MAX PLANCK INSTITUTE
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Press Release

Quantum Simulator with a Great Potential

MPQ scientists invent a new method for manipulating atomic gases

In many not yet fully understood branches of physics, scientists hope to make progress with quantum computers. The special properties of the quantum particles that serve for storage and encoding of information here are expected to make it possible to resolve complex problems which cannot be solved with classical computers due to computation time issues. The realization of a universal quantum computer that can carry out arbitrary computations remains a long term goal. But the technologies developed so far enable us to perform so called quantum simulations. Here assemblies of directly controllable quantum particles form models for complex systems which are difficult to manipulate. A new, promising technique was now developed in the group of Professor Gerhard Rempe at the Max Planck Institute of Quantum Optics in Garching. The researchers report in *Nature Physics (Advance online Publication, 6 April 2009)* that they can modify the properties of atomic gases by applying simultaneously laser light and a magnetic field. This gives the scientists a tool for manipulating the gases on short length scales in the nanometer range which can additionally be varied rapidly in time. This might help to improve the understanding of physical processes in diverse fields ranging from black holes to superconductivity.

The physicists begin their experiment with a dilute cloud of approximately 100 000 rubidium atoms which are cooled so far that they form a so called Bose-Einstein condensate (BEC): they lose their individuality and behave as one super atom. Every atom feels the presence of the surrounding atoms because it interacts with them through collisions. During a collision two atoms closely approach each other and temporarily form a molecule before they separate again as free atoms.

In order to influence the properties of such collisions, one often uses a method in which a magnetic field is applied to the gas. This extends the time during which an atom pair exists in the form of a temporary molecule, which in turn modifies the collisional properties. Along with the collisional properties, the properties of the gas as a whole are changed. This method has proven quite successful in the past decade. However, the range of its applications is limited by the fact that the geometry of the setup typically does not allow for a manipulation on very short length scales.

In recent years, an alternative method for varying the collisional properties was developed. It uses laser light instead of the magnetic field. In this case, the light frequency must be chosen close to a transition between the temporary molecules and an excited state. The light intensity can inherently be controlled with high spatial resolution, namely on the scale of the optical wave length (several hundred nanometers) so that the properties of the gas can also be adjusted on the same length scale. Besides the desired effect, application of the laser light unfortunately also causes loss of particles from the cold gas. These loss processes occur so rapidly that there is hardly any time left for practical applications.

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In the present experiment, the scientists combine for the first time both control methods, i.e., they apply a magnetic field and illuminate the atom cloud simultaneously with laser light. The researchers demonstrate in their measurements that the laser light changes the collisional properties, here too. But it turns out that now less light intensity is needed because the atoms pairs spend more time in the temporary molecular state. Due to the reduced light intensity the loss processes occur much more slowly. Hence, the properties of the atomic gas can be influenced here with laser light (and thus on short length scales) but with much reduced particle loss rates, as compared to the established technique.

These results offer a great potential for applications. For example, holographic masks can be used to create a complex light pattern and overlap it with the BEC. The light intensity can be varied on the scale of the optical wave length and, in addition, the pattern can be modified rapidly. This makes it possible to manipulate the collisional properties of the gas with light in a very flexible way. The next step will be to apply this method to a BEC in an optical lattice. This is a crystal made of light which is created by an appropriate superposition of standing laser waves so that bright and dark regions alternate periodically in space. The motion of the atoms in this light field closely resembles the motion of electrons in the crystal lattice of a solid. By combining the new method with such lattices, one can simulate much more complex systems than with previous methods which either allow for a change of the interaction strength only on all lattice sites simultaneously or introduce such fast particle losses that there is hardly any time left to perform the experiment. This opens up perspectives for a much broader range of quantum simulations. [SD/OM]

Original Publication:

Dominik M. Bauer, Matthias Lettner, Christoph Vo, Gerhard Rempe, and Stephan Dürr
"Control of a magnetic Feshbach resonance with light"
Nature Physics, Advance online publication, 6 April 2009

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