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Quantum non-locality in ultra-cold atomic gases

Non-locality, Einstein's „spooky action at a distance", has already been observed between quantum objects separated by more than one kilometer. This achievement is not a surprise – recent years have seen a major advancement in the quest for non-local systems. In their „Physical Review Letters" publication, researchers from the Faculty of Physics, University of Warsaw present a novel and versatile method for creating and detecting such correlations in a many-body system of ultra-cold atoms.

Quantum mechanics was formulated in the first half of the twentieth century. Its predictions have been confirmed in a number of experiments and applications ranging from computer chips to lasers used in medicine.

„Though the quantum theory is commonly accepted, some of its aspects are still controversial. For instance, states in superposition are described as if they were in many places at once. This has no counterpart in the classical world and is difficult to interpret. The entanglement – quantum correlation between physical objects – also cannot be compared with everyday life experience", explains Jan Chwedeńczuk (Faculty of Physics, University of Warsaw).

For many researchers the most relevant aspect of quantum mechanics, at least from the philosophical point of view, is the non-locality. We are used to accepting that the behavior of physical objects is determined by what is happening in their vicinity. We would find it hard to accept that events taking place in distant galaxies could infinitely quickly influence what is on our planet. Meanwhile, quantum theory allows for such non-local phenomena.

Imagine a pair of shoes, two boxes and a random number generator – the shoes are distributed among the boxes according to the result of the draw. Afterwards, one box is sent to Mars, while the other remains on Earth. Before we open the boxes, we would say that if the left shoe is on Earth, the other is on Mars and vice versa. In the classical realm, one of these possibilities is determined at the moment of the generation of a random number. Quantum mechanics describes this situation in such a way as if both possibilities existed simultaneously. Moreover, local manipulations of one of the boxes will immediately affect the other, no matter how distant they are. We say that quantum mechanics is a non-local theory. Only after the measurement is made and the boxes are opened, the state of each shoe gets determined.

The above example serves merely as an illustration – such subtle effects are observed at the atomic scale. Nevertheless, the mere possibility of „steering" one system with the other, without any direct interaction, drove Einstein and his coworkers to write a paper under a much-telling title: „Can quantum-mechanical description of physical reality be considered complete?".
Nearly 30 years later, a Northern Irish physicist John Bell proved that indeed the predictions of quantum mechanics contradict the postulates of „local realism", which assumes that objects

have well-determined properties (realism) and their behavior is influenced by what is happening in the vicinity (locality). Bell gave a prescription for detecting the non-locality in simple physical systems. This method is now called „the Bell inequalities".

In their recent publication Tomasz Wasak and Jan Chwedeńczuk considered a complex many-body quantum system, showed that it reveals non-local properties and finally gave an experimentally useful method for detecting such correlations. The system is a Bose-Einstein condensate of helium atoms, illuminated with two counter-propagating laser beams. In such configuration, helium atoms collide and scatter into opposite directions, forming a non-local pair.

„The scattered atoms are the analog of the pair of shoes. Similarly to this example, one can manipulate each atom locally and perform measurements to find out if the non-locality is indeed present in this system" - says Jan Chwedeńczuk.

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Physics and Astronomy first appeared at the University of Warsaw in 1816, under the then Faculty of Philosophy. In 1825 the Astronomical Observatory was established. Currently, the Faculty of Physics' Institutes include Experimental Physics, Theoretical Physics, Geophysics, Department of Mathematical Methods and an Astronomical Observatory. Research covers almost all areas of modern physics, on scales from the quantum to the cosmological. The Faculty's research and teaching staff includes ca. 200 university teachers, of which 88 are employees with the title of professor. The Faculty of Physics, University of Warsaw, is attended by ca. 1000 students and more than 170 doctoral students.

SCIENTIFIC PAPERS:

,,Bell Inequality, Einstein-Podolsky-Rosen Steering, and Quantum Metrology with Spinor Bose-Einstein Condensates''
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The scattering scheme shown with the optical lattice formed by the two counter-propagating laser beams. The gas is represented by a black dot and atoms scatter into the separate regions A and B, which correspond to the two distant shoe boxes. (Source: UW Physics)