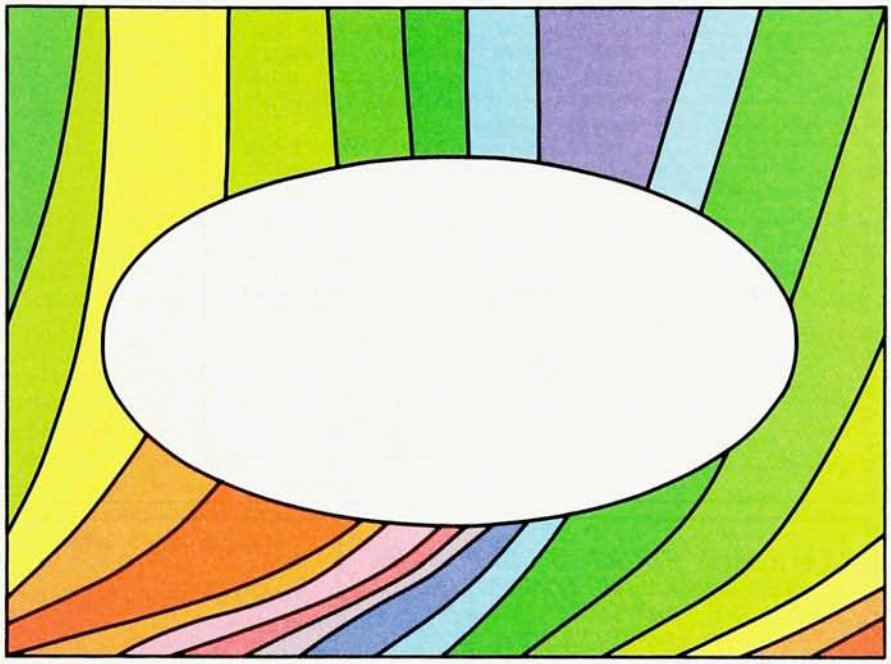
When Time Breaks Down: The Three-Dimensional Dynamics of Electrochemical Waves and Cardiac Arrhythmias

Arthur T. Winfree
Princeton U. P., Princeton, N. J., 1987. 339 pp.
$60.00 hc ISBN 0-691-08443-2; $19.95 pb ISBN 0-691-02402-2

Reviewed by John J. Tyson

The heart is an awesome machine, beating powerfully and relentlessly over one billion times in the life span of an animal. It is designed to function reliably under a variety of stresses and insults, but like any machine the heart can fail in characteristic and unavoidable ways. Some cardiac dysfunctions are relatively benign: skipped beats, atrial flutter, transient elevated pulse rate. Others are more serious. Rapid stimulation of the ventricle can degenerate into fibrillation, that is, complex, disorganized small-scale spasms of the ventricle that in the absence of drastic medical intervention end quickly and surely in death.

When Time Breaks Down sets forth Arthur Winfree's curiously roundabout journey from circadian rhythms, by way of chemical oscillations, to an idiosyncratic understanding of how and why hearts break down. The failure is woven mysteriously into the fabric of time and space, and like Sherlock Holmes (whose advice he liberally quotes) Winfree teases from a few seemingly insignificant threads the telltale clues to the mystery. The first clue comes from the geometry of biological time. Biological clocks, which cycle continuously through a circular sequence of states, must (Winfree argues) manifest a state of timelessness, that is, a state that marks either no time or all times, and clocks can be pushed into this timeless state by just the right disturbance applied at just the right time. Consider, by way of analogy, how a pendulum clock can be stopped elegantly if one strikes the bob at the bottom of its swing with just enough force to reduce its momentum to zero. That such singular time-breaking disturbances must exist for any (continuous) timekeeping mechanism is a topological necessity that Winfree explains ingeniously in terms of rainbow-colored diagrams. (The color wheel is a continuous circular sequence just like the clocks Winfree has in mind. Winfree exploits color wheels to great advantage in a companion volume, *The Timing of Biological Clocks* [Scientific American Books (Freeman), New York, 1987], which deals primarily



Timelessness in a resettable clock. The clock is reset by stimuli of various strengths (ordinate) applied at various phases in the clock cycle (abscissa). For a given combination of previous phase and stimulus strength, the new phase of the clock after resetting is represented by the color of the corresponding point. Stimuli of very small strength, for instance, cause negligible resetting, so the new phase is close to the old phase, and the clock goes through a complete cycle of phase (red-violet-blue-green-yellow-orange-red) along the bottom edge. In contrast, stimuli of large strength, at the top of the rectangle, reset the clock to a limited range of new phases (blue-green). To see what happens for stimuli of intermediate strength, color in the white oval in as simple and continuous a fashion as possible. You will find a point of ambiguous color somewhere inside. (Adapted from *When Time Breaks Down* by permission of the publisher.)

John J. Tyson studies oscillations and traveling waves in chemical, biochemical and biophysical systems at Virginia Polytechnic Institute and State University.

with circadian rhythms.)

The second clue comes from space. Consider a spatially distributed population of clocks, such as the pacemaking region of the heart (the sinoatrial node). A wave of initiation passes across the field, creating a gradient of phase (local time) in the population. Orthogonal to the phase gradient Winfree imagines a graded disturbance ranging from weak to strong. Somewhere in the field, then, there must lie that singular combination of disturbance strength and timing that reduces the local clocks to timelessness. More significantly, round about the timeless spot one finds a complete cycle of clock phases. From this pinwheel of initial states a rotating spiral of activity (electrical stimulation and muscular contraction) evolves. If the oscillators are electrically coupled to their neighbors, the spiral will spin rapidly with a period just sufficient to allow the cardiac cells to recover between beats. Indeed, an electrically coupled population need not even be spontaneously oscillatory to support such high-frequency rotating spiral waves of activation.

These pinwheels of phase can be created, Winfree argues, by aberrant electrical stimulation of the ventricle arriving during a vulnerable phase of the heartbeat, just as the ventricles are recovering from a contraction. Such a vulnerable phase, about 50 milliseconds in duration, has long been known to cardiologists. The spiral wave developing from the pinwheel rotates about four times per second, characteristic of ventricular tachycardia (rapid heartbeat). In a heart damaged by coronary occlusions, the high-frequency volley of excitation from the original spiral soon fractures into myriad rotating spiral wavelets, which Winfree interprets as ventricular fibrillation.

The story does not end here, for the ventricle is a three-dimensional tissue and the curious rotating waves are not spirals but scrolls, spinning around a filamentous core that itself twists and writhes about within the muscle. The last section of the book dissects these fascinating structures in a spectacular series of computer graphics.

Relying on color diagrams and geometric intuition, Winfree avoids equations and technical details. This approach gives his argument great generality and appeal but entails in places some unconvincing "handwaving." Not to worry, though; there is solid ground underneath and you are in the company of a reliable guide. [See also Winfree's article in PHYSICS TODAY, March 1975, page 34.]

Anyone interested in spatiotemporal organization in biological systems will enjoy and profit from reading Winfree's incisive and brilliantly inventive thoughts about cardiac function and failure.

Physics at Surfaces

Andrew Zangwill
Cambridge U. P., New York, 1988. 454 pp.
$69.50 hc ISBN 0-521-32147-6;
$27.95 pb ISBN 0-521-34752-1

At last the physics and physical chemistry communities have available the book that has been so badly needed for so long. I am referring to the delightful *Physics at Surfaces* by Andrew Zangwill just published by Cambridge University Press. Zangwill calls the book "a traveling companion—a tour guide if you will—through the world of surface physics.... [but] not a textbook—at least not in the traditional sense." By rights it nonetheless will become the classic "teaching book" for graduate-level introductory courses in solid-state surface physics. But the book also provides the coherent synthesis of much of what purports to be surface physics that active teachers and researchers in the field are so in need of.

The book is sensibly structured, with an inevitable division between clean and adsorbate-covered surfaces. Thermodynamic arguments are presented as useful complements to the detailed microscopic models here, in contrast to the usual situation, in which thermodynamics appears to be invoked only by default. Within each half of the book, separate chapters cover crystal structure, electronic structure, phase transitions, and excitations and energy transfer. Such scope necessarily dictates a certain lack of rigor in a book of roughly 450 pages. Fortunately, Zangwill consistently comes up with enlightening simple arguments and physical pictures (which could easily be obscured by more rigor) presented in conjunction with actual data, either computed or observed. Zangwill displays in a very positive way to the reader the scenario by which system-specific individual studies are woven into the fabric of a "bigger picture." Make no mistake though, this is not a handbook or a "how to" recipe book for setting up shop as a surface-science tradesman; instead, it suggests by example how to look at nature, as surface physicists see it, from a vantage point where the attainment of understanding is deemed a more important goal than gathering in yet another concept-free number. The necessity of a symbiotic relationship between experimental and theoretical inquiry is evident throughout. For the reader who has a reasonable mastery of solid-state physics at the level of Neil Ashcroft and David Mermin's *Solid State Physics* (Holt, Rinehart and Winston, Philadelphia, 1976), the book is self-contained. Although not intended as either a comprehensive review or a research monograph, the book has nearly 600 well-chosen references. On this basis, the reader should be able to enter the research literature sensibly.

Physics at Surfaces, used together with Gerhard Ertl and Jürgen Küppers's fine, techniques-oriented monograph *Low Energy Electrons and Surface Chemistry* (VCH, Weinheim, FRG, 1985), would be an ideal combination for teaching a graduate course. Both Zangwill and Cambridge University Press are to be complimented for providing this handsome volume in not only hardcover but also inexpensive paperback, making the book financially accessible to everyone with an interest in surface physics. Certainly anyone who is now being introduced to the discipline of surface physics will find his or her training profoundly and positively influenced by the availability of *Physics at Surfaces*.

J. W. GADZUK
National Institute of Standards and Technology

Spin Glass Theory and Beyond

M. Mezard, G. Parisi and M. A. Virasoro
World Scientific, Singapore (Teaneck, N. J.), 1987. 461 pp.
$86.00 hc ISBN 9971-50-115-5;
$48.00 pb ISBN 9971-50-116-3

The term "spin glass" first became widely used about 15 years ago. It was coined to describe disordered magnetic systems that appeared to have a phase transition to a state in which each magnetic atom was aligned but the direction of alignment varied randomly from one atom to another. In 1975 David Sherrington and Scott Kirkpatrick wrote a paper that had the provocative title "Solvable Model of a Spin Glass," but which presented a paradox rather than a satisfactory solution. Not until four or five years later did Giorgio Parisi find an apparently satisfactory solution. Several more years elapsed before the significance and physical interpretation of this solution were understood.