A measurement of the $2S_{1/2}$ hyperfine interval in atomic hydrogen

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The simple structure of the hydrogen atom allows for precise calculations that can be compared with experiment. The ground state hyperfine interval in atomic hydrogen has been measured extremely precisely. A comparison of the experimentally determined value with theory is limited by an insufficient understanding of proton structure effects. However, a linear combination of the $1S_{1/2}$ and $2S_{1/2}$ hyperfine intervals given by

$$D_{21} = 8\,f(2S_{1/2}) - f(1S_{1/2}), \tag{1}$$

largely eliminates the theoretical uncertainty in nuclear structure and is a stringent test of fourth-order bound-state QED [1]. A high-precision numerical calculation of the self-energy was performed in 2008, resulting in $D_{21}^{\text{Theory}} = 48\,954.1(2.3)$ Hz [2], which is the most up-to-date published value.

In addition to bound-state QED tests, several authors have noted that measurements of D_{21} can be used to provide constraints on light bosons with weak coupling to Standard Model particles [3, 4, 5]. Such hypothetical particles could manifest themselves by producing an additional spin-dependent interaction between the proton and electron, which would cause a deviation between the experimental and theoretical values of D_{21}.

We have recently completed a measurement of the $2S_{1/2}$ hyperfine interval, which when combined with precise measurements of the ground state hyperfine interval, provides a measure of D_{21} [6]. The measurement was done using Ramsey spectroscopy with a thermal beam cooled to cryogenic temperatures. The measured value is 177 556 838.87(85) Hz, which represents the most precise determination of this interval to date. Using the value of $f(2S_{1/2})$ from this work gives a value of $D_{21}^{\text{Exp}} = 48\,959.2(6.8)$ Hz, which is in agreement with the theoretical value of $D_{21}^{\text{Theory}} = 48\,954.1(2.3)$ Hz.

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