Quantum mechanics

And Einstein was not right

In quantum physics, particles influence over long distances. You do not believe that? Then you are like Albert Einstein. But the genius was wrong.

By Philipp Seibt

Imago / Eibner

the Milky Way

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Albert Einstein's relationship to the theory of the smallest particles has always been ambivalent. On the one hand, he has decisively helped to develop quantum theory; on the other hand, Einstein never really got used to the consequences of theory.

This skepticism culminated in a world-famous scientific essay in 1935: "Can the quantum-mechanical description of the physical world be complete?" Einstein asked there with his colleagues Boris Podolsky and Nathan Rosen.

The three researchers wrote down what an acceptable physical theory has to fulfill in their opinion - and showed that quantum mechanics violates it and therefore must be wrong. But in the past 80 years, not quantum mechanics has been refuted, but Einstein and his colleagues.

With an experiment on the rooftops of Vienna, an international research team has once again confirmed the quantum mechanical concept of the world - and thereby closed an important loophole. The central ingredient of the experiment was 600-year-old starlight, they write in the journal Physical Review Letters .

What did Einstein think?

In her essay, Einstein and colleagues, among other things, gave the following two conditions to a theory that would describe the world:

- **Reality:** A particle - for example, a light particle or photon - should have specified properties. The properties are independent of whether a researcher measures the photon or not.
- **Locality:** The measurement of the particle A does not affect the properties of the particle B - as long as the particles are spatially separated.

Both conditions together are called local realism.

What does quantum mechanics say?

Quantum mechanics contradicts the two conditions of Einstein, Podolsky and Rosen:

- **Reality:** In quantum mechanics, a particle only has a certain property when it has been measured by a researcher. By the time of measurement, the particle has all possible properties at the same time - and quantum theory can only predict how probable a property is. Therefore, a physical measurement has no fixed result - but resembles the throwing of a coin.
- **Locality:** In quantum mechanics particle pairs can be generated, where the measurement of the particle A determines the property of the particle B. It is said that the particles are "entangled". The amazing thing is that this works without the exchange of signals and also when the particles are arbitrarily far apart. Einstein once described this consequence as a "ghostly remote effect".

How can you test who is right?

Einstein's essay began dust for almost 30 years. Only the theoretical physicist John Bell took a decisive step in 1964: Bell derived an inequality , which must be true if the world obeys a locally realistic theory, as Einstein and colleagues have imagined.

Quantum mechanics violates this inequality - it is not local-realistic. The clou: The quantities in the inequality can be measured in the laboratory. Bell provided the physicists with a recipe for experimentally testing quantum theory.

That's exactly what researchers have been doing ever since. The result was always: The predictions of quantum mechanics are correct, Einstein was wrong, we are not living in a local-realistic world.

The back door

But all experiments also had a "but" - a theoretical possibility, why the world is perhaps still local-realistic. These backdoors are called "hidden variables" - and have already been suggested by Einstein and his colleagues as a solution.

Ultimately, this is a kind of cosmic conspiracy theory: Hidden variables that we do not know make the physical experiments seem random - even though they are not really random.

There are basically three of these backdoors: the locality back door, the measurement backdoor, and the free-choice backdoor (for a full explanation of all three, see here).

At first, researchers could only stuff individual holes. In 2015, they managed to exclude the first two backdoors at the same time. Now the research team in Vienna has closed both the first and the third backdoor at the same time - and so can almost completely exclude the idea of "hidden variables".

The new experiment

For this, the researchers set up a complex experiment on the rooftops of Vienna. On the roof of the Institute for Quantum Information, the scientists generated two interlinked photons, that is, light particles.

The one photon sent them to the roof of the Austrian National Bank 557 meters away. The other Photon traveled 1149 meters to a second university building. At both sites, a property of the incoming photons - their polarization - is then measured.

This can be done in two directions - which direction is chosen, the random decides. So far, the random numbers have been generated on Earth - but then theoretically a hidden variable milliseconds before the experiment could make the numbers look random, even though they are not.

600 years old starlight

So researchers used light from stars in the Milky Way to generate the random numbers they captured with a telescope. Then they measured the energy of the incoming light. If it was below a certain threshold, it was measured in one direction; she was over it, in the other.

Finally, the researchers compared the polarization of the two photons. The results again showed the "ghostly long-range effect" and confirm the predictions of quantum mechanics.

But could not a hidden variable have produced the result? Because of the long time the light was traveling, this is very unlikely: "For a crazy mechanism to play quantum mechanics in our experiment, it must have been 600 years ago," says Alan Guth of the Massachusetts Institute of Technology the study was involved. "The mechanism would have had to send photons in exactly the right order 600 years ago to reproduce the results of quantum mechanics here and now on Earth."

The probability of such a mechanism was calculated by researchers at 1 to 6 trillion. It seems Einstein really was wrong.

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1. Distorted representation

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We live in a simulation, and to make it seem random, each person has their own variables. Example: All our senses supply sensory impressions to the brain. Every sensual input such as smell, optics, noise, [...]

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3. Stupid

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