The forking paths of semiclassical physics

The Semiclassical Way to Dynamics and Spectroscopy. , Eric J. Heller, Princeton U. Press, 2018, $99.50 Buy on Amazon

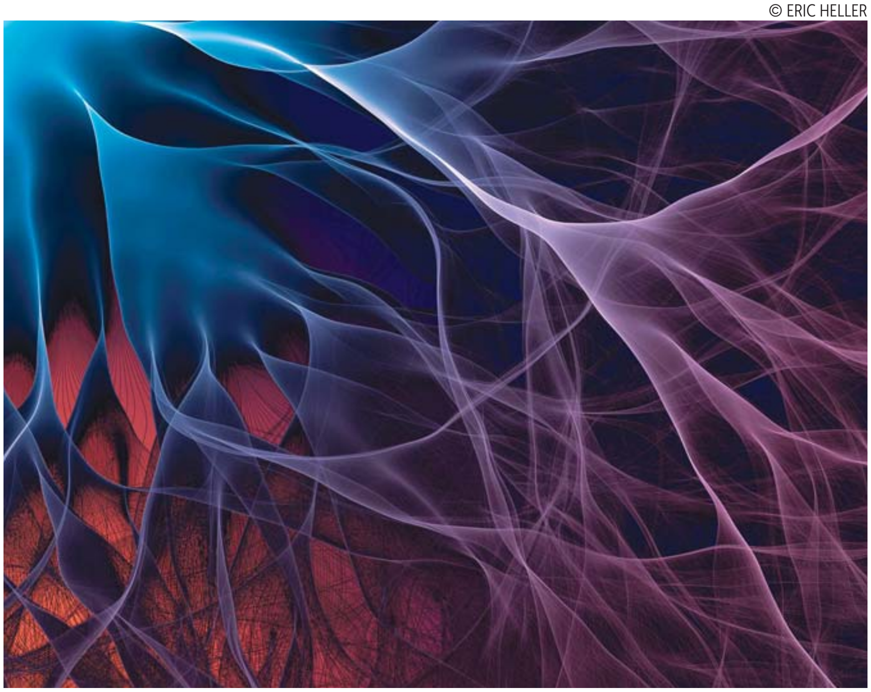
John McGreevy

Physics Today **72** (1), 56–57 (2019);
https://doi.org/10.1063/PT.3.4115

needs of minoritized scientists. The march paid lip service to diversity only after significant pressure from those scientists.

As a Martin Luther King Postdoctoral Fellow at MIT for nearly five years, I spent a decent amount of time in the Vannevar Bush Room. I will never look at its name the same way again, now that I've read about Bush's efforts to protect US scientists from having to be accountable to anyone but themselves. Rather than seeing him as a scientific hero, I now see him as a leader who successfully took science's relationship with society in a questionable direction. Readers of *Freedom's Laboratory* may find that they too will see familiar names in a different light.

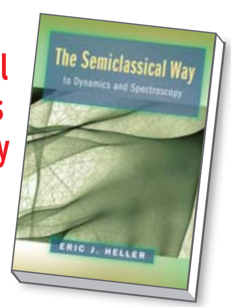
Chanda Prescod-Weinstein
University of New Hampshire
Durham



The forking paths of semiclassical physics

Which is more fundamental, classical mechanics or quantum mechanics? Admittedly, it is illogical to claim that an approximate description that is only valid in certain limits is more fundamental than the complete theory it sometimes resembles. Nonetheless, Eric Heller's new book *The Semiclassical Way to Dynamics and Spectroscopy* can be read as an argument that classical mechanics underpins quantum mechanics. The path integral, which is expressed in terms of familiar quantities from classical mechanics, is the tool that allows physicists to entertain that point of view.

The Semiclassical Way to Dynamics and Spectroscopy
Eric J. Heller
Princeton U. Press, 2018. $99.50



Heller centers his book on the semiclassical physics of a few continuous degrees of freedom. He is an acknowledged grand master in that area and is known for discovering the mysterious and deep phenomenon called scarring—the existence of energy eigenstates whose wavefunctions are enhanced on certain classical periodic orbits. In *The Semiclassical Way to Dynamics and Spectroscopy*, Heller intentionally emphasizes physics in the time domain. Less explicitly intentional is his emphasis on continuous few-body systems, as opposed to spins or many-body systems. By narrowing the focus to situations in which semiclassical methods can be applied, he is able to provide a relatively uniform treatment of various rich phenomena.

Heller begins with a review of phase-space dynamics of few-variable systems, and proceeds to examine the path-integral formulation of quantum mechanics and its approximation by stationary phase, culminating in the Gutzwiller trace formula and its time-domain counterpart. Even the elementary part of the discussion is punctuated by partisan interjections, such as Heller's claim that the equation for the short-time limit of the free-particle Green function "can (and should!) be taken as the founding postulate of quantum mechanics." The shortcomings of that starting point, however, would become glaring when one tried to study systems with finite dimensional Hilbert spaces.

The book really gets started with a collection of methods to approximate dynamics of few-body systems, based on the idea of treating the wavefunction as a wavepacket and the instantaneous potential around the center of the wavepacket as quadratic. I was not previously aware of that line of work, which the author pioneered.

Much of chapter 19 illustrates those methods' successes by giving an extremely detailed semiclassical account of the spectrum of a particular organic molecule. The description of the molecule's wiggling is startling in its precision. Indeed, I would have liked to see some explanation of the success beyond "serendipity," such as an analysis of the regime of validity or, better still, of systematic corrections. I was unable to find such a discussion in the text. In its place I found many instances of baffling phrases like "as $\hbar$ goes to zero" and "when $\hbar$ is small." Heller's intended meaning is that the constant $\hbar$ is small compared with some scales in the problem. Such colloquialisms are useful only when everyone knows what those scales are.

The book's final part, on chaos and quantum mechanics, includes a discussion of wavefunction nodes and Berry's conjecture that chaotic energy eigenstates can semiclassically be approximated as random superpositions of suitable classical states. Heller's presentation is rich and thought-provoking. But I must quibble with the assertion that "nodal surfaces in wavefunctions are by definition . . . co-dimension 1." In the absence of time-reversal symmetry, they occur at codimension two.

Furthermore, the discussion of Berry's conjecture concludes with what I found to be a misplaced analysis of the short-time behavior of Green functions in noninteracting particle systems. Any smooth potential is a relevant perturbation of the free-particle Hamiltonian $p^2/(2m)$, hence its effects disappear at short times and high energies. I believe that, rather than any manifestation of chaos, is what is illustrated by the noninteracting calculation Heller discusses.

Stylistically, the book has many idiosyncrasies: sentences that are extremely long, colloquialisms that some readers may find off-putting, captions that are too short for figures on which the narrative relies. The book oscillates between huge chunks of equations and huge chunks of words. Most difficult for the uninitiated reader is that many concepts are mentioned in crucial sentences long before they are explained. In many places the discussion could be streamlined. For example, in section 25.3, the book sets up an artificial two-dimensional system interacting with a bath; several pages later the essential physics is declared to be visible in one dimension, and the second dimension is discarded.

The book's discussion of many-body physics is often problematic. For example, in a subsection devoted to celebrating the Laughlin wavefunction, the author complains that it is not "the exact ground state." That dismissal fails to acknowledge the Laughlin wavefunction's key victory—namely, that it represents the same phase of matter as is realized in quantum Hall experiments.

The most prominent feature of the book is its unusual point of view. The preface led me to expect that the book would explain why the world often seems classical even though it is fundamentally quantum mechanical. But the only route to be found to classical mechanics is through large quantum numbers. Chapter 25, on decoherence, is, alas, somewhat incoherent itself; for example, a complete summary of the arduous section 25.3 is "interactions create entanglement." Problematic, too, are the scare quotes surrounding "entanglement" in a quantum mechanics textbook published in 2018. That Heller feels the need to protect himself in that way is an indictment of the popular writing on the most essential feature of quantum mechanics.

The target audience for the book is not obvious. Its narrow focus makes it inappropriate as a principal text for an introductory course on quantum mechanics, but it can be a good source of supporting material. Chemists working on the quantum dynamics of few-body systems should find the book useful, as many of the examples are drawn from molecular chemistry and spectroscopy.

The Semiclassical Way to Dynamics and Spectroscopy is full of provocative ideas and insightful material that won't be found elsewhere. A second edition to fix the shortcomings described above would be welcome.

John McGreevy
University of California, San Diego