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Penning trap precision experiments for fundamental physics

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Experiments with single ions confined in a Penning trap enable access to a broad range of observables that are of fundamental importance for our understanding of fundamental physics. In the magnetic field of the trap, the cyclotron frequency of an ion can be determined with unique precision and gives direct access to the charge-to-mass ratio. Furthermore, we have access to the gyromagnetic g-factor via a measurement of the (Larmor) spin precession frequency. This way, we have determined a number of fundamental parameters, such as the electron, proton, neutron and deuteron atomic masses with leading precision.
This way, in our new generation experiment ALPHATRAP we have recently measured the g-factor of highly charged, hydrogenlike ^{118}Sn. A comparison to a precise prediction by quantum electrodynamics (QED) allows probing the validity of QED in extreme electric fields, in the order of 10^{15} V/cm.
Furthermore, by crystallizing two ions simultaneously in one trap we have achieved a leap of two orders of magnitude on the precision frontier. With this new technique, we have recently determined the isotopic effect of the g-factor in hydrogenlike neon ions, at 13 digits precision with respect to g and are consequently sensitive to previously invisible contributions, such as the QED recoil, and can set limits on hypothetical new physics such as dark matter mediated couplings.
Currently, we are designing a novel experiment that will allow storing a single positron and cooling it to the ground state of motion. Then, using a similar technique will enable comparing the spin precession of electron and positron with 14 digits precision, which would yield a very stringent test of CPT in the lepton sector.
Finally, the possibility to determine the internal state of a single ion gives us access to systems that were previously difficult to handle, such as the molecular hydrogen ions. Currently, we are performing spectroscopy on HD^+ and soon H_2^+. The development of the necessary toolbox will be a seminal step towards a possible future spectroscopy of the antimatter equivalent, $\bar{H}_2^-$, which will enable a unique test of charge-parity-time (CPT) reversal symmetry.

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