The Science of Ocean Waves: Ripples, Tsunamis, and Stormy Seas

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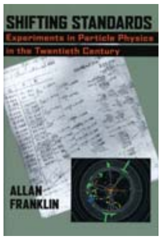
Raising the bar for statistical rigor

Shifting Standards
Experiments in Particle Physics in the Twentieth Century

Allan Franklin
U. Pittsburgh Press, 2013. $50.00
(360 pp.). ISBN 978-0-8229-4430-0

Reviewed by Paul Halpern

As Allan Franklin rightly points out in his informative new book, *Shifting Standards: Experiments in Particle Physics in the Twentieth Century*, the Higgs boson discovery in 2012 was a high-water mark for media coverage of the role of statistics in particle physics. Numerous news articles at the time drew attention to the litmus test for gauging whether the detected signals conclusively heralded the expected Higgs decay: a significance of at least five sigma (standard deviations) from the background distribution. In other words, the odds of such signals appearing by chance would be less likely than landing 20 heads in a row in a coin toss.



Demonstrating that such a strict cutoff has a makeshift quality, Franklin calls for a reasoned analysis of an experiment's specific conditions, including the suppositions of researchers and the factors that contribute to the background. Drawing on numerous detailed examples, he argues that a simple numerical criterion is far from the full picture. And yet, five sigma has become the standard for high-energy physics—a measure by which papers claiming discovery have been accepted or rejected.

Through a series of case studies spanning many decades, Franklin expertly shows how the five-sigma rule emerged from less demanding statistical standards. The jump in expectations has coincided with an enormous increase in researchers' ability to collect and process vast quantities of data, such as from the ATLAS and CMS detectors of CERN's Large Hadron Collider and formerly from the DZero and CDF detectors at Fermilab.

Of course, early 20th-century experiments—for example, Robert Millikan's famous oil-drop studies in the 1910s of the fundamental charge of an electron—involved far smaller data sets. Millikan's notebooks indicate only 175 drop values, half of which were discarded in his 1913 paper. "Millikan's selectivity and exclusion were hidden from the physics community," notes Franklin. Standards back then were far looser, yet physics progressed.

Franklin offers interesting cases of clashes resulting from disagreements about statistical measurements. Disputes over the reality of purported dark-matter particle findings offer a prime example. Some groups have claimed detection of such particles; others have been skeptical and have pointed fingers at what they see as inadequate statistical analysis. A smoking gun to some is just smoke and mirrors to others.

Although it is a well-researched book, *Shifting Standards* seems targeted at a limited audience: readers with a strong background in the terminology and methods of particle physics. Nonspecialists will no doubt find the author's detailed accounts of various experiments hard to follow. Often, Franklin introduces technical nomenclature—Monte Carlo simulations, scattering angle, scintillation, silicon vertex detectors, torsion balances—with not even simple definitions, let alone explanations. The style he uses matches the dry, precise language of technical journals rather than the more inviting discourse of books aimed at nonspecialists. He presumes that readers are familiar enough with the standard model and its components that they would understand why experimenters would wish to record certain types of interactions and seek particular parameters.

That said, *Shifting Standards* serves as a valuable, albeit specialized, guide to the history of statistics in high-energy physics. Franklin's study is timely, given the increasing requirement for modern discoveries to be validated by the weeding out of untold terabytes of background data, by running simulations, and by using statistical techniques that reveal a glimpse of a rare, fleeting interaction. His background is well suited for this exposition. He has published amply in the history and philosophy of science, including many books and articles about milestones in particle physics.

In a visit to the ATLAS experiment some years ago, I spoke with several graduate students and asked them what their day-to-day tasks were like. Most were involved with computer simulations rather than hardware. What a far cry from my own graduate days, I thought, when working with cables, counters, monitors, and duct tape in a stifling trailer or subterranean enclave was a universal initiation to the field. Any young researcher thinking of studying high-energy physics today would do well to delve into *Shifting Standards*. When it comes to the business of identifying new particles and measuring their parameters, avoiding statistics would be a bad bet.

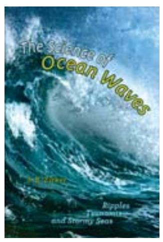
Paul Halpern is professor of physics at the University of the Sciences in Philadelphia and the author of several books, including *Collider: The Search for the World's Smallest Particles* (Wiley, 2009).

The Science of Ocean Waves
Ripples, Tsunamis, and Stormy Seas

J. B. Zirker
Johns Hopkins U. Press, 2013. $39.95
(248 pp.). ISBN 978-1-4214-1078-4

Few topics in physics can match the complexity of air–sea interactions. So it is no wonder that an astrophysicist, a practitioner in a similarly complex system, took up the challenge of summarizing for the general reader the modern scientific view on ocean waves.

In his new book, *The Science of Ocean Waves: Ripples, Tsunamis, and Stormy Seas*, J. B. Zirker offers a comprehensive and up-to-date account of a familiar phenomenon whose complexity is hardly appreciated by nonscientists. Zirker's deep insights, historic perspectives, and excellent narrative, which he provides with minimal graphics and without a single equation, make the book a fascinating read. It is also an unusual approach to a topic that has com-



manded the attention of mathematicians, physicists, oceanographers, meteorologists, and engineers for almost 200 years, and especially in the past 60 years.

Wind-generated waves, even in their relatively simple deep-water incarnation, illustrate the complexity of ocean waves. They are produced by turbulent air, dissipated through violent and sporadic breaking, and evolve due to weak and slow nonlinear interactions between waves of different scales. All those processes are equally important and therefore need to be modeled and solved simultaneously. But they play out over time scales that range from a fraction of a wave period to thousands of wave periods. And our understanding of those processes ranges from pretty good to zero. In addition to those intricacies, we should consider waves in finite depths and add the effects of extreme weather. Moreover, waves come in a wide range of sizes—from tiny capillary waves to enormous planetary-scale waves—and propagate in many distinct environments governed by their own specific physics.

After a brief introduction into the general concept of waves as propagating oscillations—in particular, waves on the ocean surface—the first half of the book is dedicated to theoretical and experimental research on wind-generated waves. The author rigorously presents the fundamental insights developed in the 20th century on water and ocean waves—for example, the Zakharov equation, the Hasselmann integral, the Benjamin–Feir instability, and the Jeffreys, Phillips, and Miles theories for wave generation. The presentation is suitable for a professional scientist and for a person with a basic background in physics and oceanography.

Essential to ocean-wave research are experimental studies, which are numerous in the field. The author consistently highlights significant experimental milestones, including the measurements that led to the benchmark 1964 parameterization by Willard Pierson and Lionel Moskowitz of a "fully developed sea," the Joint North Sea Wave Project observations in 1973 that modified the Pierson–Moskowitz result, and the modern-day satellite remote sensing of ocean waves. He also makes a good attempt to describe rogue waves and the dynamics of wave breaking—the field's most elusive aspects—which are difficult to probe experimentally and still lack consistent theoretical approaches. The topic of numerical wave modeling is reviewed in detail. Zirker's may be the first book to reconstruct the continuing development of that important approach from the early attempts dictated by naval needs during World War II to modern-day global-wave forecasts and hindcasts.

The book's second half is dedicated to large-scale waves and engineering applications related to ocean waves. Zirker describes tsunamis; internal waves, including such subtle phenomena as Kelvin and Rossby waves; storm surges; tides; and even ocean currents. He outlines how some of them can be connected to the climate system through El Niño events. The last two chapters sketch maritime engineering problems such as ship waves, which slow ships down, and how those problems are linked to naval architecture and the increasingly relevant issue of harnessing ocean-wave energy.

The final chapter, "The Future," depicts the author's expectations for developments in ocean-wave science. Quite rightly, he stresses the role—yet to be fully appreciated—of ocean waves in large-scale air–sea interactions and climate systems. He also properly emphasizes improved high-spatial-resolution satellite observations of the ocean and ultrafast and powerful supercomputing as supports and complements to experimental efforts. His several predictions include a new generation of ocean and wave forecast models and better understanding of complex nearshore dynamics and the coupling of microscale-wave-related processes with various air–sea exchanges.

The Science of Ocean Waves is a truly remarkable achievement. It has a great chance to become a standard text for students, scientists, weather and ocean forecasters, engineers, climate modelers, and anyone else whose curiosity or professional interests relate to ocean waves.

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Polarons

David Emin
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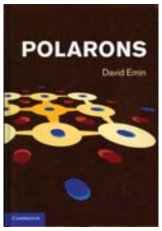
The polaron was proposed by Lev Landau in 1933 to describe an electron moving in a dielectric crystal whose atoms displace from equilibrium to screen the electron charge. Large polarons, whose radii are much larger than the lattice constant, are described by a Hamiltonian named after Herbert Fröhlich. Small polarons, whose radii are of the same order of magnitude as or even smaller than the lattice constant, were first studied in the late 1950s by Theodore Holstein, Jiro Yamashita, and Tatumi Kurosawa. Holstein introduced a simple model for short-range electron–phonon interactions that lead to the hopping motion of what would be identified as small polarons.



Polarons come in several varieties, including acoustic polarons, piezopolarons, and polarons in organic materials. Polaron-like states can even be found in Bose–Einstein condensates. Both the large- and small-polaron pictures are used for the interpretation of experiments on optical, thermal, and electromagnetic response in crystals.

With *Polarons*, David Emin aims to present a relatively simple, mostly empirical introduction to the relevant physics. The first section qualitatively describes the formation of several polaron states: large and small polarons, molecular polarons, and large and small bipolarons (bound polaron pairs). Its final subsection, on magnetic polarons, gives a nice explanation of colossal magnetoresistance in ferromagnetic semiconductors. The book's second section addresses manifestations of polarons in the physical properties of crystals. The third section treats extensions of the polaron concept, including the presently hypothetical bipolaron superconductivity.

Emin is at his best discussing small-polaron phenomena, a subject to which he has devoted most of his own research, some of it in collaboration with Holstein. But in treating large-polaron physics, the book is sometimes less accurate: In particular, chapter 9 has a flawed description of the theory of large-polaron optical absorption at strong coupling. The book fails to discuss recent optical experiments indicating that Fröhlich polarons—as well as small polarons—can act as charge carriers in strontium titanate. Emin omits some key methods and topics in polaron theory, including Richard Feynman's path-integral variational approach; Sin-itiro Tomonaga's translation-invariant description used by T. D. Lee, Francis Low, and David Pines; Nikolai Bogolyubov's field-theoretic treatment; and the diagrammatic quantum Monte Carlo method refined by Andrei Mishchenko and colleagues. Frederick Brown and coworkers' seminal experiments on Fröhlich polarons are also missing.

Polarons mainly addresses graduate students, but it can also be useful for advanced researchers, particularly experimentalists. I would recommend the book as a qualitative introduction to the physics of small polarons. As such, it nicely complements the existing literature.

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In Search of the True Universe
The Tools, Shaping, and Cost of Cosmological Thought

Martin Harwit
Cambridge U. Press, 2013. $50.00
(393 pp.). ISBN 978-1-107-04406-7

When I was 12, my father told me that one of the best things to do when going to sleep is to rehash the day. "Go over