Einstein v/s Bohr: What actually happened?

by Anjan Jyoti Deka - Thursday, December 21, 2017

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> "For today all physicists know, from studying Einstein and Bohr, that sometimes an idea which looks completely paradoxical at first, if analyzed to completion in all detail and in experimental situations, may, in fact, not be paradoxical". - Richard Feynman

Albert Einstein and Niels Bohr; are two of the greatest theoretical physicists of all time. Today, let us go back in time and enjoy the series of public disputes between these two legends! These two gentlemen always liked each other, respected each other and enjoyed the debates among them. An interesting twist came before the debates, soon after photons were introduced in physics. These days, we view photons as a hallmark of quantum theory. So, we might generally expect the pro-quantum theory guy to be a great champion of photons and the anti-quantum theory guy to be their foe. But, the truth was the other way around. Surprisingly, Einstein liked the photons and Bohr did not. So, let us get some facts regarding the greatest debate in the field of physics.

The quantum revolution of the mid-1920s occurred under the direction of both Einstein and Bohr. The shock for Einstein began in 1925 when Werner Heisenberg introduced matrix equations that removed the Newtonian elements of space and time from any underlying reality. The next shock came in 1926 when Max Born proposed that mechanics were to be understood as a probability without any causal explanation. Then, Einstein wrote a letter to Born with the famous quote , *"At any rate, I am convinced that God does not throw dice"*, which means that the universe is not governed by chance.

In the first stage of Einstein's opposition towards quantum mechanics, he ambitiously disagreed with the proposition that one can't measure the position and velocity of a particle (or its particle-like and wave-like properties) at the same moment. He would say that one may detect an interference pattern but one may still determine from the screen's momentum which slit the particle went through. Bohr already understood these things, so he quickly found the bug in Einstein's method: the screen obeys the laws of quantum mechanics, too. So, if the vertical position is accurate enough for the experiment to preserve the beautiful interference pattern, and it usually is, then it has an uncertainty of the vertical momentum too and this uncertainty is large enough for us to be unable to determine which slit the electron actually reflected from. As Bohr said, *"In particular, it must be very clear that .... the unambiguous use of spatiotemporal concepts in the description of atomic phenomena must be limited to the registration of observations which refer to images on a photographic lens or to analogous practically irreversible effects of amplification such as the formation of a drop of water around an ion in a dark room."*

Einstein's second criticism was attacking the "energy-time uncertainty relationship" which he stated during the sixth Solvay conference in 1930. Einstein stated that he could measure time and energy at the same time if he used a gravitational field. It was a real shock for Bohr, who at first could not think of a solution. As described by Leon Rosenfeld, a scientist who had participated in the sixth Solvay conference *"For the entire evening Bohr was extremely agitated, and he continued passing from one scientist to* *another, seeking to persuade them that it could not be the case, that it would have been the end of physics if Einstein were right; but he couldn't come up with any way to resolve the paradox. I will never forget the image of the two antagonists as they left the club: Einstein, with his tall and commanding figure, who walked tranquilly, with a mildly ironic smile, and Bohr who trotted along beside him, full of excitement."* But, Bohr triumphed in the next morning when he pointed out that the time won't be measured accurately because the vertical position of the weight will have a nonzero uncertainty and this vertical position (and its inaccuracy) will affect the measured proper time (and its inaccuracy) because of the gravitational red shift. We can recall that clocks tick slower if they're deeper in the gravitational field. Actually, Einstein forgot to include his own relativistic effect. Therefore, it proved the power of key ideas in physics. They are so powerful that we can use them against their discoverers too.

But, the genius didn't give up. In 1935, Einstein, Boris Podolsky and Nathan Rosen developed an argument, published in the journal Physical Review with the title ***Can Quantum –Mechanical Description of Physical Reality Be Considered Complete?***, based on an entangled state of two systems which is simply known as the EPR paradox. The EPR paradox involves two particles which are entangled with each other according to quantum mechanics. Under the Copenhagen interpretation of quantum mechanics, each particle is individually in an uncertain state until it is measured, at which point the state of the particle becomes certain. At that exact same moment, the other particle's state or the system also becomes certain. The reason that this is regarded as a paradox is that it seemingly involves communication between two particles at speeds greater than the speed of light, which is a conflict with Einstein's theory of relativity. Bohr's response to this argument was published, five months after the original publication of EPR, in the same journal and with exactly the same title as the original. Bohr attacks the assumption of EPR by stating: *The statement of the criterion in question is ambiguous with regard to the expression "without disturbing the system in anyway". Naturally, in this case no mechanical disturbance of the system under examination can take place in the crucial stage of the process of measurement. But even in this stage there arises the essential problem of an influence on the precise conditions which defines the possible types of prediction which regard the subsequent behaviour of the system … their arguments do not justify their conclusion that the quantum description turns out to be essentially incomplete . This description can be characterized as a rational use of the possibilities of an unambiguous interpretation of the process of measurement compatible with the finite and uncontrollable interaction between the object and the instrument of measurement in the context of quantum theory. Simply, if we consider two particles A and B, then the explanation is that the wavefunction which describes the superposition of possible quantum states exists at all points simultaneously. The instant the measurement on particle A is made, the entire wavefunction collapses into a single state. In this way, there's no distant communication taking place.*

There is a very nice story regarding these debates: After the exchange of pleasantries, battle began almost at once, and according to Heisenberg, *"continued daily from early morning until late at night"*. During one discussion, Schrodinger called *"the whole idea of quantum jumps a sheer fantasy"*. *"But it does not prove there are no quantum jumps"* Bohr countered. All it proved, he continued, was that *"we cannot imagine them"*. Emotions soon ran high, Schrodinger finally snapped, *"If all this damned quantum jumping were rally here to say, I should be sorry I ever got involved with quantum theory". "But the rest of us are extremely grateful that you did"*, Bohr replied, *"your wave mechanics has contributed so much to mathematical clarity and simplicity that it represents a gigantic advance over all previous forms of quantum mechanics"*.

In this astonishing way, through the series of debates Einstein and Bohr contributed to develop Quantum Mechanics. Although the majority of the community agrees that Einstein was wrong, the current understanding is still not complete. There is no scientific consensus that determinism would have been refuted.

> "Science never solves a problem without creating ten more" - George Bernard Shaw

This is what these two greatmen did and the success of science lies somewhere there.

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