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Cavity-enhanced Lamb-dip spectroscopy of HD at 1.39 μm with 10^{-10} precision[1]

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Energy levels in the electronic ground state of the hydrogen molecule can be calculated precisely based on quantum electrodynamics (QED) and a few fundamental physical constants. Therefore, precision spectroscopy of H_2 (and its isotopologues) is a test ground of QED and may serve for determination of those constants. Recent progress shows that the accuracy of calculation is approaching the level of sub-MHz [Puchalski et al., PRL 2018, 121:073001]. However, high-precision measurements of the ro-vibrational spectroscopy of the hydrogen molecule is very difficult due to extremely weak transition moments. Recently, two of the very sensitive laser spectroscopy methods both utilizing the sensitivity enhancement from high-finesse cavities, cavity ring-down spectroscopy (CRDS) and noise-immune cavity-enhanced optical heterodyne molecular spectroscopy (NICE-OHMS), have been applied to detect the Doppler-free Lamb dips of the lines in the first overtone band ($V = 2-0$) of HD at 1.39 μm. However, the R(1) line centre given by CRDS [Tao et al., PRL 2018, 120:153001] differs from that by NICE-OHMS [Cozijn et al., PRL 2018, 120:153002] by 0.9 MHz which is about 8 times of the combined uncertainty. In this talk, we will review the methods and present our recent experimental progress. We developed an instrument realizing three different cavity-enhanced spectroscopy methods - CRDS, NICE-OHMS, and cavity enhanced absorption spectroscopy (CEAS). Owing to a considerably improved sensitivity, we revealed the reason of the discrepancy observed in previous measurements: The Lamb-dip line of HD has a very unique dispersion-like feature. So far as we know, such profile has not been observed before in other molecules. The line profile was confirmed by all three methods, CRDS, CEAS, and NICE-OHMS, and also by the comparison to the spectra of a nearby C_2H_2 line observed at same experimental conditions. The weighted centers of the HD line determined from three methods, agreed with each other within a few tens kHz . Provided that the theoretical analysis can also achieve the similar accuracy, the result would lead to a new determination of the proton-to-electron mass ratio at the 10^{-10} level.

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