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The Hunt for Vulcan…And How Albert Einstein Destroyed a Planet, Discovered Relativity, and Deciphered the Universe

The Hunt for Vulcan…And How Albert Einstein Destroyed a Planet, Discovered Relativity, and Deciphered the Universe. Thomas Levenson 244 pp. Random House, New York, 2015. Price $26 (hardcover). ISBN 978-0-8129-9898-6.

Steve Ruskin

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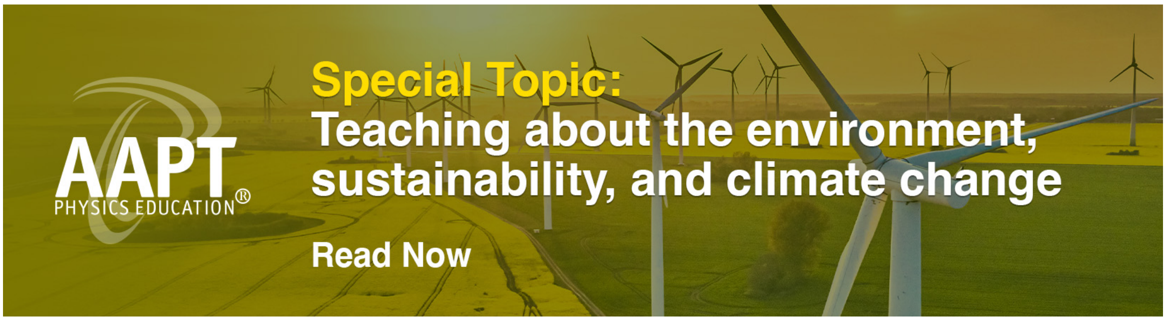

BOOK REVIEWS

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The Quantum Handshake: Entanglement, Nonlocality, and Transactions. John G. Cramer. 243 pp. Springer, 2016. Price: $69.99 (hardcover). ISBN 978-3-319-24642-0. (Louis Marchildon, Reviewer.)

In a foreword to *The Quantum Handshake*, Carver Mead recalls Richard Feynman's verdict on Young's two-slit experiment and on quantum mechanics in general: "Nobody knows how it can be like that." Mead himself is more optimistic. In fact, Feynman's quote came more than ten years after David Bohm had resurrected Louis de Broglie's pilot wave theory, providing at least a possible way of understanding the two-slit experiment. Bohm's theory gives an answer to the question "How can the world be for quantum mechanics to be true?" Answering this question is, I believe, precisely what is meant by interpreting quantum mechanics. The Copenhagen Interpretation, Everett's approach in its different guises and, more recently, Quantum Bayesianism, all propose their own answer to this fundamental question.

In a paper published 30 years ago in *Reviews of Modern Physics* [**58**, 647 (1986)], John G. Cramer suggested a different and original answer, which he called the Transactional Interpretation of quantum mechanics. *The Quantum Handshake* is an elaboration of this work, written for "the intelligent reader with some grasp of basic mathematics and a curiosity about quantum mechanics…" It enlarges upon the RMP paper with many topics that have developed in the past three decades, like quantum computing, interaction-free measurements, entanglement swapping, to name a few.

Inspired by the Wheeler-Feynman electrodynamic theory, the Transactional Interpretation (TI) postulates that the complex conjugate of a solution of the Schrödinger equation is just as important as the genuine solution. Both originate from a time-symmetric relativistic version of the Schrödinger equation (like the Klein-Gordon equation). In a quantum process like the emission and subsequent absorption of an alpha-particle, the solution of the Schrödinger equation is to be viewed as an "offer wave," which propagates from the emitter to one or several potential absorbers. The absorbers respond by "confirmation waves," i.e., the complex conjugate solutions, which propagate backward in time to the emitter. Cramer argues that the confirmation wave leaving an absorber at space-time point ($\mathbf{r}$,t) reaches the emitter with a strength proportional to $\psi(\mathbf{r},t)\psi^*(\mathbf{r},t)$. A transaction is henceforth established between the emitter and one of the absorbers, which enforces relevant conservation laws. The probability of a transaction with a given absorber is proportional to the strength of that absorber's confirmation wave, from which Born's rule follows.

After motivating and developing TI, Cramer proceeds to apply his interpretation to more than 20 different real or thought experiments, every one of them presenting some paradoxical aspect. Cramer argues that TI does much better than the Copenhagen Interpretation in dissolving the paradoxes. Nonlocality, for instance, has a straightforward explanation in TI. In experiments about Bell's inequalities, correlations between Alice's and Bob's results are not enforced through superluminal influence, but through backward causation effected by confirmation waves. That is, correlations are explained if the world is such that waves do indeed propagate in the negative time direction.

Cramer claims that TI "solves *all* of the interpretational problems and paradoxes of quantum mechanics…" Moreover, he believes that TI does this much better than the Copenhagen or other interpretations, although his explicit comparisons mainly focus on the former. Why then has TI received comparatively little attention? There is Ruth Kastner's 2013 book (*The Transactional Interpretation of Quantum Mechanics: The Reality of Possibility*), but a quick search of arXiv yields only about 17 titles on TI, compared with about 45 on Everett's approach and 200 on Bohm's.

I believe there are essentially two reasons for this. The first one has to do with advanced causation. Even if carefully balanced so as not to result in pathological causal loops, advanced causation is for most people hard to swallow. This may or may not be an intellectual prejudice, just like the view against splitting into many worlds or against a quantum potential acting on particles without being acted upon in return.

The second reason, however, has little to do with prejudice. In an important sense, TI is not better defined than the Copenhagen Interpretation or von Neumann's theory of measurement. In Bohr's view, classical mechanics is logically prior to quantum mechanics, but we are not given the precise conditions under which an aggregate of particles behaves classically. Similarly, von Neumann does not specify conditions under which Process 1 (collapse) takes over Process 2 (unitary evolution). In Cramer's view, transactions play the part of collapse. True, they are somewhat immune to questions like "When does the collapse occur?," but they require emitters and absorbers. These should be macroscopic (classical) objects if transactions are truly irreversible. The classical-quantum distinction or apparatus definition therefore plagues Cramer's view just as it does Bohr's or von Neumann's.

All interpretations of quantum mechanics are subject to strong criticism. This is what makes the field fascinating. My criticism of TI should therefore not deter anyone from reading *The Quantum Handshake*. In fact, Cramer has written a very good book, living up largely to its objective of reaching the intelligent general reader. His overview of the conceptual development of quantum mechanics is clear and concise, just as his discussion of entanglement and nonlocality. Chapter 6 on Quantum Paradoxes and Applications of the TI is especially interesting, his description of experiments being informed by decades of experience. An appendix provides Cramer's own answers to general questions on quantum mechanics or specific ones on TI. Careful editing and proofreading has caught most typos. All in all, this is a book everyone will learn from. It is as good a take as any other on the difficult problem of interpreting quantum mechanics.

Louis Marchildon is Professor of Physics (Emeritus) at Université du Québec à Trois-Rivières. In the past 15 years, his research has focused on the interpretation of quantum mechanics. He is the author of Quantum Mechanics: From Basic Principles to Numerical Methods and Applications (Springer, 2002).

The Hunt for Vulcan…And How Albert Einstein Destroyed a Planet, Discovered Relativity, and Deciphered the Universe. Thomas Levenson. 244 pp. Random House, New York, 2015. Price $26 (hardcover). ISBN 978-0-8129-9898-6. (Steve Ruskin, Reviewer.)

In November 1915, Albert Einstein delivered a series of lectures before the Prussian Academy of Sciences in Berlin, in which he laid out his theory of general relativity. When he stepped down from the podium on November 18, he had upended our conception of gravity and dethroned over two centuries of Newtonian physics. He also destroyed an entire planet.

If you have never heard of the planet Vulcan, you are not alone. Thomas Levenson, the head of MIT's science writing program, digs into the past to tell the story of this non-planet and what it reveals about the process of scientific discovery. Vulcan never existed, but during the nineteenth century astronomers convinced themselves that it must. Why? Because Mercury's orbit exhibits a small precession that the gravity of the sun and known planets cannot explain. Something had to be interfering with Mercury's predicted path. If Newton's theory of gravity was correct, that something was almost certainly another planet, hiding somewhere between Mercury and the sun.

Nineteenth-century astronomers were not wrong to assume that there were undiscovered planets in our solar system. After all, they had a precedent: Neptune. In 1846, Neptune's existence was predicted purely mathematically, well before astronomers observed it in their telescopes. How? The problem lay with Uranus, which Levenson calls a planetary "troublemaker." Since its discovery in 1781, Uranus was never quite where Newton's laws of gravitation predicted it would be; it was prone to "wandering off course." This led to the disturbing possibility that there were exceptions to Newton's laws. Yet the very thought that Newton was wrong was anathema; Uranus's orbit represented a crisis of 19th-century scientific belief.

Enter the Parisian mathematician Urbain-Jean-Joseph Le Verrier. He had a solution, albeit a difficult one. Churning through a series of calculations—first with 13 variables, and later a more manageable nine ("which is to say," quips Levenson, "merely a hugely difficult operation, instead of an impossible one")—Le Verrier demonstrated that the actual orbit of Uranus, as opposed to its predicted one, made sense if it was under the gravitational influence of another, previously unknown, planet. The Frenchman did the math and then told the young German astronomer Johann Gottfried Galle where to point his telescope. It only took Galle one night's observing from Berlin's Royal Observatory to find it. Voilá! A new planet.

Levenson writes that the discovery of Neptune through Le Verrier's mathematical genius (and Galle's diligent observing), "was the climax of what was almost immediately understood to be the popular triumph of Newtonian science." And yet the puzzle of Mercury's strange precession could not be solved. Le Verrier tried, others tried, but the planet's erratic orbit resisted the standard Newtonian solution.

So, as with Uranus, it was naturally assumed there was another planet whose mass was causing Mercury's wobble. This planet was given a name—Vulcan—and astronomers set out to find it as well, although it was presumed to be orbiting so close to the sun that it was nearly impossible to see under normal conditions.

From the 1850s to the end of the 1870s, occasional reports of Vulcan sightings were published in scientific journals. But none were confirmed. Even Le Verrier, whose fame (and ego) had reached massive heights, could not crack it. It was simply too hard to find a small planet against the blinding surface of the sun. Total solar eclipses, which would temporarily block the sun's overwhelming brightness, offered the best chance for locating Vulcan. But those came infrequently and lasted for an agonizingly short time—mere minutes. And even when they occurred, Vulcan (assuming it did in fact exist) would have to be out to one side of the sun, not in front or behind it. Talk about a needle in a haystack.

Vulcan's big reveal was expected during the total solar eclipse of July 29, 1878, which occurred over the Rocky Mountains. Astronomers came from all over the world to CO, WY, and TX. Not all of them were looking for Vulcan, but for those who were it was a make-or-break event. A few Vulcan sightings were claimed, but they were nearly as short-lived as the eclipse itself. No one could definitively confirm Vulcan's discovery that summer day in the Rockies, and so for nearly four decades the matter was left alone. Mercury maintained its odd precession, while science maintained its unshakable faith in Newton.

But the problem of Mercury's orbit could not be ignored forever. Either Vulcan would have to be found, or Newtonian gravity would have to be revised—or even abandoned altogether.

That November of 1915, Einstein finally broke the deadlock. At the Prussian Academy of Sciences (less than a mile from where Galle first observed Neptune in 1846), he demonstrated that the curvature of spacetime, and not a hidden planet, convincingly accounted for Mercury's odd orbit. "Vulcan was gone, dead, utterly unnecessary," Levenson concludes. "The sun with its great mass creates its dent in space-time…until, as Einstein finally captured in all the abstract majesty of his mathematics, the orbit of [Mercury] precesses away from the Newtonian ideal."

The Hunt for Vulcan is a splendid little book—so much is done so well, and in so few pages, that upon finishing the reader is left with the impression of having read a much longer, much denser work. Levenson also resists the easy temptation to make the story about losers and winners. He does not dismiss 19th century Vulcan hunters as foolish or misguided. Instead, he recognizes that they were working with the best theory then available: Newtonian physics.

Those who study scientific revolutions recognize that scientific theories remain viable only as long as they are able to explain observed phenomena *and* account for new observations. When a theory ceases to be able to do this—as when Newtonian gravity was unable to explain Mercury's orbital precession—alternative theories are sought. Einstein's general theory of relativity not only accounts for everything Newtonian gravity does, it also explains that which Newton could not, and, in the case of Mercury, without the need for hypothetical planets. For Levenson, then, the death of Vulcan is not so much a cautionary tale as an important scientific milestone. "For more than two centuries humankind lived in the cosmos Newton discovered. Vulcan's nonexistence did not demolish that dwelling place; rather it is the marker on which its passing is written."

Steve Ruskin received his Ph.D. degree in History and Philosophy of Science from the University of Notre Dame. His is the author of one book and numerous articles on the history of astronomy, including "'Among the Favored Mortals of Earth': The Press, State Pride, and the Eclipse of 1878."

BOOKS RECEIVED

Introduction to Modern Magnetohydrodynamics. Sébastien Galtier. 283 pp. Cambridge U.P., New York, 2016. Price: $74.99 (hardcover) ISBN 978-1-107-15865-8.

To Measure the Sky: An Introduction to Observational Astronomy, 2nd ed. Frederick R. Chromey. 474 pp. Cambridge U.P., New York, 2016. Price: $79.99 (paper) ISBN 978-1-107-57256-0.

Cosmic Magnetic Fields. Philipp P. Kronberg. 295 pp. Cambridge U.P., New York, 2016. Price: $140 (hardcover) ISBN 978-0-521-63163-1.

Storm in a Teacup: The Physics of Everyday Life. Helen Czerski. 275 pp. W. W. Norton, New York, 2016. Price: $26.95 (hardcover) ISBN 978-0-393-24896-8.

Physics: The Ultimate Adventure. Ross Barrett, Pier Paolo Delsanto, and Angelo Tartaglia. 234 pp. Springer Nature, New York, 2016. Price: $59.99 (hardcover) ISBN 978-3-319-31690-1.

Research Methodology: The Aims, Practices and Ethics of Science. Peter Pruzan. 338 pp. Springer Nature, New York, 2016. Price: $99 (hardcover) ISBN 978-3-319-27166-5.

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