Bounds on a fifth force from hydrogen, deuterium and helium spectroscopy

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It has been recognised for some time that stringent bounds on the strength of a fifth force are set by high precision spectroscopy of hydrogen and deuterium [1–5]. We have revisited and continued these earlier investigations in the light of recent experimental and theoretical advances in the spectroscopy of hydrogen, deuterium, helium-3 and helium-4 and their muonic counterparts [6, 7]. Our main results, which we present in this poster, are bounds on a fifth force interaction between an electron and either a proton or a neutron. We also discuss the potential offered by a future high-precision measurement of the $1s_{1/2} - 2s_{1/2}$ interval of $^4He^+$ [8] for setting bounds on the interaction of an electron with a deuteron. These results do not depend on specific assumptions on how the interaction would couple to a deuteron compared to a proton or would couple to an α particle compared to a helion. They depend on its coupling to a muon, but not in a significant way for carrier masses below 100 keV if one assumes that the strength of the interaction with a muon would be of a similar order of magnitude as the strength of the interaction with an electron.

Specifically we consider the wide class of models that can be described by an effective Yukawa-type interaction between the nucleus and the electron (or the muon for the muonic species). We parametrize the strength of this new physics (NP) interaction by the product of the respective coupling constants — $g_e g_p$ for the interaction between a proton and an electron or $g_e g_n$ for the interaction between a neutron and an electron. We find that it is possible to set bounds on $|g_e g_p|$ that are orders of magnitude more sensitive than those set using a single isotope only provided the interaction couples differently to the deuteron and proton. Further enhancements of these bounds by an order of magnitude or more would be made possible by extending the current isotope shift data to measurements of a transition between the 2s state and a Rydberg s-state with an experimental error of 100 Hz or better [4, 6]. In the mass region considered, the bounds on $g_e g_n$ based on the World spectroscopic data for hydrogen and deuterium tend to be more stringent than the bounds arising from the analysis of King plots nonlinearities, in the current state of development of the latter approach — see, e.g., Figure 1 and Refs. [4] and [7]. Measuring the isotope shift of the $1s_{1/2} - 3s_{1/2}$ interval in hydrogen and deuterium to a precision of ~ 1 kHz would provide a useful independent check of these bounds [6].

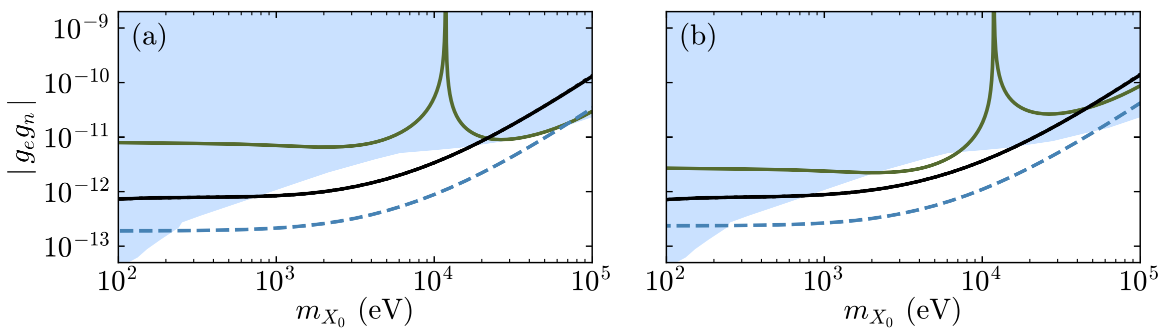

Figure 1: Bounds on $g_e g_n$, (a) for an attractive NP interaction, (b) for a repulsive NP interaction. Shaded area: region excluded by neutron scattering data combined with measurements of the anomalous magnetic moment of the electron [4]. Solid green curves: bounds derived from the Yb/Yb$^+$ isotope shift [9]. Solid black curves: bounds based on the World spectroscopic data for hydrogen and deuterium. Dashed curves: bounds based only on the $1s_{1/2} - 2s_{1/2}$ interval of eH, the isotope shift of the $1s_{1/2} - 2s_{1/2}$ interval and the μH and μD Lamb shifts. Adapted from Ref. [7].

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