ABSOLUTE OPTICAL FREQUENCY MEASUREMENTS OF THE CESIUM D_1 TRANSITIONS AND THEIR EFFECT ON ALPHA, THE FINE-STRUCTURE CONSTANT

Abstract

by

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The fine-structure constant or electromagnetic coupling constant, α_e, is a dimensionless ratio which unites many physics subfields. Although known precisely via experiments in each subfield, there is disagreement within and between subfields. In particular, precise values obtained via electron $g_e - 2$ experiments which depend heavily on QED calculations have not always been in agreement with those obtained via muon $g_\mu - 2$ experiments. Also, solid state measurements (quantum hall effect and AC Josephson effect) often disagree with neutronic $\frac{h}{m_n}$ measurements. α_e is often said to vary with energy but the question remains as to whether or not its low energy value is stable now or has been stable over the history of the universe. Improved precision helps resolve these issues as they relate to physics, possibly beyond the standard model.

The Optical Frequency Measurements group in the Time and Frequency Division at the National Institute of Science and Technology (NIST, Boulder, CO) developed and maintains a femtosecond laser frequency comb which is calibrated with respect to the cesium fountain clock implementation of the second. A single frequency component of the femtosecond laser comb is used together with a solid state diode

laser and cesium thermal beam to precisely measure the cesium D_1 $F \in \{3, 4\}$ transition frequencies. The value of $f^{D_1}_{\text{centroid}} = 335\ 116\ 048\ 748.1(2.4)\,\text{kHz}$ obtained for the transition centroid is over fifteen times more precise than the most recent previous measurement. A precise value for the cesium D_1 hyperfine splitting $f_{\text{HFe}} = 1\ 167\ 723.6(4.7)\,\text{kHz}$ is reported as well. This value is also over fifteen times more precise than the most recent previous measurement.

These new neutral ^{133}Cs $6s\ ^2S_{1/2} \rightarrow 6p\ ^2P_{1/2}$ transition (D_1) frequencies, when combined with the 2002 CODATA values of the Rydberg, proton/electron mass ratio, cesium atomic mass, and cesium recoil frequency, provide an almost QED-free value of alpha: $\alpha_e = 1/137.036\ 0000(11)$ or 7.7 ppb. This value for α_e is comparable in precision with these other measurements. When this value is combined with the other measurements used to calculate the 2002 CODATA recommended value, an improved value of $\alpha_e = 1/137.035\ 999\ 08(46)$ is obtained.