

Emergence Is in the Eye of the Beholder

A Different Universe: Reinventing Physics from the Bottom Down

Robert B. Laughlin
Basic Books, New York, 2005.
\$26.00 (254 pp.).
ISBN 0-465-03828-X

Reviewed by Anthony Leggett

I suspect that if the friends and colleagues of Robert B. Laughlin were asked to choose a single adjective to characterize him, that adjective would be “irrepressible.” Certainly nothing is repressed in *A Different Universe: Reinventing Physics from the Bottom Down*. It is an ebullient, wide-ranging, provocative mélange of physics presented in informal terms, with no equations darkening its pages, and loosely organized around the currently fashionable concept of emergence. Interspersed throughout are lots of personal anecdotes and discussions, embellished by a fascinating set of footnotes on everything from Galileo to the accident rate among Minnesota ice fishermen. Laughlin, who shared the 1998 Nobel Prize in Physics for his theoretical work on the fractional quantum Hall effect, gives us the benefit of his opinions on just about every subject under the Sun. Along the way he takes swipes at quantum computing, nanotechnology, string theory, evolutionary biology, and much else.

For whom is *A Different Universe* written? At first glance, its lack of equations and style of prose suggest a *Scientific American*-level readership. Laughlin’s writing is exceedingly good, and I doubt if one in a hundred of his colleagues could write English this well. However, although some of the earlier material—for example, the excellent chapter on the notion of measurement—should be accessible to such a readership, who will no doubt also enjoy the anecdotes, much

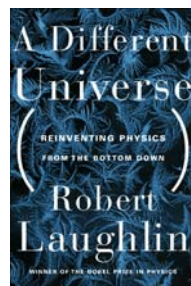
of the arguments in later chapters, such as the one on superconductivity, seem to presume as background the kind of specialized knowledge that only Laughlin’s condensed matter colleagues are likely to have. Much of the book is apt to be completely lost on a lay readership.

As regards the physics content, the book is a kind of curate’s egg. Much good material is interspersed with passages and even chapters that betray either extreme haste in the writing or, less charitably, some rather fundamental and surprising misconceptions. To nitpick, for instance, we are told in chapter 9, “The Nuclear Family,” that the lifetime of the free neutron is “about a minute,” and in chapter 8, “I Solved it at Dinner,” that “the electron sea . . . will become superconducting at sufficiently low temperatures if there is any atomic motion whatsoever.” More seriously, although any attempt to explain subtle quantum issues without the use of mathematics arguably deserves the benefit of the doubt, the one-page dismissal of quantum computing in the chapter on “The Quantum Computer” inspires little confidence that its author has understood either the nature of algorithms such as Peter Shor’s or the principles underlying quantum error correction.

As for chapter 5, “Schrödinger’s Cat”—well, Laughlin himself remarks that “one tries to be nice about [misconceptions concerning the quantum measurement problem], but the temptations to be mean are sometimes irresistible.” They are indeed, so here goes: I not only find Laughlin’s “resolution” of the problem—allegedly based on, you guessed it, emergence—totally incoherent, I seriously doubt whether he even understands what the problem is in the first place. (He seems to believe it has something to do with “indeterminism”; a charitable view might be that he has simply confused the notion with indeterminacy, which, in a physics context, is a quite different concept. But even then I can make little sense of his formulation.)

Yet, in the end, readers’ overall appraisal of Laughlin’s book must rest on how convincing they find his central thesis—that emergence is a funda-

mentally new paradigm that should revolutionize our thinking about physics and much else. One thing needs to be said right away: For all his oft-repeated claims of “radicality,” he does not think to challenge—indeed he even endorses in the preface—the fundamental dogma of reductionism or, as he defines it, the thesis that “things will necessarily be clarified when they are divided into smaller and smaller component parts.” Moreover, he implies, incorrectly, that “all physicists” share this view. (In fact,



a number of highly respectable theorists, including the late John Bell, have been prepared—often as a result of their having thought more deeply about the quantum measurement problem than Laughlin evidently has—to at least entertain scenarios that imply the falsity of the reductionist thesis as so defined.)

Within this overarching and, arguably, deeply conservative framework, the most radical part of his thesis is that “all physical law we know about has collective origins, not just some of it.” This postulate leads him to, among other things, the conclusion that Minkowski spacetime may not be genuinely fundamental—a conclusion which has, of course, been reached by others on rather different grounds and which, were it to be established by experiment, would needless to say be truly revolutionary. Alas, the proof of that particular conjectural pudding is certainly in the eating, and the specific ideas that Laughlin has published along these lines, although certainly intriguing, do not seem obviously any closer to real-life experimental test than are those of the string theories he derides.

What of the condensed-matter implications? Consider the following propositions: that there is no interesting macroscopic system whose behavior can be obtained by pure deduction from microscopic principles; that the models and principles of condensed matter physics are in some sense autonomous; that at least some observed macroscopic universalities, both qualitative and even perhaps quantitative, may be the result of collective interactions and independent of the detailed nature of the microscopic components;

Anthony Leggett, a 2003 Nobel laureate in physics, is the MacArthur Professor and a professor of physics at the University of Illinois at Urbana-Champaign. He supervises several graduate students who work on various topics in low-temperature physics and quantum information.

that the law of large numbers, sometimes augmented by topological considerations, may allow one to measure quantities such as the flux quantum h/e more accurately on many-body systems than we could on microscopic ones. All of the above are valid and important points, but all of them were being made in the literature long before emergence gained its current buzzword status—and by others besides Philip Anderson and Ilya Prigogine, whom Laughlin explicitly acknowledges as his intellectual precursors.

So where's the extra beef? What is emergence? For the first three-quarters of *A Different Universe* the reader has to live with the definition given in chapter 1: "a physical principle of organization." What exactly are these allegedly ubiquitous principles of organization? Let's consider one of Laughlin's showcase examples: superconductivity. In chapter 8, the organizational principle is explicitly identified as "superfluid symmetry breaking," and he puts great weight on the existence of multiple "equivalent solutions," by which he presumably means solutions corresponding to different overall condensate phases.

My problem with this point of view is that, for all its historical importance, "spontaneous breaking of gauge symmetry" and the consequent multiple solutions are quite simply myths. The Meissner and Josephson effects, which Laughlin identifies as the essence of superconductivity, can be derived just as simply, and with much less danger of generating pseudo-problems, by using a much more transparent postulate originally formulated explicitly by C. N. Yang—namely, that there occurs a sort of Bose–Einstein condensation (BEC) of Cooper pairs (or, more technically, that the two-particle reduced density matrix has a single macroscopic eigenvalue). The point becomes even more evident in the case of recently stabilized weakly repulsive Bose alkali gases, in which the analogs of the Meissner and Josephson effects are manifestly just single-particle effects amplified by BEC.

So what are we to conclude, that superconductivity/superfluidity is an emergent phenomenon in the case of superconductors but not in the case of the alkali gas? Or that BEC is itself an example of emergence? If the latter, then presumably, a fortiori, just about any application of the central limit theorem in physics will qualify. Where has the "organizing principle" gone?

The example of superconductivity seems to me to epitomize the central

weakness, at least in a condensed matter context, of Laughlin's thesis. The concept of emergence, touted as a revolutionary new paradigm, turns out at the end of the day to be little more than a catchall label for a miscellaneous collection of things we all understood perfectly well already. As an explanatory or even heuristic principle in its own right, "emergence" is completely vacuous.

Still, we all had a lot of fun along the way, so maybe we shouldn't complain.

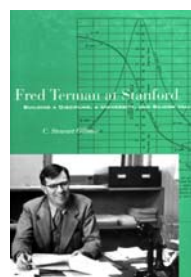
Fred Terman at Stanford: Building a Discipline, a University, and Silicon Valley

C. Stewart Gillmor
Stanford U. Press, Stanford, CA,
2004. \$70.00 (642 pp.).
ISBN 0-8047-4914-0

The closer you get to Stanford University, the more you hear that Frederick Terman was the "father of Silicon Valley." Stanford can be truly proud of the many achievements of this electrical engineer who became one of its most accomplished administrators after World War II, building what was already a strong university—albeit regarded by many as somewhat of a country club—into an intellectual powerhouse now recognized as one of the leading academic institutions in the world. Along the way, he encouraged close interaction between industry and academe, an intercourse that almost all universities studiously avoided during the 1950s and 1960s. The resulting exchanges of people and ideas did much to foster the growth of high-tech industry in the Santa Clara Valley, which was until the late 1960s much better known for its apricot orchards than for semiconductor manufacturers.

In *Fred Terman at Stanford: Building a Discipline, a University, and Silicon Valley*, C. Stewart Gillmor, a historian of science at Wesleyan University in Connecticut, has written what will be regarded as the definitive biography of Terman. It is so thoroughly researched and so richly detailed that I cannot imagine anyone attempting another. After having glanced through the Terman archives at Stanford while conducting research for articles and a book on semiconductor history, I know what a vein of gold Gillmor has mined. And I can attest to the care and thoughtfulness with which he has used the material.

Terman was born at the dawn of the 20th century and grew up the son of Lewis Terman, a now-famous psychologist who pioneered the measurement of intelligence and the development of the Stanford–Binet IQ tests. Early in young Fred's life, while he studied at Palo Alto schools and played on campus streets, he became absorbed with the notion that quality could be measured and quantified. As Gillmor recounts, the idea was to remain with him the rest of his life, shaping his approach to building Stanford and Silicon Valley.



But instead of following in his father's intellectual footsteps, Terman turned to engineering when he matriculated at Stanford during World War I. As an early ham-radio enthusiast, he drifted nat-

urally into the emerging discipline of electrical engineering and did well at it. So well, in fact, that in 1922 he headed east to MIT for graduate work in the field, becoming Vannevar Bush's very first doctoral student.

That apprenticeship, and a well-deserved reputation as one of the nation's best radio engineers, helped plug Terman into the leadership of the US scientists and engineers who, under Bush, rose to meet the technological challenges of World War II. From 1942 to 1945, he directed Harvard's Radio Research Laboratory (just upriver from the famed MIT Radiation Laboratory) and oversaw the development of such radar countermeasures as jamming and chaff. It was a career-molding experience for him.

Terman found himself among a select, privileged group of what historians have come to call "master builders"—scientists and engineers who had served their country during the war, grasped its organizational lessons, and formed extensive networks of trusting government and military contacts to turn to during the postwar years. He also was among the first to understand that universities would have an important research role to play in the military–industrial complex that was emerging during the ensuing cold war. As Stanford's dean of engineering from 1946 to 1959 and provost from 1955 to 1965, Terman drew upon his extensive contacts and funding sources to build what he called "steeples of excellence" in fields such as electrical engineering, physics, chemistry, biology, and medicine. The Microwave Laboratory, a