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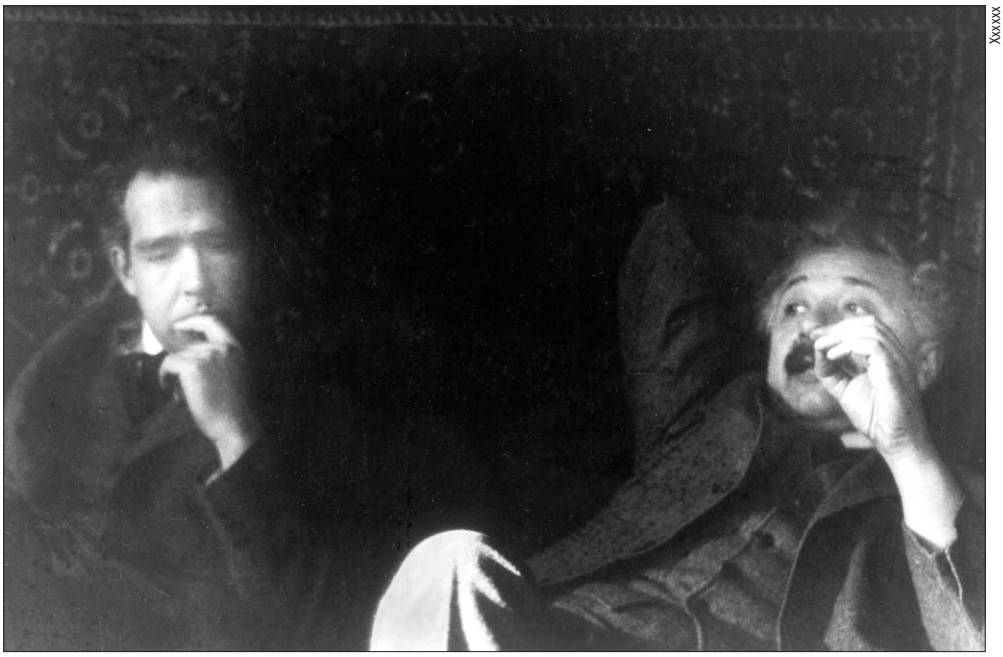
The story of the quantum



Begging to differ
Einstein and Bohr were great friends, but they could not agree on the philosophical implications of quantum theory.

Quantum: Einstein, Bohr and the Great Debate About the Nature of Reality
Manjit Kumar
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The emergence of quantum theory is one of the great stories of modern science. One reason is that the theory represents a genuine scientific revolution, on a par with the theory of evolution by natural selection or the general theory of relativity. Another is that it emerged gradually over a number of decades, with distinct contributions from many great scientists. Lastly, while quantum theory underpins much of today's technology, at its dark heart lie problems of interpretation unprecedented in science, bringing into question our most basic assumptions about the nature of reality.

The quantum revolution occurred in roughly three phases. In the "classical" or phenomenological phase, physicists sought to describe new observations in the micro-world by bolting ad hoc postulates onto the known laws of classical physics. Planck's hypothesis of energy exchange via discrete bundles of energy – *quanta* – falls into this phase, as does Einstein's postulate of the light quantum and Bohr's quantization of the orbits of electrons in atoms. The second phase saw the emergence of "new" quantum theory in the guise of Heisenberg's matrix mechanics and Schrödinger's wave mechanics. Finally, the work of Paul Dirac opened the door to quantum field theory, setting the stage for the spectacular success of modern theories such as quantum electrodynamics and quantum chromodynamics.

As the theory developed, so did a great debate concerning its philosophical implications. This debate is best exemplified by the opposing viewpoints of Einstein and Bohr. For Bohr, quantum theory amounted to rules of calculation for the probable behaviour of observables. In essence, the new physics concerned not reality itself, but "what we can say about it". Einstein was dismayed by the limitations of this outlook and firmly believed that an objective reality existed that a good theory should describe. When he failed to show that Bohr's interpretation was logically invalid, he became convinced that quantum theory must be an incomplete description of reality.

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The major theme of Manjit Kumar's book *Quantum: Einstein, Bohr and the Great Debate About the Nature of Reality* is indeed the serious disagreement between the two great scientists concerning the meaning of the theory that they helped develop. However, Kumar's opus is really two books. The first gives a history of the emergence of quantum theory, with a lengthy description of both the "classical" period and the subsequent development of quantum mechanics. The second describes the problem of the philosophical implications of quantum theory, focusing on Einstein's objections to the Bohr group's so-called Copenhagen interpretation. The debate is then brought up to date with a description of the subsequent work of scientists such as David Bohm, John Bell, Alain Aspect and Anton Zeilinger.

While pitched at the interested layreader, *Quantum* is quite a comprehensive tome. For example, Planck's quantum of action, Einstein's light quantum and the Bohr orbits are each assigned long chapters, with hundreds of footnotes. Some may enjoy this approach, but I found the unfolding story sometimes obscured by the frequent biographical diversions, quotes and anecdotes. Also, the order of presentation does not always aid understanding – for example, the Pauli exclusion principle and the postulate of electron spin could have been included in the "classical" phase of the story, while the discovery of the wave aspect of matter really marks the beginning of the second phase. That said, the feeling of a picture gradually emerging as various scientists contributed pieces to the puzzle comes across well. I particularly liked Kumar's emphasis on the contribution of lesser-known figures such as Born, Jordan, Klein and Sommerfeld.

The second half of the book is the better of the two. The emergence of Bohr's philosophy is clearly described, as is the nature of his disagreement with Einstein. Again, there are many diversions, but Kumar's description of Einstein's attempts to defend both locality and realism via gedankenexperiments is well done. Common simplifications of the debate are avoided and points carefully made; a good example is Kumar's explanation that

"Einstein wanted to disprove …that quantum mechanics was a complete fundamental theory of nature by demonstrating that there exist objective elements of reality that the theory did not capture".

It is often wondered how the Irish physicist John Bell managed to design what Einstein and Bohr could not: an experiment that can distinguish between the local realism advocated by Einstein and the "spooky action at a distance" of the Copenhagen interpretation. Kumar explains this by charting the development of Bell's theorem from the work of Bohm. The description of the subsequent experiments by Aspect is very exciting and the chapter closes with a moving reference to Bell's sudden death from a brain haemorrhage in 1990. This part of the book works well, although some physicists may wish to turn to books like the 2004 edition of Alastair Rae's *Quantum Physics: Illusion or Reality?* for a discussion of the more recent experiments.

Indeed, one slight worry with Kumar's book is that while the layperson may find the story tough going due to the wealth of material, it may not be technical enough for professionals. For example, it is not mentioned in the chapter on matter duality that the De Broglie relation arose from a consideration of the mass–energy equivalence of relativity in a most beautiful way. Nor does the author discuss the Dirac equation – an equation that reconciled quantum theory with special relativity, established a theoretical basis for electron spin and predicted the existence of antimatter. There is almost no mention of the rise of quantum field theory (or of the difficulty of constructing a quantum theory of gravity, which may indicate that quantum theory is incomplete after all). Finally, the omission of quantum tunnelling is a pity, as it is one of the most convincing demonstrations of the strangeness of the quantum world.

Notwithstanding all of the above, *Quantum* is an interesting and informative read. The story of the emergence of the theory is well told and the historic puzzle of interpretation accurately depicted.

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