The age of chance

Uncertainty: Einstein, Heisenberg, Bohr, and the Struggle for the Soul of Science
by David Lindley
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In *Uncertainty*, David Lindley tells the intriguing tale of how Albert Einstein, Werner Heisenberg and Niels Bohr (among others) struggled to create and understand the new quantum physics. Lindley organizes his tale around the issue of indeterminism, which Max Born raised in 1926 in the paper that introduced probability as fundamental to interpreting the quantum world. Within a year, at the end of his paper on the uncertainty principle, Heisenberg declared determinism (or causality) dead, a pronouncement that brought probability, chance and uncertainty into the quantum domain in a fundamental way.

Lindley tracks the rise of chance from its roots in statistical reasoning (brownian motion and entropy) through to Bohr's 'jumping planetary model' of the atom and beyond. He selects important episodes from this 'old' quantum theory and then retells them in a lively and insightful manner. This provides the background for Heisenberg's theory of matrix mechanics and Erwin Schrödinger's wave mechanics. The author tells how Bohr encouraged, derided, cajoled, inspired and browbeat all sides to orchestrate the Copenhagen synthesis to meet his own physical intuitions and philosophical likings. Lindley captures the passion of the struggle, showing both the public controversies and the sometimes harsh private judgements (for example, writing to third parties, Heisenberg and Schrödinger each described the other's work as repulsive, and worse).

What elicited this passion is the question of whether the behaviour of atoms (quanta) can be described continuously in space and time. Heisenberg's strange matrix methods are driven by his belief that they cannot, whereas the wave approach opens up the possibility that they can. That prospect, and the divisive reaction to wave mechanics, was bolstered by a development that Lindley scarcely mentions. It concerns Louis de Broglie.

Lindley does mention de Broglie, but describes his brilliant association of waves with particles as merely an "elementary idea that crossed his mind". This is a stab-in-the-dark history that rips the important de Broglie relations from their theoretical context. That context was de Broglie's proposal for a radically non-newtonian dynamic theory in which particles followed trajectories determined by an associated wave. De Broglie showed how this could account for basic interference phenomena (as waves) as well as quantized energy (as particles). That drew it to the attention of Einstein and Schrödinger, who found the ideas promising, and to Heisenberg, Pauli and Bohr, who felt threatened by them. But de Broglie lacked a general treatment of the waves that guided his particles, and that is where wave mechanics comes in.

The fifth Solvay conference, held in Brussels in October 1927, was a major event involving nearly all the figures mentioned in Lindley's story. Lindley describes the struggle between updated versions of wave and matrix mechanics, and Einstein's informal challenges. The confrontation also included an updated de Broglie theory, with continuous space-time trajectories. Moreover, full determinism was guaranteed by linking de Broglie's new dynamics with Schrödinger's waves. Lindley's book misses all this, misrepresenting de Broglie as fighting a rearguard action on behalf of Schrödinger. It's as if the head-on collision over determinism, the introduction of a radically different dynamics, the discussions, thought experiments, probing challenges and responses never occurred.

Lindley touches on several significant later events in his story, including an encounter between Einstein and Bohr during the 1930 Solvay conference, reactions to the Einstein–Podolsky–Rosen paradox and an update on Schrödinger's cat. Other sections also mention a few sociological and philosophical reactions, which Lindley criticizes and quickly dismisses, along with any dissent from the orthodox view. These sections are disappointing. It seems, unfortunately, that Lindley's perceptive and sympathetic treatment of ideas and figures is reserved for the winning side of the struggle. He marginalizes Einstein's concerns by presenting him as a young revolutionary turned old reactionary. Lindley keeps returning to Einstein's desire for causality, while downplaying Einstein's equally strong insistence that physics, causal or not, should deal with nature itself, not just our observations. The author also overlooks Einstein's radical critique of the classical, physical concepts used in quantum theory, as well as his programme for developing new concepts, and his eventual openness to an algebraic, rather than a spatiotemporal, setting for the physics (not exactly a reactionary agenda).

For a different perspective, readers may be interested in David Cassidy's *Uncertainty: The Life and Science of Werner Heisenberg* (W. H. Freeman, 1991), Mara Beller's *Quantum Dialogue* (University of Chicago Press, 1999), and two books by Abraham Pais, *Subtle is the Lord* (Oxford University Press, 1982) and *Niels Bohr's Times* (Clarendon, 1991). A forthcoming book by Guido Bacciagaluppi and Antony Valentini, *Quantum Theory at the Crossroads* (Cambridge University Press, 2007; available online at http://arxiv.org/abs/quant-ph/0609184), will offer a reanalysis of the 1927 Solvay conference.

Uncertainty tells the tale of the struggle over quantum theory from the perspective of an omniscient narrator. The narrator turns out not to be all that impartial. He is also not omniscient, stumbling a few times (and not just by omission), as anyone might in such a complex tale. Yet the story is told with verve, has some interesting historical asides, and makes a good read. Still, you might not want to believe it; well, certainly, not all of it. ■

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P. EHRENFEST/AIP EMILIO SEGRE VISUAL ARCHIVES

Niels Bohr (left) and Albert Einstein sought to shape the development of quantum physics in 1930.