Two takes on an epic discovery

The Particle at the End of the Universe
How the Hunt for the Higgs Boson Leads Us to the Edge of a New World

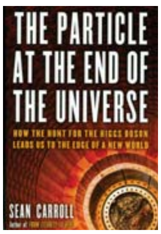
Sean Carroll
Dutton, New York, 2012. $27.95
(341 pp.). ISBN 978-0-525-95359-3

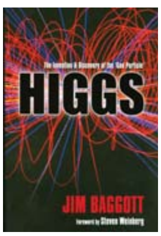
Higgs
The Invention and Discovery of the 'God Particle'

Jim Baggott
Oxford U. Press, New York, 2012.
$24.95 (277 pp.).
ISBN 978-0-19-960349-7

Reviewed by Don Lincoln

With the highly publicized successes of CERN's Large Hadron Collider research program, it is not surprising to see new books that tell the dramatic tale of the LHC's start and the discovery of what might be the Higgs boson. Two such books are Sean Carroll's *The Particle at the End of the Universe: How the Hunt for the Higgs Boson Leads Us to the Edge of a New World* and Jim Baggott's *Higgs: The Invention and Discovery of the 'God Particle.'* Both books describe the epic saga of the Higgs boson, and although each author has his own take on the story, both emphasize the people involved. Indeed, it is in describing the histories and personalities that both books are strongest.





Carroll tells the story from a quasi-insider perspective. He is not directly involved in LHC research; he is a theorist and a physics blogger of some repute, and in today's world, the rumors of a discovery are played out in the blogosphere before any official announcement is made. Research qualifications notwithstanding, Carroll relates how he attended the Higgs boson announcement in July 2012 by parlaying his media credentials.

The Particle at the End of the Universe begins with an introductory description and brief history of the standard model. Carroll then gives a theorist's cursory explanation of how the detectors at the LHC work. The focus of the book is on the Higgs field and boson, so the author spends some time on symmetries and how they are broken—and even what it means to have a broken symmetry. His chapters on the Higgs mechanism and the LHC are interesting and well written. This book is well suited for a reader interested in a conversational description of the Higgs boson and its significance. Your nonphysicist neighbors will enjoy it.

Carroll's book does have a few weaknesses. A good book should absorb the reader into the narrative until all else disappears. The second half of the book does that quite well, but in the first half, Carroll's writing voice often appears. Also, he introduces quantum field theories, describing how the electrons, photons, and all other subatomic particles can be expressed as vibrational modes of different fields. Because that particular insight is rarely seen in the popular literature, it had the potential to make *The Particle at the End of the Universe* a real contribution to the library of a lay reader interested in the nuts and bolts of modern physics.

However, Carroll elected to give a shallower treatment to quantum field theories than I would have liked. A few more pages at a level appropriate for the target reader would have significantly improved the book. One final criticism is that Carroll's frequent mention of gravitons, admittedly acknowledged as speculative particles, may leave an unwary reader with the impression that they are an accepted fact rather than a theoretical prejudice.

Higgs has a different flavor. Baggott is a freelance writer, not a physics insider. His writing is crisper, and the reader can fall into the narrative easily, without ever being jarred out. Despite its rather narrow title, the book is really about symmetries—the discovery of the Higgs boson is simply the crowning achievement of the past hundred years, during which scientists have increasingly appreciated the role of symmetry in our universe. In the first chapter, the book introduces Emmy Noether, a brilliant mathematician who tied together mathematical symmetries in physics theories with conservation laws.

However, that chapter also introduces a significant flaw. Baggott gives the common examples of spatial and time symmetries leading to momentum and energy conservation respectively, but he tries to explain the origins of charge conservation through the symmetry of quantum mechanical phase. That is accurate, but I am not convinced that the nonexpert will understand his description. In my opinion, the reader is more likely to simply accept that another symmetry was found and that it implies conservation of charge, but to have only the sketchiest understanding of what a quantum mechanical phase is.

Higgs continues in a historical vein, introducing along the way other great minds and their own discoveries of how new symmetries fit into the bigger picture. Its historical tale is an interesting whirlwind tour of some of the highest-impact innovations in 20th-century particle theory. The many insights are interesting, though they do come at the reader rather quickly. The weakness of the historical presentation is that the $SU(2)$ symmetry of the weak force and the $SU(3)$ of the strong force are introduced but not really explained. Again, I fear most readers will see those symmetries as merely phrases and mentally translate them as "some symmetry that I don't understand but that seems very important." I am not sure the $SU(3)$ of the strong force was even worth introducing, since it is not crucial to the narrative of the Higgs mechanism, which the book's title suggests is the central subject.

The second half of the book is more focused on the story of electroweak symmetry breaking, and the Higgs mechanism's role in it. This section is stronger, without some of the vagueness associated with the book's earlier description of fundamental concepts.

Unfortunately, *Higgs* contains a myriad of scientific errors that are obvious

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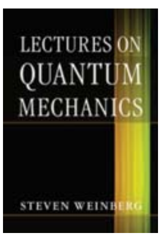
to any expert reader. Baggott says that the quark content of a proton (two ups and a down) violates the fermion statistics embodied in the Pauli exclusion principle, which states that two identical particles cannot inhabit the same quantum state. But if the spins of the two up quarks are opposite, there is no problem; it is baryons like the Δ^{++} with its three up quarks or the Δ^{-} with its three down quarks that inspired Oscar (Wally) Greenberg, Moo-Young Han, and Yoichiro Nambu to propose quark color. And in describing the role of beta decay in helping physicists work out the nature of the weak force, Baggott shows Feynman diagrams that illustrate neutrino scattering instead of beta decay.

Similar mistakes are sprinkled throughout the manuscript. Although they might not be enough to condemn the whole book (some readers will not catch such mistakes in the details), one is left with the unsettling suspicion that comparable errors are to be found in the historical sections as well. Although *Higgs* is more up-to-date, perhaps a safer choice detailing the history of the Higgs boson is Ian Sample's *Massive: The Missing Particle That Sparked the Greatest Hunt in Science* (Basic Books, 2010; reviewed in PHYSICS TODAY, May 2011, page 47).

Lectures on Quantum Mechanics

Steven Weinberg
Cambridge U. Press, New York, 2013.
$75.00 (358 pp.).
ISBN: 978-1-107-02872-2

Steven Weinberg, a Nobel laureate for his contributions to the standard model of elementary particles, has a well-deserved reputation as a writer who draws on great depths of physical insight to produce exceptionally clear prose. Until now, his books have been intended either for a general or advanced audience. For general readers, his books include *The First Three Minutes: A Modern View of the Origin of the Universe* (Basic Books, 1977) and *Lake Views: This World and the Universe* (Harvard University Press, 2010). For advanced readers, he has written *Gravitation and Cosmology* (Wiley, 1972), the three-volume *Quantum Theory of Fields* (Cambridge University Press, 2000), and *Cosmology* (Oxford University Press, 2008).



Weinberg now turns his attention to a core subject in physics with *Lectures on Quantum Mechanics*, a text based on a year-long course he has taught to first-year graduate students. The book begins with a 27-page "Historical Introduction" that concisely and elegantly summarizes the development of quantum physics, including an explication of Werner Heisenberg's matrix mechanics and its equivalence to Erwin Schrödinger's wave mechanics. We also find some little-known historical tidbits, such as who coined the word "photon."

The detailed discussion of quantum mechanics then begins with the Schrödinger equation for a particle in a central potential. Even in such well-worn territory, Weinberg finds interesting twists. For example, he neatly shows how the separability of the wavefunction follows directly from rotational symmetry. He also comments on how the energy levels of different atoms influence the cooling rates of astrophysical gases. This pattern of detailed mathematical exposition enlivened by examples—sometimes surprising ones—of physical