'Wet' Physics: The Physics of Biological Phenomena

Physics with Illustrative Examples from Medicine and Biology

George B. Benedek and Felix M. H. Villars

Volume 1: Mechanics. *AIP Press/Springer-Verlag, New York, 2000 [1973] 2nd ed. $69.95 (548 pp.). ISBN 0-387-98769-X*

Volume 2: Statistical Physics. *AIP Press/Springer-Verlag, New York, 2000 [1974] 2nd ed. $69.95 (640 pp.). ISBN 0-387-98754-1*

Volume 3: Electricity and Magnetism. *AIP Press/Springer-Verlag, New York, 2000 [1979] 2nd ed. $69.95 (670 pp.). ISBN 0-387-98770-3*

Volumes 1–3: *$169.00 set ISBN 0-387-98952-8*

Reviewed by Russell K. Hobbie

The physics department at the Massachusetts Institute of Technology began about 30 years ago to offer a special calculus-based introductory course for freshmen and sophomores interested in biology. This led to the first edition of George B. Benedek and Felix M. H. Villars's *Physics with Illustrative Examples from Medicine and Biology*. The book was issued by Addison-Wesley in 1979 as three paperback, typescript volumes. The books fascinated many physicists with the application of physics to problems in biochemistry and physiology, but they have been out of print since 1990. Now that AIP Press and Springer-Verlag have issued a second edition, as printed volumes, a new generation of physicists can learn from them.

The content is unusual for an introductory physics course. Many of the topics are traditionally considered to be physical chemistry, biochemistry, or physiology. However, physicists usually approach them from a slightly different point of view; physics should reclaim them as its own.

In the mechanics volume there are three topics that I found particularly fascinating. One is the physiologic effects of altitude sickness. The book describes an ascent of Mont Blanc in 1869 and a tragic balloon flight in 1875. Both are explained by combining the decrease with altitude in oxygen partial pressure with some simple observations from pulmonary physiology and the empirical oxygen dissociation curve for hemoglobin. The second topic is surviving a fall from a great height. Survival can be related to the distance traveled and duration of the decelerating impact. A number of amazing survivals in falls from aircraft are documented. There is also a discussion of feedback systems not usually found in an introductory text. It begins with the variations in speed of a steam engine under load, shows that these variations can be reduced with the centrifugal governor, and goes on to describe the instability that results from the introduction of a time delay in the feedback system. Biological examples include regulation of body temperature and blood glucose.

Some of the topics in the statistical-physics volume are quite important in physiology, but are usually ignored by physicists. Two examples are diffusion, which is important for transport at the cellular level, and the flow of solute and solvent across a membrane, effected by a combination of drift and diffusion.

Many other examples, such as the chemical potential, entropy of mixing, and Helmholtz and Gibbs free energies, are normally found in physical chemistry or biochemistry courses. Here we see how we can teach them from a physics perspective. Particularly fascinating is the Luria–Delbrück experiment, a classic in bacterial genetics. When *E. coli* bacteria are infected by a bacteriophage virus, some of them survive and reproduce, and their descendants inherit resistance. The experiment, reported in 1943, showed conclusively that resistance in descendants does not obey simple Poisson statistics but is due to mutations—a wonderful example of quantitative analysis in genetics.

The volume on electricity and magnetism is novel. Coulomb's law is introduced as the force between an atomic nucleus and an electron, rather than as a force between macroscopic charged objects. The discussion of field lines is more thorough than usual. The Laplace equation is derived and a "stockpile" of solutions is presented for later use. There is an extensive discussion of polarization and dielectrics, including gases and nonpolar and polar liquids. Electrocardiography is explained using a dipole model. Unusual in a physics text, but important for biology, are the Nernst–Planck equation, Debye shielding, Poisson–Boltzmann equation, electrophoresis, electrochemistry, Debye–Hückel theory, and Donnan equilibrium, all of which lead to the cable model of the axon and the Hodgkin–Huxley model for the action potential. The last chapter, on electromagnetism, is a standard but compact introduction to magnetism, Maxwell's equations, and electromagnetic waves.

Some differences exist between the first and second editions, but not as many as one might expect. In the section on feedback systems, I wish that the authors had added something about our current understanding of chaotic behavior in nonlinear systems. The most extensive changes are in volume 2, in which a section has been added on the Monod-Wyman-Changeaux allosteric model for oxygen binding to hemoglobin and on other models for ligand binding to proteins. I was disappointed to find that, in volume 3, the magnetic field associated with the heart was not described. There are interesting similarities between the electrocardiogram and the magnetocardiogram, both of which arise from the current dipole associated with cardiac activity. I also did not find mention of the importance of gated channels that we now know lead to changing sodium and potassium conductances of the Hodgkin–Huxley model.

This is not your typical introductory text, in terms of format and style as well as content. The writing is com-

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pact. It has none of the color drawings and photographs that take up so much space in current introductory texts. Vector differential and integral calculus are used extensively. The text discusses solutions of the Laplace equation with various boundary conditions. A teacher will have to examine it carefully and decide whether to use it as the only text or as a supplementary text in an introductory course.

These are classic books, and anyone planning to include biophysical examples in a calculus-level course should study them carefully. The authors are to be congratulated for their work, and I commend AIP Press and Springer-Verlag for making the books available again.

Statistical Physics: Statics, Dynamics, and Renormalization

Leo P. Kadanoff
World Scientific, River Edge, N.J., 2000. $78.00, $38.00 paper (483 pp.). ISBN 981-02-3758-8, ISBN 981-02-3764-2 paper

Even though I had few standards by which to gauge graduate students, it was clear that Leo Kadanoff, one of my first students, was special. No subject—from the mathematical properties of coherent states, which he studied with Roy Glauber, to the heating of nose cones, on which he consulted for a local defense contractor—was too abstract or too applied, and no calculation was too daunting. He took pride in finding answers speedily and cleverly. Spelling was not his forte, but there were few words between his equations. His talent and eclecticism were apparent, but the clear, elegant, economical, and idiosyncratic style that marks his lectures and writings was not yet evident.

With Gordon Baym, Kadanoff published his first book on statistical physics, *Quantum Statistical Mechanics* (Benjamin), in 1962. His recently published *Statistical Physics: Statics, Dynamics, and Renormalization*, is strikingly different. It is hardly surprising that books on statistical physics written almost 40 years apart should have little in common or that the newer of the two should be more inclusive or general.

In the most abstract sense, statistical physics encompasses all natural phenomena. Every process obeys the laws of physics and no system can be described with arbitrary precision. But this observation has no consequence. The significant fact is that the statistical mechanical techniques that were primarily used to explain the properties of gases and crystals fifty years ago, are now being widely applied to "squishy" matter (polymers, gels, and biomaterials), to living things, and even to such "unnatural" phenomena as financial systems and computational networks.

Readers of *Quantum Statistical Mechanics* might infer that microscopic dynamics and macroscopic thermodynamics are tightly linked and that techniques for calculating the static and dynamic behavior of complex systems are not beyond reach. Readers of *Statistical Physics* will immediately appreciate, from Kadanoff's provocative allusions to glasses, turbulent fluids, chemical reactions, and vortices in superconductors, that (1) the links between thermodynamics and both hydrodynamics and microscopic dynamics are often very tenuous, and (2) the construction of relevant dynamical models is an art. Models that have no apparent connection with the underlying equations for fluid flow may be relevant both for turbulent flows and for stock price fluctuations.

The piquant hors d'oeuvres in the introduction to *Statistical Physics* may raise the expectations of some readers excessively. Apart from an interesting discussion of multiplicative random processes that explains why Gaussian distributions drastically underestimate the frequency of rare events, the ingredients of the main course are relatively conventional. The subjects, derivations, and examples that appear in the text (as distinct from the reprints)—in the half of the book that covers general statistical mechanics—are old friends: ensembles, Gaussian distributions, diffusion, Langevin and Fokker–Planck equations, conservation laws and hydrodynamics, correlations and fluctuations in systems at or near equilibrium, and noninteracting Bose and Fermi gases.

Some of these subjects are subtle, and Kadanoff spices his wide-ranging presentation with illuminating observations, illustrations, and instructive problems. The first half of the book concludes with reprints (altogether, reprints compose about 40% of *Statistical Physics*) on diffusion-limited aggregation and self-organized criticality, two "big ideas" on which Kadanoff and his colleagues and collaborators have worked. Readers who haven't experienced Kadanoff's classes may well wonder what prompted the author to bind these reprints to the preceding text, interesting as they both may be. Readers may also lament the absence of what surely would be a valuable exposition of some aspects of the complex natural phenomena to which Kadanoff alludes. How about a second volume, Leo?

In the second half of the book (about 60% of which consists of reprints), Kadanoff discusses second-order phase transitions, an area in which his seminal contributions are legend. After an introductory chapter on mean-field theory, he discusses the phenomenological theory of scaling (a theory that he attributes to Ben Widom but that Kadanoff had developed independently before I referred him to Widom's papers). Then he deals with fixed points, universality, operator expansions, duality, the Ising model, real space renormalization methods, and systems with two-dimensional continuous symmetries. One still marvels at the beauty and generality of the physical and mathematical concepts and the ingenious calculational techniques Kadanoff introduced during the late 1960s and early 1970s and lucidly reviews here, to say nothing of his work with Jack Swift on mode coupling and lattice hydrodynamics and its relation to the work of others on dynamic critical phenomena!

Nonetheless, should a text on applications of the renormalization group to continuous phase transitions say nothing about upper and lower critical dimensions? And should it dispense in a single sentence ("The most remarkable application of [Wilson's] theory was the [Wilson and Fisher] development of an expansion about 4 dimensions.") with the expansion techniques (involving dimension and the inverse of the number of components of the order parameter) that are widely used to calculate critical exponents?

In short, *Statistical Physics* is a collection of valuable essays and papers. Both the text and the reprints display Kadanoff's ingenuity, imagination, and clarity. They're worth having and reading, as are most of the classic papers of others, (including Tom Witten and Leonard Sander; Mike Kosterlitz and David Thouless; and David Nelson) that the book contains. Students who took courses in which Kadanoff discussed these papers were very well served.

But students not lucky enough to have heard Kadanoff in person may wonder why some classic materials are not included and wish that Kadanoff had bound the contents together with more pedagogic glue. They'll also note