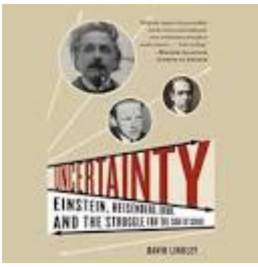

Uncertainty:
Einstein, Heisenberg, Bohr, and the Struggle for the Soul of Science

By David Lindley
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Having researched the details of the International Space Station (ISS) Space-QUEST (Quantum Entanglement for Space Experiments) experiment I wanted to know more about the origins of quantum mechanics – not being a studied physicist myself I was looking for an "understandable" book to learn more details. The "Uncertainty" book by David Lindley (2008, Anchor Books) was exactly the book I was looking for.

> If you do not get schwindelig [dizzy] sometimes when you think about these things then you have not really understood it [quantum theory]
> Niels Bohr

It all was started by Robert Brown (Brownian motion) in 1827 after he began a detailed study of the pollen Clarkia Purchella. Under his improved microscope he discovered the jiggling of pollen which could not be explained by external influences. The following long chain of unsuccessful attempts to explain or even calculate this phenomena ranging from Wiener, Maxwell, Poincaré and Boltzmann is described until Einstein introduced statistics for atomic movements and offered the first analytical explanation in 1905.

The next chapter describes the breathtaking struggle of defining an atomic model which would satisfy all originally not interconnected phenomena of entropy, electrical current, spectral analysis and radiation initiated by Madame Curie, Becquerel and J.J. Thompson ("plum-pudding model") and others. Rutherford, experimenting with alpha particles introduced the idea that alpha particles must be bounced off something he called nucleus and that radioactive decay would be caused by an atom changing from one state to another without being able to predict which individual atoms are going to change (unpredictable "transmutation"). This question intrigued also Niels Bohr who in 1913 used the term of energy "quantum" to explain the "vibrations" of an electron within an atom, however allowing only discrete amounts of "quanta". With this assumption he was referring to Max Plank's postulated "energy- quantum" for explaining the various glowing shades of heated bodies in 1900 (black body problem).
Also in 1905 Einstein introduced the "light quantum", i.e. little packets of energy, to explain the photoelectric effect. To his own puzzlement this was in conflict with the usual wave behavior thus introducing the disturbing notions of "spontaneity" and "unpredictability" to the classical understanding of physics.

Disrupted by the first word war science activities slowly gained foot again and under the tutorship of Sommerfeld the stage finally was set for Pauli (1918) and Heisenberg (1920).

While Sommerfeld talked of the "music of atoms", Bohr raved in one of his first discussions with Heisenberg "when it comes to atoms language can be used only as in poetry, not describing facts but creating images".

The author David Lindley describes emphatically and comprehensible like an participating eye-witness the turbulent development of the Bohr/Sommerfeld atomic model with electrons moving around a nucleus on fixed orbits started during the 1920's. Heisenberg's half-quantum theory and Landé's efforts to explain the Zeeman-effect observed in various line-spectra, the "Bohr-Festspiele [festival]" in Goettingen, and finally

Bohr's reception of the Nobel Prize in 1922 "***for his services in the investigation of the structure of atoms and of the radiation emanating from them"*** were notable milestones.
David Lindley also points out the sometimes confusing and supporting events like Einstein's explanation of the photo electric effect introducing light quants, the Compton effect and the brave attempt to defend Bohr's atomic model with the BKS theory ("The quantum theory of radiation" by Bohr, Kramers and Slater)
In view of the "virtual oscillators" promoted in the BKS paper Pauli was the first to raise the question as to which extent it would be allowable to speak of defined orbits in an atom.

After a stay in Copenhagen in 1924 and a brief cooperation with Kramers the idea of virtual oscillators took hold with Heisenberg and he had the idea to apply the Fourier analysis to atoms i.e., to write down the classical elements of position and velocity not as mechanical equation but in terms of frequency and amplitude and after "feverish" calculations recovering from a hay-fever attack at Helgoland he found to his own surprise that inserting his ideas into standard equations of mechanics and grouping similar components into usable terms to help to clean up the "mess of mathematics" the energy of mechanical systems quantized itself, but to his surprise the new calculation method was not reversible, however could explain the observed behavior in the spectral lines. Jubilant he noted for himself: "something has happened!" and published his paper on quantum mechanics in August of that year which caused Einstein to note, "Heisenberg has laid a large quantum egg"
Two years before, in 1923 DeBroglie, with his own experiments attributed electrons with associated wavelengths around the atom (standing waves), causing Einstein to breathe easier ("The fog is lifting"). Schrödinger picked up this idea and found a wave equation describing the change from one status into another as a "fluid, not abrupt transformation" according to his notion that particles are not particles but the caps of an underlying wave.

The mathematician Max Born finally introduced matrix algebra rules to Heisenberg's calculation and also Dirac confirmed matrix calculation results using a different approach.
Again after much deliberations, trials and tribulations it was agreed that quantum mechanics and wave mechanics were using the same mathematical principles and could be considered using the same theory (Schödinger, Pauli, and Carl Eckart from the fledgling-Caltech).
But that was not the end to it because Max Born tried to explain the collision of two electrons as a resulting spreading wave like ripples on a pond, however the end result had to be two distinct particles moving off in two well defined directions like it happens in the Compton scattering effect. The "endless" discussions between Bohr and Heisenberg centered around the question of whether to accept probability and to give up the deterministic view, which would mean the end of classical physics or try to harmonize both (Bohr's "correspondence" principle). Einstein did not like this discussion at all ("Quantum mechanics is very imposing but my inner voice tells me it is not the real McCoy" and "God doesn't throw any dice")

Heisenberg introduced the term "uncertainty" into physics for particles after his defining moment on the isle of Helgoland (1925):
1. It is possible to measure the speed OR position of a particle, but not both,
2. The more precise the position is measured the less precise is the speed becomes,
3. The act of observation changes the properties observed,
and provides the first mathematical formulation of quantum mechanics.

Heisenberg's famous explanation: An electron flying through space and an observer shining light on it, from the scattering of light the observer can try to deduce the momentum and position. Light consists of quanta or photons, therefore the encounter of the electron with the light quanta is a quantum event. That encounter doesn't yield a single outcome but a possible range of outcomes with various probabilities and the more you know about one property (e.g. momentum) the less you know about the other (e.g. position).

After some more probing discussions with Bohr and the other supporters (Born, Pauli, Schrödinger) and opponents (mainly Einstein, but also Schödinger) in 1927 the "Copenhagen interpretation"[2] reconciled the new (probabilistic) and old (deterministic) schools, even though Einstein challenged Bohr's model during the fifth Solvey conference in October 1927 with some more of his famous Gedankenexperiments (thought experiments), but Bohr always was able to find the appropriate retorts.

1928 a young Russian and physicist, George Gamov visited Bohr explaining his interpretation of alpha-particle decay with a quantum approach called "tunneling".

During 1930 during the sixth Solvey conference Einstein still was not convinced, stating the uncertainty principle could not be the final truth, challenging Bohr with another Gedankenexperiment (photons in a box, letting only a single one escape to measure its mass unambiguously), but Bohr could also counter that one by using Einstein's own relativity theory.

According to Lindley Einstein kept one more "ace up his sleeve" with the "Einstein, Podolsky, Rosen (EPR-) paper" in his attempt to re-establish determinism with a Gedankenexperiment - example of two identical electrons: if one being measured the other's properties would be known without measuring it. Bohr and -Rosenfeld objected, but could not convince Einstein.
In 1964 John Bell established his theorem and was considered as kind of a referee in the ongoing Einstein / Bohr dispute. Bell's theorem is a 'no-go theorem' that draws an important distinction between quantum mechanics and the world as described by classical mechanics.

> *In its simplest form, Bell's theorem states:*
>
> No physical theory of local hidden variables can ever reproduce all of the predictions of quantum mechanics. [4]

In the meantime Bell's theorem has been falsified by various sophisticated EPR-test setups (see also my article "Spooky Interaction Experiment on the ISS").

Schödinger's support of the EPR paper is illustrated by the famous "cat-in-the-box" example which, in another Gedankenexperiment the cat could be, following the logic of probability laws for alpha-decay half dead or half alive. I personally liked Bohr's cool reply very much stating that if you would look into the box you would find out whether the cat is dead or alive.

The author David Lindley augments his book with an in depth analysis of the influence of the uncertainty and Bohr's complementary principles on our society taking us into the no-man's-land of physics, metaphysics, philosophy and sociology ending up with the conclusion that "the birth of our universe was a quantum event".

In 1932 Heisenberg received the Nobel Prize.
In 1938 Einstein left Germany to join the Institute of Advanced Scienc in Princeton and Born, Pauli and Schödinger left Germany also.
In 1962 Niels Bohr died in Copenhagen
In 1976 Heisenberg died in Munich having outlived the "old voices".

Heisenberg's visit to Bohr in 1941 is briefly mentioned, alluding to Heisnberg's role in the development of the "German fission program". As very little is known about the official or in-official plans and discussions David Lindley refers to the excellent fictitious play "Copenhagen", written by Michael Frayn [3].

Note: If there are any discrepancies of my review with the book it is my fault, because I conducted the review with the audiobook-version and sometimes got "schwindelig" myself – but I think the spirit of the

grandiose “scientific” years of 1900 -1932 and the achievements (not small steps but “quantum” leaps) are well captured and will be an additional motivation to read the book.
David Lindley wrote an excellent book which nobody should miss, being interested in understanding our technical world and how the uncertainty- and completmentary principles influenced modern philosophical thinking and the solving of metaphysical questions. Personally, I have gained a deep respect for what these pioneers have achieved during this very short period of time.

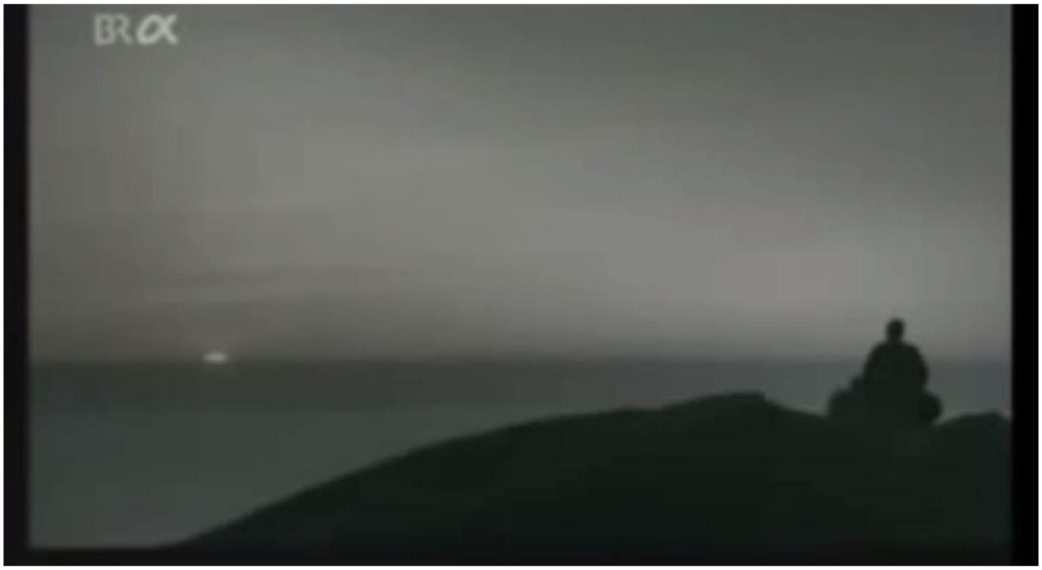
The book definitely leads to a better understanding of the underlying technical concepts for today’s laser communications, quantum entanglement used for code encryption and quantum computer technologies.

[1] David Lindley (born 1956) is a theoretical physicist and author. He holds a PhD from the University of Sussex and has worked at Cambridge University and the Fermi National Accelerator Laboratory. He was an editor at Nature, Science, and Science News (Wikipedia).

[2] Copenhagen interpretation (Bohr, Heisenberg June 1927)
According to the Copenhagen interpretation, physical systems generally do not have definite properties prior to being measured, and quantum mechanics can only predict the probabilities that measurements will produce certain results. The act of measurement affects the system, causing the set of probabilities to reduce to only one of the possible values immediately after the measurement. This feature is known as wave-function collapse (Wikipedia).

[3] Supporting information ”Copenhagen”, play by Michael Frayn, performed by L.A Theatre Works Relativity Series 2012 (audiobook). The play gives a short account of the developments when Heisenberg came to Copenhagen to work with Bohr in 1924, but dealing primarily with questions of moral and guilt centered around the mysterious trip of Heisenberg to Copenhagen to meet Bohr in 1941. (see also http://latw.nfshost.com/wp2/)

[4] Wikipedia https://en.wikipedia.org/wiki/Bell%27s_theorem



Heisenberg at Helgoland watching the sun rise after his successful calculations.

(Documtation “Bayerischer Rundfunk” BR∝)