A window on complex and disordered systems

Spin Glasses and Complexity

Daniel L. Stein and
Charles M. Newman
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Reviewed by Stefan Boettcher

The ideas and concepts that originated with the study of spin glasses have pervaded many seemingly unrelated fields, including biology, communications, economics, computer science, and engineering. Indeed, practitioners in specific disciplines who employ spin-glass concepts are often unaware of their scope and generality; many are not even aware that they are "consumers." For instance, many inverse problems in today's big-data environment involve the analysis of correlation matrices of excitatory and inhibitory couplings between large numbers of variables; such problems have exactly the form of a disordered bond matrix connecting spins in a glass.

If your problems involve a large number of coupled variables, chances are that you could benefit from learning about spin-glass theory. That's generally a daunting mathematical task, made palpable with an intuitive but no less logical approach in Daniel Stein and Charles Newman's *Spin Glasses and Complexity*. I highly recommend this book to any reader with a scientific interest in disorder or complexity.

Stein and Newman succeed in translating into plain language a subject that can seem esoteric, and they convincingly argue its importance for those who study complexity in any discipline. The discussion is put carefully within reach of a scientifically literate audience. Unlike conventional popularizations, it deals with profound concepts in depth and does not shy away from, say, exhibiting a spin-glass Hamiltonian in an equation or describing the impact of bond distributions.

The authors' focused and emphatic style pulls readers in and guides them along. Well-placed summary and overview paragraphs—frequently starting with "Let's review what we have so far"—orient the reader before the next line of argument commences. Apart from the 240-page text, some 30 pages of notes, a 20-page glossary, and 300 references to primary sources and books for more in-depth study unclutter the main thrust of the story.

The authors start with the question of why even a physicist would care about the humble spin glass, with its rather undistinguished electronic characteristics and, of late, little experimental interest. Unlike other esoteric subjects, such as black holes, a spin glass doesn't have the flash that immediately captures the imagination. Yet, its efficient display of experimentally observed aspects of disorder has inspired some fundamental questions about our understanding of materials and the universality concept for phase transitions. While pedagogically linking glasses to complexity in the first four chapters, the authors also lay the groundwork for the claim that statistical physics is indispensable for dealing with complex systems that typically have a large number of variables.

The inevitable turn to the Sherrington–Kirkpatrick spin glass and replicas in chapter 5 may seem disconcerting to the uninitiated reader. But the authors never lose sight of the big picture: They subsequently relate the mean-field concepts developed in that chapter to a range of complex problems, like the traveling salesperson, neural networks, and protein folding. Naturally, the authors present their interpretation of finite-dimensional spin glasses. They confine that discussion to chapter 7, which explores the poorly understood nature of the finite-dimensional spin glass and its relation to the rich features derived from Giorgio Parisi's exact mean-field solution. It is a challenging chapter, but it does not distract from the book's overall flow.

The concluding eighth chapter is a philosophical discourse on complexity, infused with historical references. In it, the authors make a compelling case for a deep connection between the hallmark features of spin glasses—disorder, constraints, frustration, and hierarchies—and our still tenuous attempts to identify the underlying principles of complexity. They posit the spin glass as a constitutive model of complex behavior, analogous to the Ising model for critical behavior.

Because it would have exploded the size of the book, the discussion of nonequilibrium dynamics is decidedly brief. The behavior we observe for real-world complex systems is rarely in equilibrium, with poorly understood consequences; little can be said even for the model spin glass. More significant is the book's dearth of contemporary examples of the evermore widespread application of the mean-field replica theory to communications, inference, data analysis, and algorithm development. As those topics relate directly to the everyday big-data concerns of a large potential readership, their scant mention understates the present impact of spin-glass theory.

Spin Glasses and Complexity is not a journalistic book that merely reports on the subject. Based on profound mathematical insights, here distilled into an incisive presentation, it represents the fruit of the lifelong commitments two experts have made to spin-glass theory within and beyond physics. Some nice textbooks and technical reviews already exist to introduce students to the subject, but *Spin Glasses and Complexity* is unique in successfully bringing this thrilling theme to a broader scientific audience.

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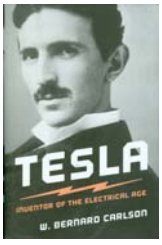
Tesla
Inventor of the Electrical Age

W. Bernard Carlson
Princeton U. Press, 2013. $29.95
(500 pp.). ISBN 978-0-691-05776-7

Since the death of Nikola Tesla in 1943, his life has deserved a worthy biography. Bernard Carlson has delivered that in *Tesla: Inventor of the Electrical Age*, which portrays Tesla as intensely human—a visionary who was sometimes realistic and sometimes not, a man with insecurities and a temper who didn't always honor his debts. And not only do we meet a real person, but we meet him in the real world. Carlson

does more than re-create the inventive environment of the late 19th and early 20th centuries: With his understanding of the sociology and history of technology, he paints a world in which inventors sell a persona along with their inventions; reputation can attract investors or keep them away; public opinion can be crucial; and the ability to create a practical, durable device or system is more important than having a brilliant idea.



Working with a daunting scarcity of source material, Carlson grounds Tesla's insights and inventive style as firmly as he can in Tesla's youth and education without explaining them away. Indeed, brilliant ideas were Tesla's stock in trade. The importance of his first great breakthrough—conceiving and then demonstrating that a rotating magnetic field can drive an AC motor—can hardly be overestimated. It led to the practical development of AC power. His subsequent work on components for an AC power system was almost as significant.

One of the book's great strengths is the way Carlson deals with many of the legends and myths surrounding Tesla: He elucidates what did happen and he leaves out what did not. He fleshes out the people who surrounded Tesla, explaining and illuminating their characters and motives. We learn about Tesla's work in the battle between AC and DC, but the titanic personal struggle between Tesla and Thomas Edison, so beloved in popular histories, is nowhere to be found. Indeed, Carlson quietly introduces an 1893 letter from Tesla to his uncle in which he proudly writes of having received a photograph from Edison inscribed, "To Tesla from Edison." And in Tesla's storied attempts to transmit wireless power, we see how his inability to anticipate practical realities and problems led to his underestimating expenditures, overestimating success, and alienating investors.

Carlson's historical sophistication gives the book a contextual depth that helps the reader understand why, despite Tesla's power-transmission attempts, it is historically questionable that he anticipated the radio. Carlson's rich, careful description of Tesla's work—which is sufficiently technical to be satisfying without disrupting the narrative—is given meaning by its juxtaposition with an analysis of invention and innovation that is grounded in the real world of engineers and machines. And when Tesla and his partner Edward Adams fail to entice investors in the mid 1890s, Carlson's equally deep understanding of business and business history allows him to explain that failure clearly and thoroughly.

It is hard to resist comparing Tesla and Edison, the two most celebrated electrical inventors of their time. They both achieved remarkable early successes, but perhaps the failure of Tesla's wireless power transmission, set against Edison's 1890s failure in iron mining, is a useful illustration. Despite wrestling with and overcoming all sorts of engineering difficulties, Edison failed because he was economically overwhelmed by the opening of the rich Great Lakes ore deposits. He recognized defeat and turned his energies to developing portland cement and storage batteries. Tesla, on the other hand, "was unable to grasp the disjuncture between how he thought his system should work versus how the Earth actually responds" (p. 412), and he suffered a nervous breakdown. Carlson describes one of the great flaws in Tesla's approach to invention: his inability to think convergently, to focus his attention on a goal and sustain it. Again and again he developed an idea, and nearly as often he failed to get it from his head to the laboratory bench and then out into the world. But what he did produce was remarkable, and we now have in Carlson's biography the means to appreciate it properly. Anyone, whether simply an interested reader or a professional historian, engineer, or physicist, will finish *Tesla* with a deepened understanding of his world, character, and accomplishments.

Robert Rosenberg
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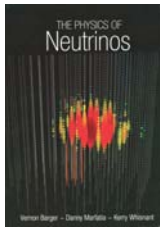
The Physics of Neutrinos

Vernon Barger, Danny Marfatia, and Kerry Whisnant
Princeton U. Press, 2012. $99.50 (224 pp.). ISBN 978-0-691-12853-5

A bit over a half century ago, physicists spotted their first neutrino. We now know that the particles are ubiquitous. They are of key importance to our understanding of nature as explored in such subdisciplines as particle physics, nuclear physics, astrophysics, and cosmology. Neutrino physics has come a long way since that first experimental observation. Indeed, the field has become positively effervescent starting about a decade ago, when neutrino oscillations were experimentally confirmed.



In *The Physics of Neutrinos*, Vernon Barger and his longtime collaborators Danny Marfatia and Kerry Whisnant address the recent developments in the field. Barger is coauthor of *Collider Physics* (updated edition, Westview Press, 1996), the highly regarded handbook of collider-physics phenomenology. Relatively slim, *The Physics of Neutrinos*, a timely overview by active and respected researchers, is packed with useful information and many valuable references. The authors intertwine contributions of theory and experiments to present both the current status of the field and what may soon come.

The authors start by recalling the basic ingredients needed to understand neutrino measurements, describing how neutrinos are produced from weak decays, explaining what neutrino-interaction cross sections are, reviewing detector techniques, and discussing how to produce a neutrino beam. They continue with a description of the theoretical formalism needed to understand the experimentally observed neutrino oscillations in vacuum and in matter. From there, they discuss oscillation experiments involving solar, atmospheric, accelerator, and reactor neutrinos. The presentation culminates by summarizing our present knowledge of the values of the so-called neutrino-oscillation parameters, provided by a global fit of all the experimental data combined.

The Physics of Neutrinos also discusses current and planned long-baseline oscillation and nonoscillation experiments and their role in unraveling some of the remaining open questions. It covers present and future experiments designed to search for neutrinos from astrophysical sources other than the Sun, and it discusses such theoretical advances as the realization that neutrino self-interactions must be taken into account when dealing with supernova neutrinos. A short chapter devoted to model building outlines important theoretical efforts to explain patterns of neutrino masses and mixings and why neutrino masses are so small.

The penultimate chapter describes two results that may be indicative of new phenomena in the neutrino sector: the LSND and MiniBooNE anomalies, as they are known in the field. It also presents alternative theoretical scenarios to the standard paradigm of three