

Description of NOVA's The Fabric of the Cosmos "Quantum Leap" Episode

Quantum physics governs the universe on the tiniest of scales. At this scale, objects pop in and out of existence, and things over here can affect others over there instantaneously—without anything crossing the space between them. How can the rules of the quantum world, which work so well to describe the behavior of individual atoms and their components, conflict so dramatically with the everyday rules that govern people, planets, and galaxies? Quantum mechanics may be counterintuitive, but it's one of the most successful theories in the history of science, making predictions that have been repeatedly confirmed. It has also launched the technological advances at the heart of modern life, like computers and cell phones. But today, even with such profound successes, the debate still rages over what quantum mechanics implies for the true nature of reality.

Main Ideas

- Quantum mechanics is weird; Particles zip in and out of existence for the merest fractions of micro-micro seconds. They're there, they're not there. Things don't like to be tied down to just one location or follow just one path. One object might pass right through another. What happens to a particle in one place can have a direct effect in another place. Yet, we believe in these bizarre laws because for more than 75 years, we've used them to predict how atoms and tiny particles behave. The behavior predicted by the laws has always been right.
- Niels Bohr explained spectral lines as the energy given off by electrons jumping between an atom's orbitals. But the electrons don't travel across the space—they show up in a different orbit without physically traveling through the "between" space. What makes the quantum leap so strange is that the electron goes directly from here to there without moving through the space in between. An electron has to be here or there and simply nowhere in between. Bohr believed that the energy of electrons and atoms comes in discrete chunks, called "quanta."
- Electrons exhibit dual properties, sometimes acting like particles and sometimes acting like waves. For example, when shot through two narrow slits at a detector, some electrons go straight through (as a particle would) and others exhibit an interference pattern (as a wave would). Looking at the pattern, scientists realized that where an electron showed up could be predicted as a probability, and that each electron seems to be a jumble of possibilities. You don't ask, "Where is the electron right now?" You ask, "If I look for the electron in this particular part of space, what is the likelihood I will find it there?" The equations of quantum mechanics are amazingly accurate, as long as you can accept it's all about probability.
- Physicists have no trouble accepting quantum mechanics, because its equations give them the power to control and direct all those tiny particles.
- Entanglement occurs when a pair of sub-atomic particles (e.g., electrons) interact physically and then become separated. Though separated, each particle can be described as having the same quantum mechanical state (e.g., momentum, spin, polarization, etc.). However, these quantum states remain indefinite until one of the particles is actually measured—quantum mechanics describes the states of both entangled particles as indefinite until one of them is measured. Only when one of the entangled particles is measured does it take on a definite value (e.g., positive charge). Simultaneously, the other member of this pair will take on the complementary value (e.g., negative charge). Entangled particles are linked across space. Measuring one instantly affects its distant partner, as if the space between them didn't exist!

- Teleportation is possible. Right now, though, it can only be done with subatomic particles. Scientist Anton Zeilinger starts by generating a pair of entangled photons in Lab A. He uses a laser to shoot one of the entangled particles over to Lab B. He uses the "entangled connection" between the two photons to teleport a third photon. Back at Lab A, the third photon is introduced to Entangled Particle #1. Their interaction gives the team key information about this new photon. That data is sent to Lab B, and it's used to transform Entangled Particle #2. In other words, Zeilinger extracts the information carried by the original and makes a new original in Lab B. It is absolutely required in the quantum teleportation protocol that the thing that is teleported be destroyed in the process. This means that Lab A's photons were destroyed in the process, but the photon at Lab B has now taken on a new state—matching exactly the introduced photon.