MAX PLANCK INSTITUTE
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Press Release

Single atoms detect extremely weak forces

MPQ-scientists demonstrate that the observation of synchronization effects in single trapped ions allows to measure forces as weak as 5 yoctonewtons (5 x 10^{-24}N).

Back in the 17th century the Dutch physicist Christiaan Huygens observed that the oscillation of two pendulums can synchronize if they have the possibility to interact with each other. Remarkably, this coupling doesn't need to be strong and it might suffice, e.g. if they are mounted on the same wall. A large variety of oscillating systems show this kind of behaviour, nowadays called "injection locking", ranging from organ pipes to lasers or electronic circuits. A team of scientists in the Laser Spectroscopy Division of Professor Theodor W. Hänsch at the Max Planck Institute of Quantum Optics (MPQ) has now succeeded in observing this technically important phenomenon in a single, extremely cold atom (Phys. Rev. Lett. 105, 013004, 2 July 2010). As was shown in the experiment, the forces necessary to synchronize the oscillation of a single ion with an external radiofrequency signal were as low as 5 yoctonewtons (5 x 10^{-24}N). Hence, single trapped ions can be utilized as unusual but extremely sensitive force detectors – perhaps even sensitive enough to measure the faint magnetic moment of a single molecule for the first time.

The heart of the experiment is a single magnesium ion stored in a so-called Paul-trap. The alternating fields of the trap keep the atom at a fixed point in space, whereas a carefully evacuated experimental chamber guarantees that the ion can oscillate essentially unperturbed. The ion is then addressed by two laser beams that have been accurately tuned to excite oscillations with an amplitude of around a tenth of a millimetre. High-resolution optics and a sensitive camera make it possible to observe this oscillation in real-time by recording the scattered light. In order to investigate the dynamics of the ion's oscillation when it is exposed to an external perturbation, an auxiliary alternating electric field is applied to an electrode nearby and the ion's motion is studied stroboscopically. The experiment shows that once the injected frequency is tuned close enough to the natural oscillation frequency of the ion, its motion indeed synchronizes with the external field.

A careful calibration of the forces exerted by the applied field shows that even minute excitations of only 5 yN give rise to synchronisation. Without a trick like the techniques described above it is very hard to detect forces of this order. To set a scale, note that a force of 5 yN would displace the ion by only around one nanometer (10^{-9} metre), whereas the ion's temperature causes it to occupy a region as large as 5000 nanometres in the trap.

The extremely high sensitivity demonstrated in this experiment offers a variety of applications. For example, it could be used to measure the magnetic field of a single atom or molecule for the first time. The experiment described here is a promising first step in this direction.

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