# Precision Spectroscopy of Molecular Hydrogen Ions in the ALPHATRAP Penning trap

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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 or alternatively the precise magnetic field strength. We have determined a number of fundamental parameters, such as the electron, proton, neutron and deuteron [1] atomic masses with leading precision . Further, we can non-destructively determine a bound electron's spin state via the continuous Stern-Gerlach effect in a magnetic bottle. This way, we get access to the (Larmor) spin precession frequency and so are able to determine the g-factors of atomic and molecular ions.

Molecular hydrogen ions (MHI) $H_2^+$ and its isotopologues ($HD^+$ and $D_2^+$ and $HT^+$) have a rich rovibrational structure. The relative simplicity of these molecules enables precise theoretical calculations, giving access to fundamental constants such as the mass ratios of the electron and the proton, deuteron and triton. At ALPHATRAP [2] we have developed a complete toolset that enables full control of the rovibrational and hyperfine state of MHI, taking advantage of the dependence of the electron spin transition frequency on the particular internal quantum state [3]. Since this technique does not require a co-trapped auxiliary ion, it is a seminal step towards a possible future spectroscopy of the antimatter equivalent, $\bar{H}_2^-$, which could enable a unique test of charge-parity-time (CPT) reversal symmetry. Our cryogenic vacuum valve enables the required extremely good vacuum conditions, while allowing the injection of external ions.

In a first step, we have precisely measured the hyperfine structure in the ground-state of $HD^+$ and so have tested the theory prediction [4]. Currently, we are performing precision laser spectroscopy of a ro-vibrational transition in a collaboration with the Schiller group from HHU Düsseldorf.

## References

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