Einstein-Bohr

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One of the most fascinating debates in scientific history was the ongoing disagreement between Albert Einstein and Neils Bohr about reality and quantum theory, particularly between "realists" and those who accepted the Copenhagen Interpretation (CI) proposed by Bohr.[1] Einstein was am unwavering realist; he believed that there is a fundamental, knowable reality at the base of all things– if only you know enough about it. "God does not play dice with the world", one of Einstein's famous quotes, sums up his refusal to believe that probability was the fundamental basis for physical reality.

[1] See post on Quantum Realities for a very brief summary of the CI and other metaphysical models of quantum mechanics.

Einstein's refusal to believe in the fundamental nature of probability led him to conclude that quantum theory was incomplete and that the probability function was not the final end point of knowledge about a particle. It was, instead, the result of insufficient understanding of the quantum world. Once we knew more about the nature of quantum world, we would be able to describe a particle in more than probabilistic terms.

Bohr, on the other hand, insisted that the probability function was the absolute, irreducible description of quantum behavior– that it simply was impossible to understand quantum behavior more concretely than was allowed by the CI. One of the specific issues around which this debate raged was the question of what happens to a pair of particles created together– for example, a pair of photons created simultaneously. Quantum theory requires that these photons have complementary characteristics, but it also requires that those characteristics cannot be known until they are measured.

The difficulty for Einstein (and other realists) comes from how those photons are connected. According to the CI, the photon pair characteristics exist only as a probability function (any characteristic can be anywhere within the range of all possible characteristics). But, and this is hugely important, both photons must have corresponding characteristics, whatever they turn out to be. Using a highly oversimplified example, let's say that the photons have a characteristic of "up/down". When a photon pair is created, both photons exist as a probability function that can be either "up" or "down", but whatever it turns out to be will be the same for both photons. However, we can't know if they are "up" or "down" until we measure one of them. At that point the probability function collapses, and we can positively say that the photon is, let's say, "up". Quantum theory says that we now know that the other photon is also "up". But if both photons existed as equal probabilities of being "up" or "down" until one of them is measured, how does the second photon know that it is “up”, as required by quantum theory. (The first photon could have just as easily been measured “down”, in which the second photon would also be “down”).

This connection between the photons is called “entanglement” in quantum theory, and was referred to by Einstein as “spooky action at a distance”. Because nothing can travel faster than the speed of light, it is impossible for the photons (moving away from each other at the speed of light) to communicate with each other about the state of “up/down”. Einstein maintained that there were “hidden variables” within each photon that determined the state of the photon pair. The fact that we don’t know about those variables doesn’t mean that they aren’t there; and how else could the photons know about their mutual state? . Einstein was an unwavering realist, and he had a lot of high-caliber company.

Ultimately, this is a metaphysical issue, and therefore one that cannot be resolved by science. But the on debate clearly illustrates how seemingly remote and abstract notions lie at the very heart of how we view our world and our place in it.