Measurement of antimatter gravity with an (anti)matter wave interferometer

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Gravitational acceleration of antimatter is an open question in fundamental physics. A measurement would test the Weak Equivalence Principle for antimatter, the cornerstone of General Relativity. Attempts to measure the gravitational acceleration of antimatter were made with positrons [1] and antiprotons [2]. These experiments with charged antiparticles were, however, hopelessly plagued by the patch effect of remanent electric and magnetic fields. The neutral antihydrogen atom would therefore be an excellent candidate.

The experiment proposed here essentially consists of a horizontal vacuum tube containing an (anti)matter wave interferometer with a position sensitive silicon detector at its end. Along the axis injected antihydrogen atoms from a beam like source fall freely over the flight distance and produce an interference pattern which sags by the same distance as the atoms fall due to gravitational acceleration (fig. 1 left). This displacement can be determined with high precision by changing the slit orientation from vertical (no gravitational shift) to horizontal. A Mach-Zehnder type of interferometer could be used [3], with two identical transmission gratings (fig. 1 right). This kind of interferometer does not require a coherent atomic source since its interference pattern is independent of source extension and wavelength of the test atoms (in vertical position). However, the divergence of the incoming atoms must be sufficiently small not to smear out the interference pattern. Further on, the speed of the atoms must be measured (TOF), to correct for their different gravitational sag.

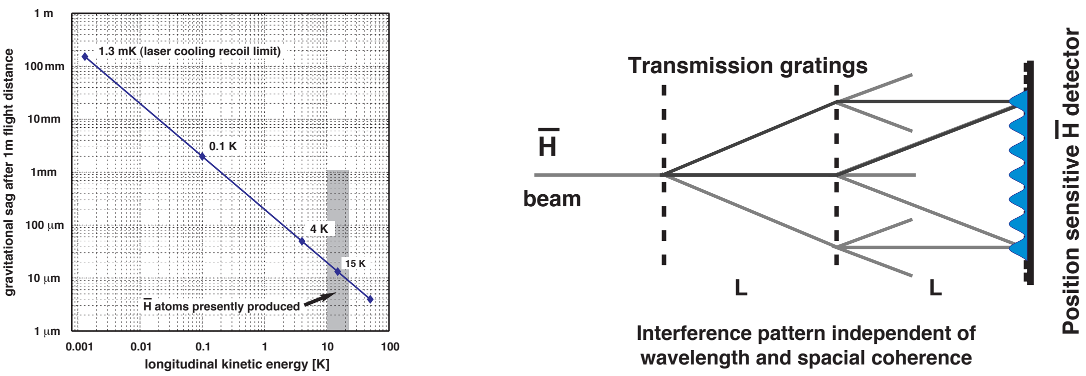

Figure 1: *Gravitational sag of $\overline{\mathrm{H}}$ in the earth field after 1 m flight distance (assuming $\overline{g} = 9.81\,m/s^2$) and a possible interferometer with two identical transmission gratings and the position sensitive $\overline{\mathrm{H}}$ detector.*

The idea of Mach-Zehnder interferometers was already applied to cold atoms and neutrons [4, 5] using a third grating to detect the phase of the interference pattern. Here the analyzer grating would be replaced by a position sensitive silicon detector, recording with high acceptance and precision the impact position and time from annihilation products of impinging antihydrogen atoms. Initially the setup could be tested on a cold neutron beam using a gadolinium absorber in front of the silicon.

The required numbers of antihydrogen atoms for a first measurement are in principle already produced routinely at CERN [6], however, R&D in the laboratory and at the AD site is needed to obtain these atoms in a suitable beam.

References

[1] W.M. Fairbank, et al., Exp. comp. of the grav. force on freely falling e^- and e^+, Science 144, 562 (1964).

[2] T. Goldman, et al., Beyond metric gravity: Progress on PS-200, Hyp. Interact. 81 (1993) 87.

[3] T.J. Phillips, Antimatter gravity studies with interferometry, Hyp.Int. 109 (1997) 357

[4] M. Gruber, et al., A phase-grating interferometer for very cold neutrons, Phys. Lett. A 140 (1989) 363.

[5] D.W. Keith, et al., An interferometer for atoms, Phys. Rev. Lett. 66 (1991) 2693.

[6] M. Amoretti, et al. (the ATHENA Collaboration), High rate production of antihydrogen, Phys. Lett. B 578 (2004) 23.