Steering by peeking: Physicists control quantum particles by looking at them

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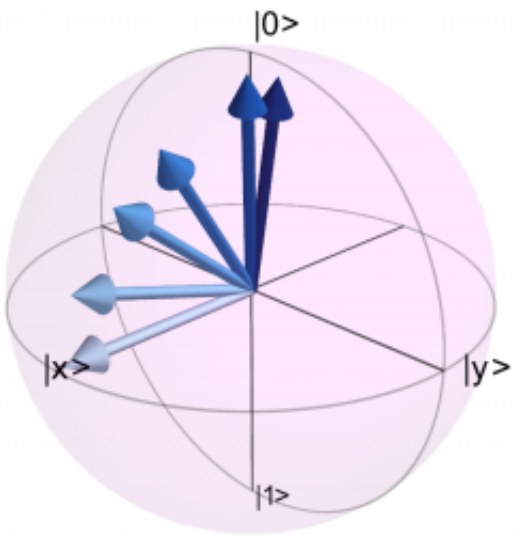

The state of the nuclear spin, visualised by the arrow, after measurements with varying strengths (light blue is very weak, dark blue is very strong). For increasing measurement strength, the state rotates towards the classical up state (arrow pointing up). This data is post-selected on one specific measurement outcome of the electron spin. For the other outcome, the arrow rotates downwards. Credit: Fundamental Research on Matter (FOM)

Scientists from the FOM Foundation and Delft University of Technology have manipulated a quantum particle, merely by looking at it in a smart way. By adjusting the strength of their measurement

according to earlier measurement outcomes, they managed to steer the particle towards a desired state. The scientists published their results online on 16 February 2014 in *Nature Physics*.

In two states at once

Quantum mechanics describes the behaviour of microscopic particles, such as atoms and electrons. When we compare it to our observations in everyday life, nature behaves very strangely at the scale of these particles. For instance, an electron can be in two states at the same time.

To demonstrate how peculiar this property is, the physicist Erwin Schrödinger proposed a famous thought experiment where the state of a quantum particle is linked to the fate of a cat. The two are situated in a sealed box. The quantum particle acts as a switch that can either open (switch on) or close (switch off) a small flask of poison. As long as the quantum particle can be simultaneously in two states (on and off), the flask with poison is open *and* closed, and the cat is both dead and alive *at the same time*.

But the weirdness doesn't end there: as soon as the box is opened to observe the state of the cat, this situation changes. The act of measurement forces the animal to be either dead *or* alive. This is called the quantum mechanical measurement back-action: the state (of the particle as well as the imaginary cat) is inevitably perturbed by the measurement and collapses to a classical state. In this work, the scientists investigated what happens when the box is only slightly opened. Is it possible to peek at the cat, without destroying the fragile quantum state?

Peeking at Schrödinger's cat

Schrödinger's cat in a box, being both dead and alive at the same time. When the box is opened completely, the state of the cat will be either dead or alive. By slightly lifting the lid, it is possible to acquire only a little bit of information, while maintaining the fragile quantum state. In this experiment, the nucleus plays the role of the cat. Credit: Fundamental Research on Matter (FOM)

Instead of a cat, the scientists in the group of FOM workgroup leader prof.dr.ir. Ronald Hanson used a nucleus in diamond. These particles carry an intrinsic property called spin that behaves like a small magnet. The spin of the nucleus can point up (cat alive) or down (cat dead).

In earlier work the group showed that it is possible to measure the orientation of a single spin, in analogy to fully opening Schrödinger's box. To partially open the box, the scientists used a trick. Instead of directly measuring the nucleus, they first coupled the state of the nucleus to a nearby electron. They then determined the state of the electron.

By varying the strength of the coupling between the nucleus and the electron, the scientists could carefully tune the measurement strength. A weaker measurement reveals less information, but also has less back-action. An analysis of the nuclear spin after such a weak measurement showed that the nuclear spin remained in a (slightly altered) superposition of two states. In this way, the scientists verified that the change of the state (induced by the back-action) precisely matched the amount of information that was gained by the measurement.

Steering by peeking

The scientists realised that it is possible to steer the nuclear spin by applying sequential measurements with varying measurement strength. Since the outcome of a measurement is not known in advance, the researchers implemented a feedback loop in the experiment. They chose the strength of the second measurement depending on the outcome of the first measurement. In this way the scientists could steer the nucleus towards a desired superposition state by only looking at it.

This result provides new insight in the role of measurements in quantum mechanics. Furthermore the combination of measurements and feedback, as demonstrated here, form an essential building block for the future quantum computer. Finally, these techniques can increase the sensitivity of magnetic field sensors.

More information: Manipulating a qubit through the backaction of sequential partial measurements and real-time feedback, M.S. Blok, C. Bonato, M.L. Markham, D.J. Twitchen, V.V. Dobrovitski, R. Hanson, *Nature Physics*. DOI: 10.1038/nphys2881

Fundamental Research on Matter (FOM)