MAX PLANCK INSTITUTE
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MPQ

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Press Release

Quantum Experiments in Microgravity

Scientists of the QUANTUS-Project probe principles of General Relativity on quantum systems.

At the beginning of the 20th century two theories have been developed that have completely changed our understanding of the forces of nature: General Relativity and Quantum Mechanics. Whereas General Relativity applies to the classical world and in particular describes the large structures in the universe, Quantum Mechanics rules the behaviour of the particles of the microcosm. Up to now scientists have not succeeded to reconcile both theories, e.g. to extend General Relativity to quantum systems. So-called Bose-Einstein Condensates (BEC) – clouds of ultracold atoms that form coherent laser-like matter waves – might represent an interesting link. Being definitely a quantum system, a BEC can take on classical dimensions of several millimetres. Joining their forces in the QUANTUS-project scientists of several research institutes, including the Universität Hannover, the Ludwig-Maximilians-Universität München (LMU) and the Max Planck Institute of Quantum Optics (MPQ), have for the first time created a BEC during free fall in the 146 metre high drop tower in Bremen (Science, June 17, 2010). In the absence of gravitational forces it was possible to observe the evolution of the matter wave over a period of up to one second. Under such conditions the precision of atom interferometers – instruments that can be used for the measurement of gravitational fields as well as for a test of General Relativity – could be improved by a lot.

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For the generation of a BEC a cloud of atoms gets cooled down to temperatures of a few nano-Kelvin. Below this threshold temperature the cloud takes on a quantum phase in which all atoms are in identical quantum states, i.e. the ensemble of about a million atoms behaves like one big super atom. This phenomenon goes back to the wave-like properties of matter which are increasingly pronounced at these temperatures: the overlap of the waves gets stronger and stronger until they form one single gigantic matter wave.

Applying a well chosen combination of laser beams and magnetic fields the atom cloud is held in place inside a so-called magneto-optical trap. In order to observe the propagation of the matter wave the fields are switched off. In usual earth-bound experiments the evolution of the wave can be followed up only for a very short time because – due to gravitation – the atoms bounce onto the bottom of the chamber within milliseconds. With the experimental set-up described here the scientists were able to more or less eliminate the influence of gravitation. All the necessary equipment for the generation of a BEC was installed inside a capsule that was dropped from the top of the 146-metre high drop tower of the “Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation” in Bremen. According to the equivalence principle of gravitational and inertial mass the freely falling capsule provided an environment with residual acceleration forces as low as one part in a hundred thousand of the terrestrial gravity.

The realization of the experiment required the miniaturization of the traps. This was made possible by the atom-chips that have been developed in the group of Professor Theodor W. Hänsch (Director of the Laser Spectroscopy Division at MPQ and Chair of Experimental Physics at LMU). Here the magnetic fields re-

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quired for trapping quantum particles are produced by the tiny electrical wires of a microchip. In order to avoid disturbances caused by mechanical vibrations the BEC was generated one second after the capsule had been released.

Snapshots of the BEC were made 30, 500, and even 1000 milliseconds after its formation by using absorption imaging techniques. Since November 2007 more than 180 experiments have been performed. The persistence of a matter wave over such a long period of time sheds a new light on the potential of atom-interferometers. These devices exploit the wave-like properties of matter for example in order to detect and measure slight variations in the gravitational field of the earth.

The "proof of principle" experiment described here is the first one bringing Albert Einstein's gedanken experiment of a "freely falling elevator" into reality for a quantum object. It is a milestone in the new era of investigating cold quantum matter in free space. Using experiments of this kind the scientists hope to explore the borders of Quantum Mechanics on the one hand and of General Relativity on the other. *Olivia Meyer-Streng*

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