Sympathetically cooled H2+/Be+ ions for mp/me metrology

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The "H_2^+ metrology" team at LKB aims at performing the first direct optical measurement of the proton to electron mass ratio m_p/m_e. It is based on measuring the frequency of the Doppler-free two-photon transition between the (v=0, L=2) and (v=1, L=2) levels of H_2^+, where v and L are the vibrational and rotational quantum numbers, Since vibrational transition energies (expressed in units of the Rydberg constant) scale as $(m_p/m_e)^{-0.5}$, accurate measurement of the transition frequency gives access to m_p/m_e with a twice as large relative uncertainty. The natural width of the transition being extremely small ($< 10^{-6}$ Hz), its frequency can be determined with a relative uncertainty well below the 10^{-10} level (corresponding to 1.6 kHz on the laser frequency) with ultracold trapped ions. The resolution will be essentially limited by the stability of the excitation laser.
Recent progress in theoretical predictions of H_2^+ transition frequencies [Korobov09, Karr11] will allow reducing the relative uncertainty down to the 0.1 ppb level in a near future. Therefore, H_2^+ high resolution spectroscopy can lead to a determination of m_p/m_e improved by a factor of 4 with respect to the present CODATA (0.41 ppb), using, in addition, a completely different method.
We have set up the spectroscopy laser system, which consists in an ultrastable laser at 9.17 μm to excite the two-photon transition [Bielsa07], and an excimer laser at 248 nm for selective photodissociation of the excited state [Karr 12]. We have estimated the two-photon transition rate (0.3/s) and measured the phodissociation rate (3/s) which, albeit small, are sufficient in view of the long storage times in ion traps. First experimental runs with H_2^+ ions created by electron-impact ionization and confined in a hyperbolic Paul trap have revealed that it is crucial to improve the ion production method and trapping geometry. We are currently implementing a source of state-selected H_2^+ ions created by resonance-enhanced multiphoton ionization (REMPI), which will increase the population of the initial state by a factor of 60. We are also setting up a linear trap designed to confine a crystal of laser-cooled Be^+ ions in order to sympathetically cool the H_2^+ ions. With those improvements, the expected single-pass signal-to-noise ratio is improved to about 25 [Karr12]. This will lead to the first observation of a two-photon transition in ultracold H_2^+ ions with kHz resolution, and hence to a determination of m_p/m_e at the 0.1 ppb level, and tests of relativistic, QED and hyperfine structure corrections.
In the longer term, state-selected cold H_2^+ ions are good candidates for quantum logic spectroscopy on a Be^+/H_2^+ ion pair, because all ro-vibrational levels of H_2^+ are metastable and insensitive to black body radiation. Spectroscopic signals beyond the 10^{-14} accuracy level may be produced for analysis of m_p/m_e time variations.
H_2^+ sympathetic cooling by laser-cooled Be^+ ions requires laser sources at 313 nm (including "repump" beams). The 313 nm radiation can be obtained by frequency doubling of extended cavity diode lasers at 626 nm (made available only very recently), with an optical power of 20-50 μW. A more powerful source (up to 750 mW at 313 nm) can be obtained using SFG of two fiber lasers: 1051 nm (5W) + 1550 nm (5W) → 626 nm (1.8 W), followed by SHG, following the NIST design [Wilson11]. The main equipments for those lasers sources are funded by the IFRAF RESIMA grant.
Control of these cooling lasers would be greatly facilitated by a fibre-coupled wavelength meter operated at 626 nm, for rough frequency tuning before stabilization on a I_2 saturated absorption line. This device could also be used for the REMPI 303 nm pulsed laser (probing the 606 nm ouput of our dye laser before SHG). In the future, this equipment will also be helpful for the LKB group led by Paul Indelicato for highly charged ion (e.g. $^{40}Ar^{13+}$) spectroscopy of fine-structure transitions in the visible domain with diode lasers.
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