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En route to a CPT test based on anti-H_2^+: vibrational spectroscopy of a H_2^+ ensemble and nondestructive spectroscopy of a single HD^+ ion in a Penning trap

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An attractive approach for testing CPT invariance is the comparison of a vibrational transition frequency of anti-H_2^+, composed of two antiprotons and a positron, with that of its matter counterpart H_2^+ [1,2].
The motivation for considering this - so far not existent - system is that its rovibrational transitions are intimately related to the presence of the antiproton-antiproton interaction, an interaction that can therefore be probed in the low-energy regime [3]. This regime is not accessible with high precision in other experiments. Furthermore, the transitions are strongly dependent on the ratio of positron mass and antiproton mass. In comparison, laser spectroscopy of antihydrogen has only a weak sensitivity to this ratio and antiproton Penning trap mass spectrometry experiments [4] face the challenge of progressing towards higher accuracy.
Due in part to (anti-)H2+ being both a molecule and an ion, its vibrational spectroscopy in a Penning trap [2] could exhibit several important advantages: need of only small particle numbers, access to multiple candidate transitions, extremely high line quality factor, ultrasmall systematic shifts [5], long trapping times, possibility of nondestructive spectroscopy of a single anti-H_2^+ for extended duration.

Here we present progress in the exploration of techniques likely to be useful for future spectroscopy of anti-H_2^+. Evidently, we use matter systems for test purposes: H_2^+ and the related HD^+ molecular ion.

Concerning the spectroscopy of vibrational transitions in H_2^+, we report on the first laser vibrational spectroscopy [6], performed in a radiofrequency trap on small ensembles of sympathetically cooled H_2^+ molecules. We employed electric quadrupole spectroscopy [7], originally proposed by Dehmelt. Our spectroscopy was limited by Doppler broadening; we shall discuss our efforts towards Doppler-free spectroscopy.

Since the production rate of anti-H_2^+ is likely to be small, it could be essential to employ an "economic" spectroscopy technique: it should be non-destructive and should be able to work with a small number of particles or even a single particle. Using the ALPHATRAP Penning trap apparatus, we have succeeded in reliably confining and performing spectroscopy on one single HD^+ molecule for many weeks without interruption [8]. Electron spin resonance spectroscopy was performed on several transitions, allowing determination of the g-factor of the bound electron and the spin structure of the rovibrational ground level. The spectroscopy did not destroy the state, much less the molecule itself.

Finally, we have identified rovibrational transitions of H_2^+ or anti-H_2^+ having systematic Zeeman shifts in a Penning trap allowing for attractive levels of overall spectroscopic accuracy [2].

These results lead us to consider the next explorative step: implememting high-accuracy laser spectroscopy of H_2^+ in ALPHATRAP. The prospects will be outlined.

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