2019
6-7 KWIETNIA
SYMPOZJUM MŁODYCH NAUKOWCÓW
WYDZIAŁU FIZYKI UW

The charge-radius puzzle

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The nuclear charge radius is one of the electromagnetic moments of the nucleus and, as such, is independent of the system the nucleus is in. The proton charge radius inferred from the Lamb shift measurement in muonic hydrogen [1,2] disagrees by 5.6σ with that obtained from ordinary hydrogen. The description of hydrogen spectrum within the current theory is extremely precise. If those experimental results are correct, such disagreement might indicate unknown effects and unknown interactions that cannot be explained by straightforward modifications of the Standard Model [3].

Existence of the discrepancy in the proton charge radius has led to extending the interest in muonic systems to deuterium (μD) and helium (μHe). The deuteron charge radius determined from the spectroscopy of μD [4] also deviates from that inferred from ordinary deuterium [5].

However, the calculation of atomic energy levels becomes increasingly difficult for systems with complex nucleus. One of the major limitations in precise theoretical description of the Lamb shift in muonic deuterium is the contribution of nuclear-structure effects [6]. In this work, we calculated the electron vacuum polarization correction to the nuclear-structure contribution to the energy. This correction is surprisingly large and changes the predicted value of the deuteron charge radius and the deuteron-proton charge-radii square difference, which is now consistent with the priecise value obtained from the ordinary H-D isotope shift in the 1S-2S transition [7]. It effectively resolves the deuteron-radius puzzle.

Agreement in the deuteron-proton charge-radii square difference suggests that we have sufficient knowledge of nuclear-structure effects to calculate polarizability contributions in heavier nuclei. Most importantly, it is a strong evidence that muonic experiments are correct and that the disagreement in the proton charge radius is due to an underestimated uncertainty in ordinary hydrogen spectroscopy.

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Studenckie Koło Nanotechnologii Nanorurki

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