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Tests of CPT and Lorentz invariance and the principle of equivalence using antihydrogen

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Synopsis Recent developments at CERN hold out the prospect of carrying out precision measurements on cold antihydrogen. The underlying theory to be tested will be discussed in this poster.

There has been extensive work at CERN over many years by the ALPHA (formerly ATHENA) and ATRAP collaborations to trap cold antihydrogen so that its properties can be measured. Recently, ALPHA reported that they had successfully observed 38 annihilation events consistent with the controlled release of trapped antihydrogen from their magnetic trap [1]. This should soon make it possible to carry out precision measurements on antihydrogen, using the same techniques as have been developed for hydrogen. This is very important as it will make it possible to test fundamental principles of physics

To explain the existence of antiparticles such as the positron and the antiproton that make up antihydrogen, it is necessary to combine quantum mechanics and special relativity. The starting point for this was the Dirac equation, which led to the development of relativistic quantum field theory, which is currently used to explain quantum phenomena. From very general considerations, it is considered that this theory must be invariant under the operation CPT, made up of charge conjugation (C), parity (P), i.e. space inversion, and time reversal (T), taken in any order. See, for example, [2].

The resulting overall description of quantum phenomena is the Standard Model (SM). Underlying special relativity is Lorentz invariance. This is a very well established theory but it is a fundamental principle of science that all theories should, as far as possible, be tested by experiment. Kostelecký and collaborators[3] have introduced what they call the Standard Model Extension (SME). This is the most general extension to the SM that allows for violations of Lorentz invariance. It is appropriate to choose the form that preserves the renormalisibility and gauge invariance properties of the SM. Kostelecký and collaborators obtain the SME by adding a phenomenological term to the Dirac Lagrangian that contains tensor operators with spacetime indices. This Lagrangian gives rise to a modified Dirac equation that is no longer Lorentz invariant and, for example, predicts new terms in the spectrum of the hydrogen atom [3, 4]. This and other predictions of the SME have been extensively tested by experiments on matter. However, to date there is no compelling evidence for Lorentz violation. [5].

As proof of CPT invariance requires Lorentz invariance [2], it is to be expected that CPT will not hold, in general, in the SME and this can be shown to be the case. Thus the SME predicts differences in the spectra of hydrogen and antihydrogen. It is planned to check these predictions using trapped antihydrogen.

It is also planned to use a pulsed cold beam of antihydrogen to examine how it behaves in the Earth's gravitational field [6]. To a very high degree of accuracy, all bodies are observed to fall at the same rate in a gravitational field. This result forms the basis of Einstein's principle of equivalence. It seems likely that this will apply to antimatter, though ways that violations could occur are known [4].

The underlying theory behind the proposed tests will be discussed in the poster.

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