The meandering road to quantum fields

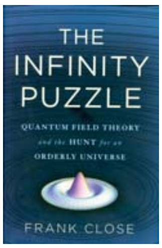
The Infinity Puzzle

Quantum Field Theory and the Hunt for an Orderly Universe

Frank Close
Basic Books, New York, 2011. $28.99 (435 pp.). ISBN 978-0-465-02144-4

Reviewed by Chad Orzel

Most general-audience books on the history of science tend to present a sort of whiggish view—a streamlined version in which scientific progress is steady. Professional scientists, of course, know that real science proceeds in fits and starts, with numerous side trips, missteps, and missed opportunities along the way. Thus it's a pleasure to read books that present a more complete story, such as David Lindley's *Uncertainty: Einstein, Heisenberg, Bohr, and the Struggle for the Soul of Science* (Doubleday, 2007); Louisa Gilder's *The Age of Entanglement: When Quantum Physics Was Reborn* (Knopf, 2008); and Abraham Pais's magisterial *"Subtle Is the Lord . . .": The Science and the Life of Albert Einstein* (Oxford University Press, 1982).



Frank Close's *The Infinity Puzzle: Quantum Field Theory and the Hunt for an Orderly Universe* is another entry in this too-small category. *The Infinity Puzzle* takes on the complicated and somewhat controversial history of the development of modern quantum field theory, beginning with quantum electrodynamics in the 1940s and walking the reader through electroweak unification and quantum chromodynamics in the 1970s. (The title is a reference to the infinities that plagued the earliest attempts to calculate basic properties of quantum particles.) This book covers much the same ground as, but with considerably more detail than, Ian Sample's more whiggish *Massive: The Missing Particle That Sparked the Greatest Hunt in Science* (Basic Books, 2010; reviewed by Michael Peskin in PHYSICS TODAY, May 2011, page 47). Sample provided a high-level overview of the theoretical developments leading up to what is now called the Higgs mechanism; Close gets into the details of who predicted what, and when, and also who missed what, and when.

As Close points out, the Higgs mechanism might be better called the "Anderson-Brout-Englert-Guralnik-Hagen-Higgs-Kibble-'t Hooft mechanism" for the eight men who independently developed it in the early 1960s. The story of its development is a tale of interdisciplinary physics, in that key insights regarding symmetry breaking in electroweak interactions come from condensed-matter physics; odd coincidences, such as the British postal strike that prevented Carl Richard Hagen and Gerald Guralnik from learning of their competitors' work; and missed opportunities. The tangled history could easily become incomprehensible, but Close tells the story very well, particularly in highlighting poor communications that delayed by years the completion of the electroweak unification theory. Examples include a brief conversation between Sheldon Glashow and Peter Higgs, neither of whom realized that their two theories could be combined; another encounter in which John Ward prevented Guralnik from talking about his research; and Robert Marshak's discouraging Guralnik from continuing to work on the weak force.

Another important contribution by Close is a detailed reconstruction of the disputed history of the strong-interaction theory. David Gross, Frank Wilczek, and David Politzer shared the 2004 Nobel Prize in Physics for that work, but each has provided somewhat contradictory descriptions of how they reached their conclusions and about how much discussion took place between Gross and Wilczek at Princeton University and Politzer and Sidney Coleman at Harvard University. Close goes over their stories in detail, drawing on published comments and personal conversations in an attempt to piece together a coherent chronology; his explanation of the reconstruction process is almost as fascinating as the underlying science.

In some places, Close's focus on the details—in particular his discussion of Abdus Salam's work—threatens to become inside baseball. Close devotes the better part of a chapter to the question of how Salam came to share the 1979 Nobel Prize in Physics and how Ward, his key collaborator, was left out. The section might strike some readers as being too much Nobel gossip and perhaps a little uncharitable toward Salam.

The physics explanations in *The Infinity Puzzle* are admirably clear. That is impressive since the book contains no equations and yet goes into more detail than similar popularizations about gauge invariance, Yang–Mills theories, Goldstone bosons, superconductivity, and Bjorken scaling in electron–proton scattering experiments. Those detailed discussions require more work from the nonexpert reader, but the extra effort will be well rewarded.

The Infinity Puzzle is an excellent presentation of the history of what is arguably the greatest achievement of 20th-century theoretical physics. Anyone with an interest in physics will enjoy the book, but physicists and those studying the history of science will find it particularly rewarding.

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Introduction to Statistical Mechanics

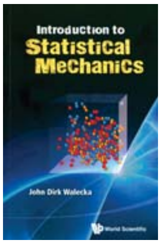
John Dirk Walecka
World Scientific, Hackensack, NJ, 2011. $98.00, $58.00 paper (365 pp.). ISBN 978-981-4366-20-5, ISBN 978-981-4366-21-2 paper

Statistical Mechanics in a Nutshell

Luca Peliti
(translated from Italian by Mark Epstein)
Princeton U. Press, Princeton, NJ, 2011. $75.00 (398 pp.). ISBN 978-0-691-14529-7

When students are first exposed at the undergraduate or graduate level to statistical mechanics, they are still processing the tools and concepts of classical mechanics, quantum mechanics, and electromagnetism. Thus it is important that a statistical mechanics course include expert teaching and guidance to relate that course's concepts to students' emerging interests. And students who eventually become researchers will find it helpful to have understandable textbooks with which they can quickly reference important details for successful application of statistical mechanics.

Two new statistical mechanics texts provide clarity on the subject's key concepts and applications.



Introduction to Statistical Mechanics by John Dirk Walecka makes the subject inviting and reads as a nice sequel to his *Fundamentals of Statistical Mechanics: Manuscript and Notes of Felix Bloch* (Stanford University Press, 1989; reviewed by Robert Pelcovits in PHYSICS TODAY, July 1990, page 69), which Walecka prepared and edited. *Statistical Mechanics in a Nutshell* by Luca Peliti is a more sophisticated presentation that will be of value to advanced students, lecturers, and practitioners.

Walecka's edited Bloch notes influenced my views on phase space, classical versus quantum pictures, and the density-matrix formalism. I recall Walecka writing in the preface that he intended to use Bloch's approach to teaching the subject, so I engaged Walecka's *Introduction to Statistical Mechanics* with an expectation of déjà vu. However, I found the newer work to be an original and appealing presentation and not a recast of Bloch's notes.

Overall, the text's practical feel will give students a good sense of what it means to use statistical mechanics; that achievement is also shared by Ryōgo Kubo's *Statistical Mechanics: An Advanced Course with Problems and Solutions* (2nd edition, North-Holland, 1988). Walecka provides a clear narrative with several standard calculations that students are often left alone to figure out on their own. One example concerns the method of steepest descent, an important technique used in several areas of physics. He also presents various applications of statistical ensembles, particularly in the section on molecular spectroscopy. In the classroom, applications tend to be limited to the problem sets, yet in this case students will gain from Walecka's descriptive treatment of diatomic or polyatomic molecules in explaining molecular spectroscopy. Moreover, he also plants seeds for future learning in the chapter "Special topics," which includes discussions of mean-field theory and order–disorder transitions.

Promising though it is as introductory text, *Introduction to Statistical Mechanics* contains some awkward notation. Instead of using the widely accepted β, Walecka writes out $1/k_BT$. Also, I found it initially off-putting to see the partition function labeled as "p.f.," though I came to appreciate that label more when I thought about how much effort it takes to write symbols for partition functions of different canonical ensembles. Such stylistic choices in notation and labeling may bog down students, who should be focused on applying the tools of statistical mechanics to real, physical systems. I believe Walecka's notations were intended to dissuade students from rote memorization and to focus them on a physical understanding of temperature and on building the correct partition function.

Peliti's *Statistical Mechanics in a Nutshell*—originally published in Italian (Bollati Boringhieri, 2003)—is a fantastic reference for those who know the subject, teach it, or need a quick technical reminder, especially on the topic of phase transitions, which are consistently featured in modern-day discussions and one that Walecka's book omits. Browsing Peliti's book reminded me of such texts as Kerson Huang's *Statistical Mechanics* (2nd edition, Wiley, 1987); David Chandler's *Introduction to Modern Statistical Mechanics* (Oxford University Press, 1987); and Mehran Kardar's *Statistical Physics of Particles* and *Statistical Physics of Fields* (both published by Cambridge University Press, 2007).

Of the books under review, *Statistical Mechanics in a Nutshell* provides the more general overview, with topics such as the renormalization group method. It includes a good mix of fundamental thermodynamics, phase behavior, and other key subjects. Even so, I do not see it as a standalone book for introductory students, even if they are energetic and serious; they will need an expert teacher or practitioner to make the ideas become more vivid in the classroom.

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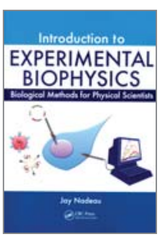
Introduction to Experimental Biophysics

Biological Methods for Physical Scientists

Jay Nadeau
CRC Press, Boca Raton, FL, 2012.
$89.95 (641 pp.).
ISBN 978-1-4398-2953-0

Each year a number of physicists leave various disciplines to become biophysicists. Those converted physicists are challenged to learn various life-science laboratory techniques applicable to molecular biology, microbiology, biochemistry, and cell biology, among other subfields. They also must become familiar with the spectroscopic, microscopic, and other important physical techniques that are now staples of many biological physics labs.



Those challenges highlight the need for effective laboratory manuals, protocols, guides, and other instructional material. Jay Nadeau's *Introduction to Experimental Biophysics: Biological Methods for Physical Scientists* is an ambitious text aimed at educating new graduate students about the important and most common techniques used in a modern biological physics laboratory; it could also serve nicely as a reference manual for advanced graduate students of new or underused protocols. Whereas most existing texts of its kind are aimed at educating biologists or biochemists, Nadeau's is aimed at young biophysicists and more seasoned researchers transferring to the field.

Introduction to Experimental Biophysics includes chapters that cover basic concepts behind commonly used biological techniques—for example, transfection, protein purification, and protein crystallography. Other, more physically flavored chapters discuss the concepts behind microscopy, surface chemistry, inorganic nanoparticles, and quantum dots. Each chapter contains protocols and the conceptual reasoning behind them, which is often useful to physicists performing biological experiments for the first time. Specific gems of the book include an overview in chapter 1 of the physical principles common in biological systems; a detailed experimental overview in chapter 5 of x-ray protein crystallization and a useful troubleshooting section to help novices; and a number of extremely useful discussions in chapter 10 on surface modification and functionalization. Surface preparation is particularly important in biophysics: If done incorrectly, it can ruin an otherwise beautiful experiment. The end of each chapter includes extensive references, information about equipment suppliers, helpful websites and software, and additional experimental protocols.

Despite its more than 600 pages, the book is still lacking in some aspects. Perhaps that's not surprising, given its broad scope and ambitious nature. First, most chapters give few details about advanced techniques. For instance, in chapter 6, which covers light microscopy, only one paragraph discusses total internal reflection fluorescence microscopy. Nowhere does the book mention optical or magnetic tweezers, which are used in force spectroscopy and are prevalent in modern biological physics laboratories. Further, various microscopies are discussed in multiple chapters, with electron microscopy (only scanning EM and not transmission EM) addressed in chapter 8 and atomic force microscopy presented in chapter 10.

The book does not mention techniques that use phospholipids, has insufficient information on chromatographic techniques, and lacks a discussion of the usefulness of centrifugation. New entrants to the field would benefit from learning about the best strategies to extract data—a skill that is not always obvious to beginners—and from knowing the limits of the various techniques, as was done in the troubleshooting section of chapter 5 on protein crystallization and in the example experiments for flow cytometry in chapter 7.

Overall, the many outstanding qualities of *Introduction to Experimental Biophysics* should make it an essential part of the biophysicist's collection. For new students, it is best partnered with the following texts. *At the Bench: A Laboratory Navigator* (Cold Spring Harbor Laboratory Press, 2005), by Kathy Barker, contains useful information about the social forces that shape the establishment of laboratories and how to cope with working in the lab on a daily basis. And *Principles and Techniques of Biochemistry and Molecular Biology* (7th edition, Cambridge University Press, 2010), edited by Keith Wilson and John Walker, provides useful basic information, including a table of units and standard formulas needed to analyze biochemical data.

Introduction to Experimental Biophysics assumes readers are already acclimated to the lab and can figure out for themselves how to analyze the data, if only they could get the data using the right biological experimental techniques. This book is likely to become increasingly useful with future editions and iterations, but in its current state, other sources—most likely collaborating biologists—will be required to fill in the gaps.

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Neither Physics nor Chemistry

A History of Quantum Chemistry

Kostas Gavroglu and Ana Simões
MIT Press, Cambridge, MA, 2012.
$40.00 (351 pp.).
ISBN 978-0-262-01618-6

The way new areas of science are birthed is similar to the way continental masses are formed: by the contact and