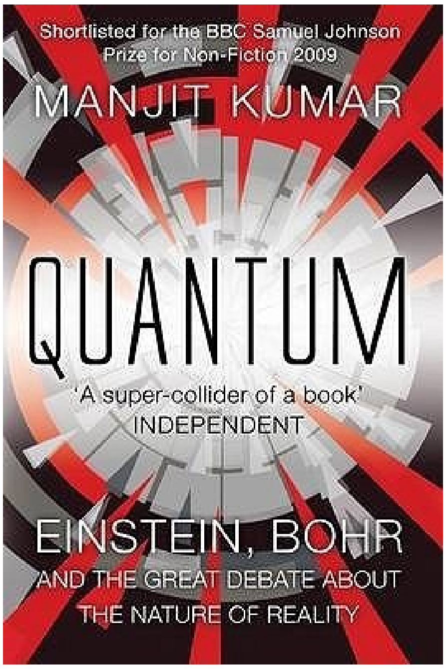

Quantum: Einstein, Bohr and the Great Debate About the Nature of Reality

Manjit Kumar

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Quantum theory is weird. As Niels Bohr said, if you weren't shocked by quantum theory, you didn't really understand it. For most people, quantum theory is synonymous with mysterious, impenetrable science. And in fact for many years it was equally baffling for scientists themselves. In this tour de force of science history, Manjit Kumar gives a dramatic and superbly written account of this fundamental scientific revolution, focusing on the central conflict between Einstein and Bohr over the nature of reality and the soul of science. This revelatory book takes a close look at the golden age of physics, the brilliant young minds at its core—and how an idea ignited the greatest intellectual debate of the twentieth century.

Quantum: Einstein, Bohr and the Great Debate About the Nature of Reality Details

Date	:	Published October 2nd 2008 by Icon Books (first published March 5th 2007)
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From Reader Review Quantum: Einstein, Bohr and the Great Debate About the Nature of Reality for online ebook

BetseaK says

In this work the author managed to give a superb account of the development of thought about quantum by bringing to life all the great physicists involved (Planck, Einstein, Born, Bohr, Schrödinger, de Broglie, Wien, Pauli, Heisenberg, Dirac, Boltzmann, Compton, Bohm, von Neumann, Bell) through vivid vignettes of their scientific accomplishments, interpersonal relations and the historical background. As it is evident from the title, the aim of the book was to present the clash of philosophical viewpoints between Einstein and Bohr about quantum theory and its interpretation. Without leaning on the equations and the mathematics of quantum theory, Manjit Kumar succeeded to accomplish it through a story that reads like an epistemological thriller. (Needless to say, though 'the Bell's Theorem tolled for Einstein', the ending is still a sort of a cliffhanger.) The quantum concepts are explained with clarity (with a couple of exceptions, but I enjoyed the book too much to be too critical).

As an afterthought: If you are interested in a mystical or religious interpretation of quantum theory, this is not the book.

And also, here's the link to a review which, in my opinion, captures the feel of this book very well: http://www.theguardian.com/books/2008/nov/15/quantum-physics-einstein-bohr-kumar

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Manuel Antão says

If you're into stuff like this, you can read the full review.

In the 15th chapter the key to Quantum Mechanics (QM). It was Richard Feynman who said, "I think it is safe to say that nobody understands Quantum Mechanics."

This book does not help either.

Quantum mechanics is the spookiest theoretical framework ever devised by man. Cats that are at the same time alive and dead ("Superposition" = "We do not know"; "Collapsing the superposition" = "finding out" whether the cat is alive and kicking), objects that are both particles and waves, etc.

3 stars for the two chapters dealing with the 1927 and 1930 Solvay conferences.

Adam says

Well-written and engaging. Clarifies and explains concepts and events in 20th-century physics in ways that enable the scientific imbecile to better comprehend what the big deal is and why it's (still) such a big deal. Also works to arm said scientific imbecile with ways to humiliate people in the humanities who just *love* to bullshit about stuff they understand even less than someone who read a pop-science history does.

Oh, and there's fun stuff in here about the personal lives of major figures in 20th-century physics. But that stuff is nowhere near as compelling as the overall drama at the heart of this account.

Murray Ewing says

It started with German physicists trying to make a better light bulb, and ended with the collapse of classical physics (if only at the subatomic level). Manjit Kumar’s **Quantum** is a history of the development of our understanding (if understanding is the right word for something nobody seems to understand) of quantum mechanics, looking into the lives of the key players as much as their discoveries.

The two major players are Einstein and Niels Bohr, who, while agreeing that the equations behind quantum mechanics worked, differed absolutely on what those equations actually meant. Einstein wanted a physics that presented an accurate, realistic model of reality; Bohr believed there *was* no reality at the quantum level — not until we measured it, at any rate — just a bunch of probabilities, and that no ‘realistic model’ was possible.

Kumar’s biographical approach highlights just how strange the path that led to the ideas of quantum science was — how, for instance, at the early stages, people presented equations that explained experimental results, but that nobody expected to be anything but a stop-gap till a more understandable (and less bizarre) solution came along, only to find that no, their bizarre equations *were* the best solution, and things were only going to get stranger.

I can’t say I now understand quantum mechanics, or that I followed every theoretical step forward — the actual steps forward are explained quite briefly, without getting too much into technicalities — but I have certainly come to a strong appreciation of what strange materials these genius-level scientists were working with. Plus, it’s a good look into the scientific process generally, how a theory is worked at, and advanced, by many players, how ideas that are later accepted as canonical can be at first ridiculed, and how every step forward in science can raise even more questions.

A good book, it certainly left me wanting to know more.

Loraine says

Whether the science in this book is light or heavy depends on who you are. For me, the science was heavy, as my fascination with science has always been greater than my knowledge of it. I am not a scientist.
That said, I loved this book. Did I understand all the theories, experiments and discussions? No. But I understood enough to follow the narrative and get excited or saddened by events and to share the passion of these giants and marvel at their tenacity and their genius.
Years ago, When I started my studies in chemistry and physics, my brother thoughtfully gave me a framed copy of the famous Solvay 1927 Conference group photo, the one mentioned in the prologue, as inspiration. Inspire it did, as I gradually learned who these participants were and what they contributed to the understanding of our world. Theirs is such a grand story, I did not need to get every scientific reference in order to love listening to it. I think that is a measure of just how good this book is.

Matt says

Quantum-Theory is a rather complicated matter of which I knew next to nothing prior to reading this book. Of course I heard of some players in this field, like Einstein, Bohr, Schrödinger, or Heisenberg, but it was all very vague and left me standing pretty much in the dark. Manjit Kumar was able to shed at least a little light (some photons if you like) on the topic, and I got a glimpse on this extraordinary achievement of human mind.

Spanning roughly the time between 1900 (Planck's constant) and the mid 1960s (Everett's *many world interpretation*) this books explains QT/QM in a language that makes it relatively easy for this layman to follow. There's hardly any mathematics in this book and only a few diagrams. The author sets the weight on the essential leaps in developing the theory and adds some intriguing biographical and historical background on the physicists involved.

I suppose everyone heard of "Schrödinger's cat". This thought experiment is explained pretty well, and also why Schrödinger invented it in the first place. Much more interesting to me though was the Einstein-Bohr debate. Apparently Einstein has spend a lot of his energy to refute Bohr's interpretation of QM. Alas, he failed.

For scientists, this book is certainly too superficial, but I think in order to gain an outside perspective on quantum mechanics this is an excellent read.

UPDATE 1/16/16
Dramatis personæ; at the Solvay International Conference on Electrons and Photons, 1927 [click to enlarge and read names]

Durvasa Gupta says

The title itself is enough to carry away someone who is a quantum nerd. The author presents the biography of not a person but a field of science “Quantum Mechanics” in a most fascinating way. It took over a millennium for people to believe that the Earth was round, not flat. It was a difficult leap for humanity. There was a similar leap needed when the quantum was discovered. All the while when people believed light was a wave and matter continuous they had to take a leap into believing light could be a particle and an atom can have discontinuities. The book not only gives a comprehensive account of the birth of the quantum to the development of quantum mechanics but also in agreement with the title, it gives captivating details of the debate between Einstein and Bohr on the ontology of quantum mechanics. Highly recommended for people passionate about science.

Britta Böhler says

A very interesting and detailed account of the development of quantum physics and the decennia-long discussion between Einstein and Bohr about the nature of reality. Not an easy subject but the author manages to make it accessible for non-scientist, (and he kept the mathematicas at a minimum). I listened to the audiobook (ca. 14 hrs), beautifully read by Nat Porter.

Irene says

Although I study chemistry and I love science, I've never been good at physics. This time I decided to make an exception and read this book. I found it absorbing like a novel, really well written and clear in explaining scientifics notions.

I especially appreciate the way the author combine science, history and scientists personal lives. As a student I often heard Einstein, Bohr, Rutherford, Planck, Shroedinger, Heisenberg, Pauli, but I never stopped thinking about them just as persons.
This book tells us about all the hard work, the passion, the struggles that these scientists experienced. Moreover gives a clear idea about how difficult is to bring new concepts in a well established academic community.

I don't know enough about quantum physics to dwell on scientific explanations that are given in this book. I simply have to trust the author knowledge!
I really recommend this book to everyone who wants to approach this fascinating subject.

Roger says

There are a lot of popular science books on quantum theory but this one is different in that its aim is to question what's meant by reality. Manjit Kumar achieves this objective admirably. He also provides what I've found to be the best and most coherent account of the history of the development of quantum theory that I've read, managing, at the same time, to bring alive many of the key physicists and mathematicians involved, and not just Neils Bohr and Albert Einstein who are in the book's title. He also succeeded in explaining many aspects of quantum theory without resorting to mathematics, which is no mean feat. An exception was Bell's Inequality Theorem but I doubt that anyone could explain that in a non-mathematical way - despite having read several accounts by different authors I still have little idea of why this theory should tell us anything about hidden variables, but evidently it does.

Whilst the subject of reality forms the main theme of the book, it's past the half way point before this topic is discussed in any serious way. But then Manjit examines the concept very thoroughly, focussing on the Copenhagen interpretation along with Einstein's objections to this interpretation, based on his belief that quantum theory is incomplete and that probability and non-locality must have some underlying explanation that is still to be discovered.

My only criticism is that I feel the book could have been shorter, perhaps my omitting some of the finer detail when it came to history or by cutting out some of the views expressed by "lesser" scientists. There is quite a lot of repetition but, from my perspective, I found that helpful in reinforcing many of the points raised. However, a reader more familiar with the area might find the repetition irritating.

Ami Iida says

It's written about the quantum mechanics history.

Max says

I thoroughly enjoyed Kumar’s book. He traces the scientific discoveries leading to quantum theory and the relationships of the scientists with a focus on the Einstein-Bohr debate over the theory’s meaning. I found Kumar’s explanations of complex theories accessible and helpful. I remember in high school and college in the 1960’s always hearing about this strange quantum world that didn’t quite exist unless someone looked at it. Kumar really helps make sense of it. My notes below summarize the science that paved the way for quantum theory, the Einstein Bohr rivalry and the various takes on the Copenhagen interpretation.

Kumar’s history begins with Max Planck’s discovery of the quantum and his eponymous constant. Working to derive a formula to predict the spectral distribution of blackbody radiation in 1900, Planck found that only whole increments of energy worked. At a time when the atom was not a widely accepted theory, this confronted Planck’s belief in the continuous nature of energy and matter. He dodged the issue by saying that only the exchange of energy was quantized, not energy itself.

Along came Einstein who accepted atoms as discrete matter and sources of discrete energy. After reading Planck’s paper Einstein challenged the prevailing wave theory of light, proclaiming light is made up of quanta. Einstein employed his quantum theory of electromagnetic radiation to explain the photoelectric effect in which light precipitates the release of electrons from metals. This was in 1905. Even in 1922 when Einstein was awarded the Noble Prize for his equation explaining the photoelectric effect, the underlying principle of light as quanta was still not widely accepted. Newton had held that light was composed of particles, but Thomas Young’s famous two slit experiment in 1801 showed light to be a wave. After overcoming the implied disrespect to Newton, scientists finally accepted light as a wave and held onto that view as tenaciously as they had held onto the particle view before. Also in Einstein’s Annus Mirabilis he explained Brownian motion with atomic theory gaining the atom much wider acceptance. And in his spare time that year he formulated the special theory of relativity and the famous E=MC2.

In 1913 Niels Bohr conceptualized the quantum atom. Recognizing that J. J. Thomson’s plum pudding model of the atom was inherently unstable Bohr assigned electrons to special orbits in which they could not continuously emit radiation and lose energy. Each orbit had a specific energy level. When an electron moved from one orbit to another an exact amount of energy (quantum) was exchanged which resulted in unique spectral patterns. Amazingly there was no in between. An electron left one orbit and appeared in another instantaneously. The Franck-Hertz experiment in 1914 confirmed that the energy released or absorbed was exactly the difference between the energy levels of the orbits. In 1922 Bohr refined his atomic model with the concept of electron shells. This allowed him to predict the chemical similarities of elements in the periodic table.

Einstein was thrilled with Bohr’s quantum atom as he felt it proved his theory of light-quanta. In 1916, finding time after his ground shattering theory of general relativity was announced in 1915, Einstein theorized that spontaneous emission occurred when an electron jumped to a lower energy orbit. The rub was that in his theory electrons made these jumps at random. His theory employed probabilities to determine the frequency of these jumps. Einstein, now as later, was uncomfortable with chance in physics theories. Einstein's light-quantum, later to be renamed the photon, was proven in an 1923 experiment by American Arthur Compton who firing x-rays at graphite recorded changed wavelengths in the reflected scattered x-rays. Only a particle would behave this way. Furthermore he found the recoiling electrons that the x-rays had bounced off of. Then a French prince, Louis de Broglie, setting the stage for quantum mechanics, postulated that if a wave could have the values of a particle, why not the reverse? Ascribing wave characteristics to electrons explained perfectly the available orbits for electrons in an atom. Only those orbits that could accommodate whole or half wave lengths were physically possible. Sure enough subsequent experiments showed that electrons diffracted just like light. Wave particle duality was now established for energy and matter.

In 1925 Wolfgang Pauli building on a paper by Edmund Stoner developed the exclusion principle. Stoner determined the number of possible energy states of electrons orbiting an atom. But the three quantum numbers denoting angular momentum, shape of orbit and orientation of orbit only allowed for half of the possible energy states. Pauli developed a fourth quantum number which would later be explained as spin. This quantum spin had two states, up or down, doubling the number of allowable electrons. It also explained the heretofore mysterious splitting of spectral lines known as the Zeeman Effect. The exclusion principle stated that no two electrons in an atom could have the same set of quantum numbers thus limiting the number of electrons.

Werner Heisenberg solved a remaining problem of the quantum atom model. Even though it now explained the frequency of spectral lines, it did not explain the different intensities. Heisenberg decided to discard anything not observable, even that electrons occupied orbits. He needed the help of Max Born who collaborated with one his students, an excellent mathematician named Pascual Jordan, to get the math to support the physical theory. This new quantum mechanics employed a strange form of matrix mathematics in which A times B does not equal B times A, but it successfully calculated spectral line intensities. In England, Cambridge student P. A. M. Dirac also developed a mathematical proof working from a draft of Heisenberg's paper.

In 1926 Edwin Schrödinger developed a wave function for de Broglie's electrons which eliminated the incomprehensible electron jumps. It also supported calculations that achieved the same predictive results as Heisenberg's matrix mechanics. The rub was picturing what the wave represented. Schrödinger claimed it was a cloud of charge that could smoothly and continuously move from one orbit to another. He denied that electrons were particles at all while Heisenberg, committed to particles, opposed the wave theory, putting the two at odds.

Heisenberg trying to settle his dispute with Schrödinger developed the uncertainty principle. This stated that quantum mechanics could not determine both the position and momentum of a particle, specifically an electron. Heisenberg, working as Bohr's assistant, toyed with the idea that the photon itself that measured the electron interfered with the observation. Heisenberg refused to imply any behavior to an electron that could not be measured. There was no assuming what happened to an electron between two measurements, thus no path at all was held to have been traveled. Basically Heisenberg was saying classical concepts of wave, particle, position, momentum and trajectory had no meaning in the quantum world until observed.

Bohr believed that uncertainty was fundamental to the quantum nature of wave-particle duality. Bohr felt the electron was both a wave and a particle, but that no experiment could measure both at the same time. He called his principle complementarity. Bohr held that observer and observed could not be separated. The way the quantum world was observed determined what was seen. Be it wave or particle, both observations were true depending on the way it was observed. Causality and regular patterns had no meaning. The only prediction quantum mechanics could make was one of probability. No experiment could ever return the deterministic clockwork cosmos of Newton to the quantum world. There was no reality at the quantum level outside of observation. This view became known as the Copenhagen interpretation.

Einstein, while accepting that quantum mechanics was a correct and important theory, did not accept this interpretation. Einstein believed the quantum world was deterministic (“God doesn’t play dice.”) and most importantly real. It was there even when nobody was looking. The stage was set for a lifelong series of challenges to this interpretation by Einstein directed at Bohr, the Copenhagen Interpretation’s champion. At the conferences in Solvay in 1927 and 1930 Einstein offered thought experiments to show quantum mechanics was an incomplete description of reality. Bohr would parry and nothing would be resolved.

After the Nazi’s assumed power in Germany In 1933 Einstein moved to Princeton. Bohr would be able to continue in Copenhagen until the Nazi’s declared martial law in Denmark in 1943. Many Physicists in Germany were Jewish or had Jewish connections. They were leaving and scattering around the world. Despite the turmoil of the 1930’s and 40’s, Einstein and Bohr carried on their quantum chess match. Einstein in 1935 published a paper with help from Princeton assistants known as the EPR paper. This thought experiment proposed measuring the momentum and position of one of a pair of entangled particles to determine the momentum and position of the other. The point was to prove the existence of the other particle independent of direct observation of it. The Copenhagen interpretation denied reality independent of observation. Key to Einstein’s argument was the concept of locality, that nothing faster than the speed of light could affect the other particle. Bohr conceded this but claimed the particles were entwined and thus one system, that a measurement of one was a measurement of both.

Einstein reached out to the sympathetic Schrödinger who came up with his famous cat in a box thought experiment. A tiny radioactive substance is placed in the box. When it decays it will trigger a Geiger counter that will trigger the release of a vial of poison killing the cat. Since the event is not observed, does it happen? In the Copenhagen interpretation of quantum mechanics only a probability wave of the event exists. Schrödinger was trying to appeal to common sense in support of Einstein believing in reality that the cat was either actually dead or still alive. But Copenhagen purists would still say that the cat was both dead and alive until the wave was collapsed by observation. The debate would dominate the minds of Bohr and Einstein over the ensuing years. Bohr last visited Einstein in Princeton in 1954. Einstein died the next year at 76. Bohr died in 1962 at 77. The night before his death Bohr had drawn on his blackboard Einstein’s light box, a thought experiment Einstein proposed at the 1930 Solvay conference in an attempt to prove quantum mechanics an incomplete theory. Over 30 years later Bohr was still refining his argument.

In 1964 John Stewart Bell put forth a theorem to test whether any local hidden variables could be used to explain the behavior of the entangled particles in the EPR thought experiment. Subsequent tests of the theorem supported non-locality between entangled particles and paved the way for today’s experiments with quantum level teleportation. But even though what Einstein called “spooky action at a distance” was proven to exist, his underlying belief that the quantum world also existed even when not measured was not disproven. In 1957 Hugh Everett III found a neat way around the problem with his many worlds interpretation. In this theory all quantum states actually exist simultaneously, obviating the probability wave. This resolved one objection to the Copenhagen Interpretation: Who observed the big bang to collapse the probability wave? God, of course, is one answer. Another issue for quantum mechanics is determining the dividing line between the quantum world and the classical world where reality is the norm.

Despite the overwhelming acceptance of the Copenhagen interpretation in the mid-twentieth century, today while quantum mechanics itself is universally accepted, many physicists don’t believe it is a complete theory. The Copenhagen interpretation has lost its luster. Nobel laurate Murray Gell-Mann said ”Niels Bohr brain-washed a whole generation of physicists into believing that the problem had been solved.” At a 1999 quantum mechanics conference at Cambridge University, of 90 physicists polled, only four accepted the Copenhagen interpretation, thirty believed the modern version of the many worlds theory and most were undecided. Famed British physicist Roger Penrose said “I would, myself, strongly side with Einstein in his belief in a submicroscopic reality, and with his conviction that present-day quantum mechanics is fundamentally incomplete.” So maybe somewhere in the great beyond Einstein is finally winning his argument with Bohr.

Nilesh says

Many good books are written to simplistically explain the theoretical revolutions brought about in The first half of the tweNtieth century. Great biographies are published on the protagonists. But this book is something just different, wonderfuLly different.

Sidestepping relativity is never easy while talking about Einstein. The book manages this. His opposition to Quantum theory is often either trivialised or made ridiculously philosOphical. The book masterfully traverses the landscape.

But the book's biggest achievement is the roles played by so many other luminaries aLong with their background, interpersonal relationShips, rivalries, along with roles played by chance, the sequencing of events that made the era possible as well as the influence of wars.

A must read for anyone interested in either science or scienlists.

Jafar says

I’ve read a few books on Quantum physics and its incredible quirks and its implications about the nature of reality. By comparison, this book is light on the science, but provides an excellent history of quantum physics. There are historical fact that I had never heard of, such as the rivalry between Schrodinger and Heisenberg. Any book on quantum physics makes you think that Schrodinger was one of the pillars of the quantum community, but in fact he was an outsider and at odds with Bohr/Heisenberg/Pauli and closer to Einstein. Einstein’s famous disapproval of the interpretation of quantum physics (“God does not play dice.”) is mentioned in many books, but here you see very well why Einstein, who was the grandfather of quantum, was so uncomfortable with what the Bohr camp was saying, and how he obsessed many years over refuting the probabilistic nature of quantum physics. All in all, a very fascinating book.

Anna says

I’ve ostensibly been reading ‘Quantum’ for nine months. Actually, I got about 70 pages in while on a train then let it sit on my bedside table for three quarters of a year. Then I took it along on another long train journey and got back into it, although it definitely benefits from the lack of distractions in a quiet carriage. The fact is, I am social scientist who hasn’t studied any actual science since I was 16 and only realised while reading this book that the word ‘nuclear’ refers to the nucleus of an atom. Thus I read ‘Quantum’ at a slower pace than I’m used to, in order to get my head around it. The author deserves commendation for making quantum physics gradually comprehensible, on some level, to a layperson. Using the format of a narrative history definitely helps with this. The account of how the Nazis destroyed perhaps the world’s best physics institute with their decree that Jews couldn’t work in universities is especially memorable.

It took me about a hundred pages to get properly involved, but after that I was hooked. Kumar explains the debates between Bohr and Einstein about quantum theory and the very nature of reality with impressive clarity. I certainly feel much closer to understanding and my interest in more recent developments in quantum physics has been piqued. I also appreciated Kumar’s turn of phrase, particularly, ‘In the past, none had emerged unscathed from an attempt to pinpoint what constituted reality’.