Precision Laser Spectroscopy of Atomic Hydrogen

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Precision laser spectroscopy of the simple hydrogen atom has long provided an intriguing path to fundamental physics research at low energies. Since the first Doppler-free saturation spectroscopy of the Hydrogen Balmer-alpha line in 1972, the accuracy of laser spectroscopic measurements in atomic hydrogen has advanced by 8 orders of magnitude, approaching the limit set by the definition of the unit of time. Such measurements permit tests of quantum electro-dynamic theory, they yield values of the Rydberg constant and the proton charge radius, and they provide a reference for laser spectroscopy of antihydrogen and of other hydrogen-like exotic atoms, notably muonic hydrogen and muonic deuterium. The rms proton charge radius as derived from laser measurements of the 2s-2p Lamb shift in muonic hydrogen some years ago is about 4% smaller than that obtained from hydrogen spectroscopy or electron scattering experiments. This "proton size puzzle" has not yet been resolved. Current experiments in our laboratory aim to confirm or resolve this puzzle. They include fluorescence spectroscopy of 2s–np transitions in a cold collimated atomic beam, and direct Doppler-free frequency comb spectroscopy of the 1s – 3s, 3d two-photon transition in a cold atomic sample.

Future precision spectroscopy of hydrogen-like cold, trapped He+ ions, using a high harmonic generation frequency comb source near 60 nm, together with measurements of the helium nuclear charge radius via the 2s-2p Lamb shift in hydrogen-like muonic helium ions, will permit even more sensitive searches for possible new physics.