

A computer-generated artwork inspired by quantum mechanics.

## PHYSICS

# Questioning the quantum

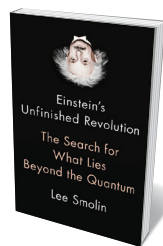
Graham Farmelo parses a takedown of the most successful physics theory ever.

Quantum mechanics is perhaps the most successful theory ever formulated. For almost 90 years, experimenters have subjected it to rigorous tests, none of which has called its foundations into question. It is one of the triumphs of twentieth-century science. The only problem with it, argues Lee Smolin in *Einstein's Unfinished Revolution*, is that it is wrong. In this challenging book, he attempts to examine other options for a theory of the atomic world.

Smolin is a theoretical physicist at the Perimeter Institute in Waterloo, Canada, and an outspoken critic of the direction his subject has taken over the past four decades. A fount of provocative ideas, he has showcased them in several popular books, including *The Trouble with Physics* (2006) and *Time Reborn* (2013). He is perhaps best known for his rejection of string theory, a widely used framework for fundamental physics that he dismisses as misguided. Although Smolin's spirited opposition to some mainstream developments in modern physics irritates quite a few of his peers, I have a soft spot for him and anyone else who is unafraid to question the standard way of doing things. As the journalist Malcolm Muggeridge observed: "Only dead fish swim with the stream."

Smolin's book is in many ways ambitious. It goes right back to square one, introducing quantum mechanics at a level basic enough for high-school science students to grasp. He points out that the field gave a truly revolutionary account of the atomic world, something that had proved impossible with the theories (retrospectively labelled 'classical') that preceded it. The mathematical structure of quantum mechanics arrived before physicists were able to interpret it, and Smolin gives a clear account of subsequent arguments about the nature of the theory, before finally setting out his own ideas.

For me, the book demonstrates that it is best to regard Smolin as a natural philosopher, most interested in reflecting on the fundamental meanings of space, time, reality, existence and related topics. James Clerk Maxwell, leading nineteenth-century pioneer of the theory of electricity and magnetism, might



**Einstein's Unfinished Revolution: The Search for What Lies Beyond the Quantum**  
LEE SMOLIN  
Penguin Press (2019)

be described in the same way — he loved to debate philosophical matters with colleagues in a range of disciplines. Maxwell's way of thinking had a profound impact on Albert Einstein, who might also be considered part natural philosopher, part theoretical physicist.

Like Einstein, Smolin is a philosophical 'realist' — someone who thinks that the real world exists independently of our minds and can be described by deterministic laws. These enable us, in principle, to predict the future of any particle if we have enough information about it. This view of the world is incompatible with the conventional interpretation of quantum mechanics, in which key features are unpredictability and the role of observers in the outcome of experiments. Thus, Einstein never accepted that quantum mechanics was anything but an impressive placeholder for a more fundamental theory conforming to his realist credo. Smolin agrees.

He conducts his search for other ways of setting out quantum mechanics in language intelligible to a lay audience, with scarcely an equation in sight. Smolin is a lucid expositor, capable of freshening up material that has been presented thousands of times. Non-experts might, however, struggle as he delves into some of the modern interpretations of quantum mechanics, only to dismiss

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them. These include, for instance, the super-determinism approach of the theoretician Gerard 't Hooft.

The book is, however, upbeat and, finally, optimistic. Unapologetically drawing on historical tradition and even modern philosophy, Smolin proposes a new set of principles that applies to both quantum mechanics and space-time. He then explores how these principles might be realized as part of a fundamental theory of nature, although he stops short of supplying details of the implementation.

Smolin concludes with the implications of all this for our understanding of space and time. He suggests that time is irreversible and fundamental, in the sense that the processes by which future events are produced from present ones are truly basic: they do not need to be explained in terms of more basic ideas. Space, however, is different. He argues that it emerges from something deeper.

Yet it is far from clear whether Smolin's new methods allow space and time to be investigated effectively. In recent decades, there have been many exciting advances in this subject, almost all made using standard quantum mechanics and Einstein's theory of relativity. In my opinion, Smolin downplays the extraordinary success of this conservative approach. It is the basis of modern quantum field theory (a descendant of Maxwell's theory of electricity and magnetism), which accounts for the results of all subatomic experiments, some of them to umpteen decimal places. Despite the impression that Smolin gives, modern theoretical physics is thriving, with potentially revolutionary ideas about space and time emerging from a combination of the standard quantum mechanics and relativity theory taught in universities for generations. Maybe the upheaval in physics that Smolin yearns for is simply unnecessary.

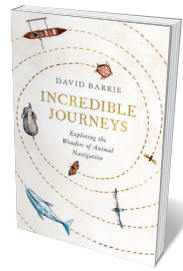
Rewarding as it is, I doubt *Einstein's Unfinished Revolution* will convert many of Smolin's critics. To do that, he will need to present his ideas more rigorously than he could reasonably do in a popular book.

One thing on which every physicist in Smolin's field can agree is that there is a crying need for more juicy clues from nature. There have been no surprises concerning the inner workings of atoms for some 20 years. It is experimental results that will decide whether Smolin is correct, or whether he protests too much. After all, although quantum mechanics might not satisfy the philosophically minded, it has proved to be a completely dependable tool for physicists — even those who have no interest in debates about its interpretation. ■

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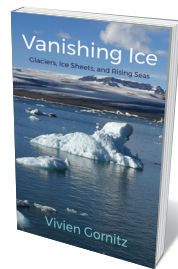
## Books in brief



### Incredible Journeys

David Barrie HODDER AND STOUGHTON (2019)

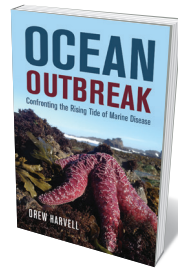
How does the blind Mexican cave fish (*Astyanax mexicanus*) navigate convoluted pools, or the tiny blackpoll warbler (*Setophaga striata*) fly non-stop for 2,770 kilometres over open ocean? In this exhilarating popular study, David Barrie reveals the roots of navigational prowess — such as the adapted eye and biological clock of the desert ant *Cataglyphis*, which function as a compass oriented to the Sun, or the myriad species that use olfaction, Earth's magnetism, sonar or cognitive mapping to find their way. The navigational nous of humans from astronauts to Indigenous peoples gets a look-in, too.



### Vanishing Ice

Vivien Gornitz COLUMBIA UNIVERSITY PRESS (2019)

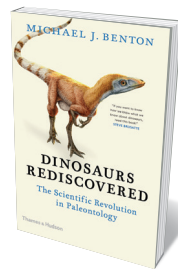
Whether it's shrinking ice shelves in Antarctica or Greenland's destabilizing ice sheet, the cryosphere is in flux, and this solid scientific primer by geologist Vivien Gornitz examines the human costs. In the context of deep time, she explores dwindling glaciers, thawing permafrost and other shifts that are leading to buckled land, diminished water supplies, serious sea-level rise and other impacts that, together with fiercer hurricanes, pose an existential threat that must be fought with decarbonization and innovative adaptation. A cogent analysis of this systemic, human-driven catastrophe.



### Ocean Outbreak

Drew Harvell UNIVERSITY OF CALIFORNIA PRESS (2019)

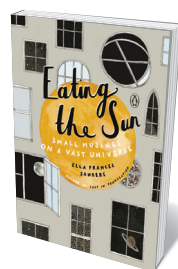
Abalone, corals, salmon and starfish: populations of these four marine animals are under siege from disease. The culprit, notes ecologist Drew Harvell in her succinct summation of two decades of research, is us — specifically, a confluence of ocean warming and acidification, dredging, oil extraction, overfishing and pollution. Harvell vividly recounts her work at the front line, studying die-offs such as the past decade's catastrophic starfish crash. Yet she is hopeful, noting that policy change, with techniques such as plant biofiltration and phage therapy, could still turn this malign tide.



### The Dinosaurs Rediscovered

Michael J. Benton THAMES & HUDSON (2019)

Palaeobiology is a field on fire with discoveries, such as China's panoply of feathered dinosaurs and the titanic sauropod fossils recently excavated in Patagonia. With advances in technology, that upheaval has transformed the discipline from natural history to testable science. In this illustrated update of dinosaur behaviour, cognition and locomotion, palaeontologist Michael Benton shows how technologies such as scanning electron microscopy reveal feather colour; 3D computer models indicate bone properties; and computation helps to build (and fell) evolutionary 'trees'.



### Eating the Sun

Ella Frances Sanders PENGUIN (2019)

With this pairing of witty illustrations and an open-weave narrative — strong on science but just this side of poetry — Ella Frances Sanders has penned a pocket-sized book vast in ambition. She distils phenomena, laws and principles, from heat, light and Earth's gravitational pull on the Moon to *Eigengrau*, the greyness seen in perfect darkness. You find yourself constantly reframed (say, as stardust, the "remnants of burning giants"), and see the Universe unpeeled to reveal the dance steps of electrons, the three hearts of a squid or the joys of noctilucent clouds. [Barbara Kiser](#)