

Quantum Uncertainty Tested in Experiment with a Real-life Moving Slit

By SONG Jianlan

Chinese physicists are sealing the UN International Year of Quantum Science and Technology (IYQ) with an experiment to help close the classic debate between Albert Einstein and Niels Bohr on quantum uncertainty. To rebut Bohr, Einstein designed a Gedankenexperiment (thought experiment in German), a revised double-slit interference experiment. His design, however, is so challenging to realize that it remained a thought experiment for a long time. Now Profs. CHEN Mingcheng, LU Chaoyang, PAN Jianwei from the University of Science and Technology of China (USTC) and their colleagues built an innovative setup to directly replicate Einstein's idea – demonstrating that he was wrong.

The Debate

In their debate, Bohr stated that different complementary properties of the same quantum particle cannot be measured at the same time (also known as the Copenhagen interpretation of Heisenberg's quantum uncertainty theory). For example, the momentum and the position of the same photon are complementary

properties, hence cannot be measured simultaneously.

To express his query on Bohr's theory, Einstein proposed to add a movable slit to the Young's double-slit interference experiment. In his classic double-slit interference, Thomas Young shone a beam of light through two narrow slits and let the photons spread onto the wall. Instead of two overlapping bright spots, he got alternating fringes on the wall. These interference fringes demonstrated the wave-like, rather than particle-like side of light. Einstein inserted between the light source and the double-slit a movable slit, and argued that when passing through the movable slit, the photon might bump on the edge of it, giving it a momentum, and further travel upwards or downwards to cover a path before reaching the wall. (In cases it did not bump on the edge, it would just go forward and directly bump onto the wall.) In response to this momentum, the movable slit would recoil a little bit; and this recoil, if measured to a precise-enough extent, would meanwhile indicate/predict its future direction – and therefore position – on the wall. In this way, both the momentum and

position of the photon would be measured, violating the complementarity principle.

In his thought experiment, the movable slit worked as an observer independent of any a human being; and this observer could simultaneously record both the momentum and the tendency of the photon to join which path.

In response to Einstein's challenge, Bohr answered that the inherent uncertainty of the photon would make it impossible to simultaneously measure both the momentum and position – the more accurate the momentum was measured, the bigger the uncertainty of the position could become. In the end, the resulting interference fringes would be blurry.

Was Einstein wrong?

The Gedankenexperiment in Real

It is challenging to test Einstein's idea in a real experiment, however. First of all, it has proven

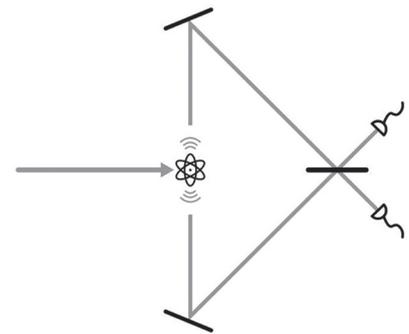
hard to make a real-life movable slit as required in his thought experiment. To work as a sensitive-enough observer, the movable slit shall have a quantum uncertainty smaller than that of the passing photon, unless the measurements would be overwhelmed by its own fluctuation. Given that a photon's momentum recoil is extremely weak (at the magnitude of 10^{-27} kg·m/s), any typical macroscopic slit in practice can go far beyond that limit.

Due to this difficulty, though many efforts have been made to replicate Einstein's conceptual experiment, direct realization of his movable slit remained a big challenge.

Despite the seemingly unsurmountable obstacle, the USTC team made this Gedankenexperiment real. Adopting a single rubidium atom as a movable slit, they performed their observation and reported the results in *Physical Review Letters* in early December, 2025.

The team chose to trap the

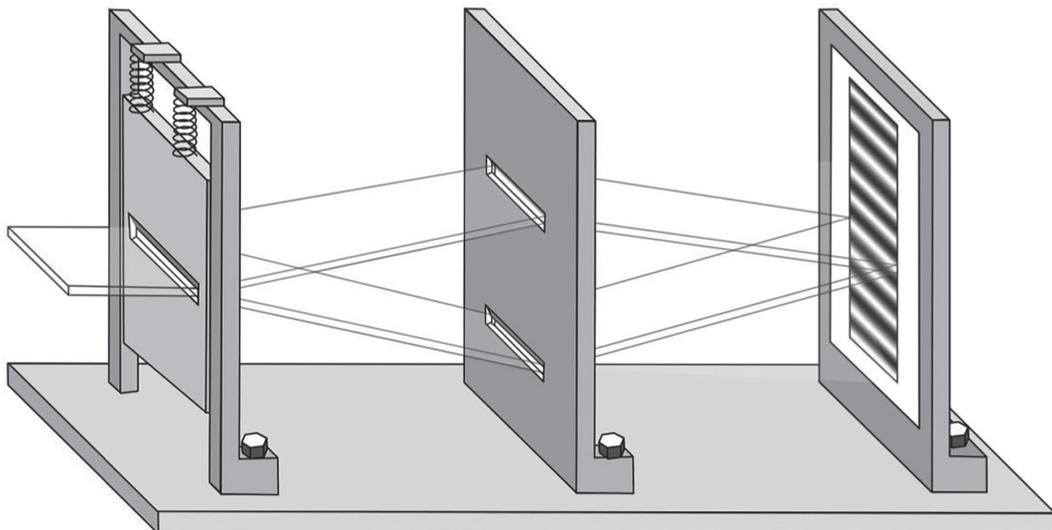
rubidium atom in an optical tweezer. To control its intrinsic momentum uncertainty to a level comparable to that of a photon, they employed three-dimensional Raman sideband cooling with a tailored beam geometry to prepare it to the ground state. On the other hand, they finely tuned and maintained the atom's intrinsic momentum uncertainty within the range between 0.78 to 1.60 times of that of a photon, via varying the trap depth of the optical tweezer.



$$\Delta p \sim 10^{-27} \text{ kgm/s}$$

The USTC team's realization of the idea of Einstein's movable slit. (Credit: USTC)

The concept of the Einstein-Bohr Gedankenexperiment. (Credit: USTC)



The team emphasized that their experimental configuration ensured that the rubidium atom's internal state and thermal motion did not leak any which-path information, so as to make the atom an ideal quantum beam splitter loyal to Einstein's design.

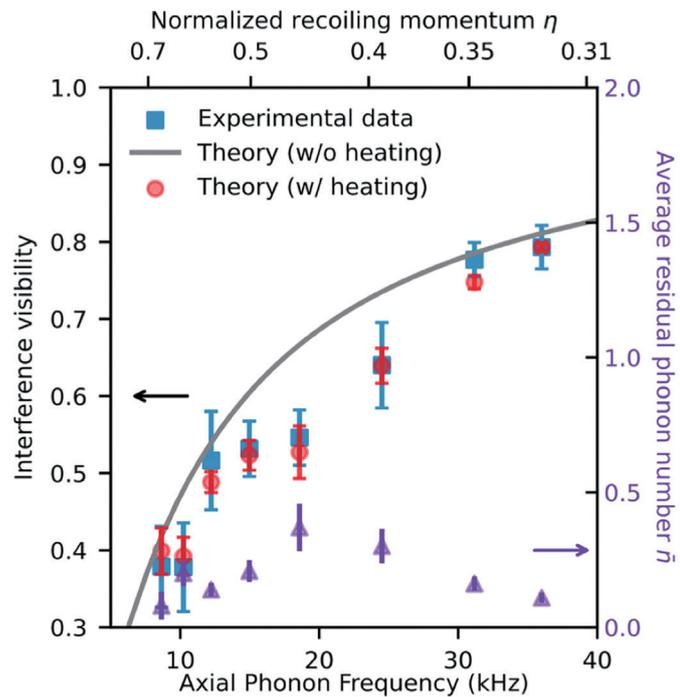
The Observation

Tuning the rubidium atom to different intrinsic momentum uncertainty, the team then tested the subsequent visibility of the single-photon interference fringes. They found that the observed visibility directly depended on the atom's momentum uncertainty: The larger the momentum uncertainty, the smaller the width of the atom's momentum wave function, and the smaller the position uncertainty; in contrast, the smaller the momentum uncertainty, the broader the width of the atom's momentum wave function, and the higher the momentum uncertainty.

After excluding the errors

resulting from atom heating, the observed results agreed very well with Bohr's theoretical prediction. Thus, Einstein proved wrong. With their experiment setup,

the team planned to further explore other aspects of quantum mechanics, for example how decoherence and entanglement influence each other.



The observed results (blue dots) agreed well with Bohr's prediction (red dots): The smaller the tweezer trap depth, the smaller the momentum uncertainty of the atom, yet the larger the position uncertainty of the photon (indicated by the interference visibility). Purple dots indicate the noise from atom heating. (Credit: USTC)