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Press Release

Equivalence principle also valid for atoms

Garching and Tübingen physicists have on an "atomic fountain" carried out Galilei's leaning tower experiment with quantum objects

In the 16th century Galileo Galilei dropped leaden, golden and wooden objects off the leaning tower in Pisa. He found that all objects reached the ground at the same time. This illustrates the more general result that in a gravitational field the motion of all bodies is the same independent of their mass and composition. Einstein took up this finding to formulate the "equivalence principle" and used it as a key assumption to develop his gravitational theory. Today, there exist a strong challenge to verify the equivalence principle on an atomic level, since corresponding experiments could provide hints on how gravitational theory and quantum mechanics, two fundamental theories in modern physics, could be combined into a uniform description.

German scientists from Garching and Tübingen have performed a modern version of the "leaning tower" experiment. They tested the equivalence principle for quantum objects in an atomic fountain with an atom interferometer, which is a quantum mechanical device. They compared the Earth's gravitational acceleration for two different rubidium isotopes (^{85}Rb and ^{87}Rb) and performed a test of the equivalence principle on an atomic level to an accuracy of two parts in ten millions (Physical Review Letters, Vol. 93, 240404 (2004), 10. Dez. 2004).

The equivalence principle is a cornerstone of general relativity. Today physicists have a strong interest to take this principle under a closer survey. Experimental tests could help to give us an answer to one of the key unresolved questions in modern physics: how quantum theory describing the world of microscopic objects and the theory of gravity explaining the cosmological phenomena can be described in a uniform and consistent way.

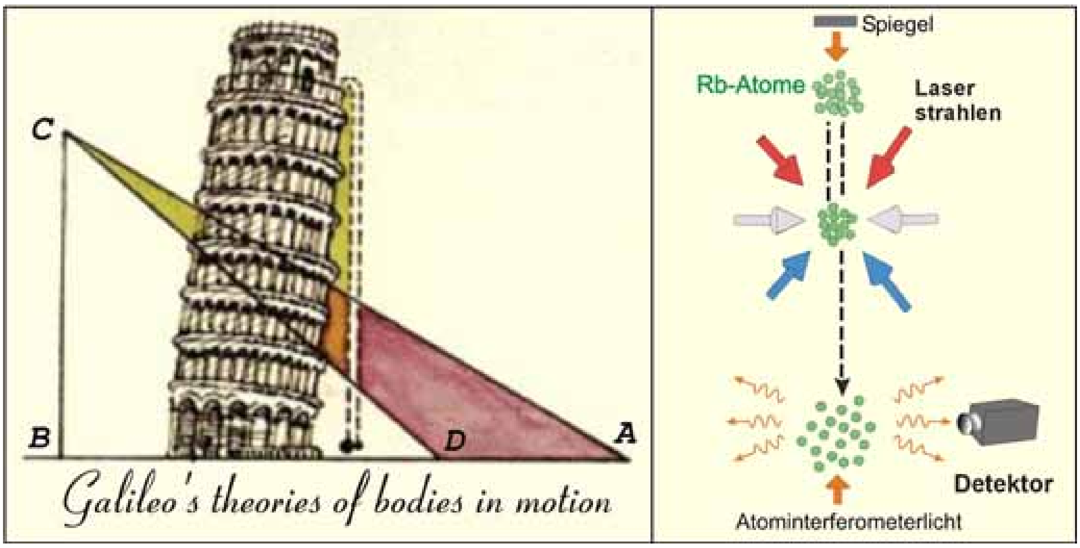

Figure
Left: A sketch of the famous leaning tower experiment of Galileo Galilei who dropped objects with different mass from the tower (http://science.nasa.gov/headlines/y2004/06may_lunarranging.htm). Right: In a vacuum chamber rubidium atoms are trapped, cooled and then launched upwards. During the free flight the traversed distance is measured precisely with an atom interferometer.

Image: Max Planck Institute for Quantum Optics / NASA

Scientists from Garching and Tübingen investigated the equivalence principle for two different rubidium isotopes with an atom interferometer, a quantum mechanical device. They stored a billion rubidium atoms in a magneto-optical trap and accelerated them upwards by light forces against gravity onto a ballistic trajectory, similar to a droplet in a water fountain. On their way down, the quantum mechanical wave nature of the atoms is exploited in an atom interferometer to determine the distance of their free flight. By this means it is possible to precisely follow the motion of the atoms.

In a conventional interferometer, a light beam is split into different paths and recombined later on a detector. If the light beams are then in phase, their field adds up and the detector measures bright light. If instead they meet at the detector with opposite phase, the fields cancel each other and then the detector signal indicates darkness. The laws of quantum mechanics tell us that atoms also show wavelike behavior. In an atom interferometer one can observe the cancellation or amplification of such waves. By carefully monitoring variations from “bright” to “dark” periods, one can determine the Earth’s gravitational acceleration on the free falling atomic trajectory. A single variation from a dark to a bright signal indicates a distance of a half millionth of a meter. This device represents a precise “ruler” for the atomic motion.

By applying this “ruler”, the physicists compared the trajectories of free falling ^{85}Rb and ^{87}Rb atoms respectively and find that the Earth’s acceleration for both isotopes is the same to within an accuracy of two parts in ten millions. By this experiment the validation of the equivalence principle is tested on an atomic level. For the future, the physicists expect that with technical improvements extremely accurate tests of the equivalence principle for quantum test particles are possible.

Original work:

Sebastian Fray, Cristina Alvarez Diez, Theodor W. Hänsch and Martin Weitz
Atomic Interferometer with Amplitude Gratings of Light and Its Applications to Atom Based Tests of the Equivalence Principle
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