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Press Release

Tunnelling in sync – atoms on the move are joined through repulsion

Physicists of Mainz University demonstrate pair tunnelling of ultracold atoms. – New publication in *Nature*

(Mainz, August 30, 2007, lei) Physicists at the Johannes Gutenberg-University in Mainz have demonstrated the simultaneous tunnelling of two strongly interacting atoms through a barrier. „Quantum theory predicts, that the two atoms cannot tunnel alone, the pair has to stay together even though the atoms repel each other. This Co-Tunnelling process for atoms was now observed for the first time.“, Simon Fölling from the QUANTUM group explains. The group, led by Prof. Immanuel Bloch, studies such tunnelling events with ultracold atoms which are trapped by a lattice of laser light. In this way, atoms and light act as a model system in order to help our understanding of properties such as magnetism or superconductivity of real materials. The new results demonstrating the simultaneous tunnelling are being published in the new issue of the journal Nature (*Nature* ***448**, 1029-1032*).

One of the special properties of quantum mechanics is the ability of particles to penetrate barriers which they would classically not be able to cross. This tunnelling process is being studied in Mainz with the help of atoms, which are cooled to a temperature only narrowly above absolute zero (-273°C) and are trapped in a lattice made by light beams. Each of the atoms is held in the lattice like an egg in an egg crate. According to classical physics each atom would be fixed on its place in the “crate”. Due to quantum mechanics, however, the atoms are allowed to tunnel through the light-barriers.

In order to investigate this phenomenon in detail the researchers constructed a modified “egg crate”, where from each site in the lattice, tunnelling is only possible to one specific neighbour. In such a “double well trap” an atom can tunnel back and forth between the two sites, or wells. Since there is no friction present, it will do this forever once the process starts.

This idealized situation makes it possible to study the tunnelling behaviour of interacting particles with high precision. For this, exactly two atoms are put on the same side of each double well, while the other side is empty. These atoms repel each other, and depending on the strength of this interaction two different things can happen. In the first case the system is prepared such that the repulsion is weak and the tunnelling rate - the speed at which the atoms can cross the barrier - is high. Now both atoms tunnel back and forth more or less independently, either simultaneously or alone.

In the second case the barrier is higher, the tunnel rate lower and the repulsion stronger. “Now something counter-intuitive occurs: Since both atoms strongly repel each other, one would expect the atoms to move in such a way that on each side of the barrier there is only one atom. Indeed this would be the ground state, the preferred state of the system. However, what happens is that the pair cannot separate by the tunnelling of a single atom. If there is to be any motion, both have to tunnel simultaneously”, explains Fölling. The phenomenon occurs because energy would be released on separation of the pair – but with no friction present, the energy cannot be taken away. Therefore, the law of energy conservation forces the atoms to stay together despite their mutual repulsion – such compounds were therefore dubbed “repulsively bound pairs” in 2006 by experimentalists in Innsbruck.

In the Mainz experiments, the co-tunnel motion of such repulsively interacting pairs was demonstrated. Such a process, which requires the simultaneous tunnelling of two otherwise independent particles, is called “second order tunnelling” or “pair tunnelling”. In a similar fashion, the experimentalists showed that it is possible to have one atom control the tunnel motion of the other - serving as a “switch” for tunnelling, similar to certain kinds of transistors for single electrons. The main focus of the research, however, is the investigation of complex tunnelling processes with atoms as a model for a better understanding of the behaviour of electrons in real materials. Here, second order tunnelling of electrons can align the so-called spins in the crystal, which is the source of magnetism in many materials.

*S. Fölling, S. Trotzky, P. Cheinet, M. Feld, R. Saers, A. Widera, T. Müller and I. Bloch: Direct Oberservation of Second Order Atom Tunnelling. Nature **448**, 1029-1032, August 30, 2007; doi:10.1038/nature06112*

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