Precise Frequency Measurement of Cesium D1 Lines, α_e (the Electromagnetic Fine Structure Constant), and You.

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The 2002 CODATA [1] value for $\alpha_e^{-1} = 137.035\,999\,11(46)$ is supposedly accurate to 3ppb. However, it changed by 5 ppb from the 1998 CODATA [2] value of 137.035 999 76(50) which was supposedly accurate to 4 ppb. Such changes are not without precedent in the short history of α_e since it was introduced in 1916 by Sommerfeld to explain the hyperfine splitting in hydrogen spectra.

α_e can be measured very precisely [3] via the anomolous electron spin, muon hyperfine splitting, de Broglie wavelength of slow neutrons, quantum Hall effect, a.c. Josephson effect, and measurements in the cesium atom. However, the first two are highly dependant on QED calculations. The next two depend on macroscopic objects for calibration and solid state physics for theory. There is disagreement. The $^{133}_{55}$Cs atom measurements give an almost QED- and macroscopic-free method of determining α_e.

Physics beyond the Standard Model of particle physics (with $m_\nu \neq 0$) suggests coupling constants depending on energy and even converging to a common value at high energy. Minor variations in α_e, (along with a few constants like $\Lambda_{\rm QCD}$) have a profound effect on new physics and the big bang. However, the detection of such variation requires high precision. Greater constraints will then be applied to theory.

We are building a temperature stabilized and current controlled 894.6 nm (infrared) diode laser using an external cavity Fabry-Perot interferometer made of 99.5% reflective 0.5" mirrors and 10 cm radius of curvature to scan the 1 GHz region of interest near 335 THz or the Cs 6s $^2S_{1/2}$ (F=3,4)$\rightarrow$ 6p $^2P_{1/2}$ (F'=3,4) transition. The laser output will interface via fiber optic to existing cesium thermal beam equipment [4] recently used to precisely measure the optical frequencies of the D2 (6s $^2S_{1/2} \rightarrow$ 6p $^2P_{3/2}$) line components at 852 nm. The output will be calibrated using NIST's femtosecond laser [5] which in turn is calibrated to the cesium atomic clock. We expect uncertainties on the order of 8 kHz or 25ppt, or five to ten times more precise than the most recent measurements of $f_{\rm D1}$ or $f_{\rm D1_{hfs}}$ [6]. When combined with precise values for the Rydberg [1], m_p/m_e [1], the cesium atom mass, [3] and recoil velocity, [7] we expect on the order of ppb precision in estimating α_e.

[1] B. Taylor, *et al,* to be published (2004).

[2] P. Mohr, and B. Taylor, Review of Modern Physics, **72,** 351 (2000).

[3] M. Bradley, J. Porto, S. Rainville, J. Thompson, and D. Pritchard, Physical Review Letters **83,** 4510 (1999) and Atomic Physics 17, (2001), 73.

[4] V. Gerginov, A. Derevianko, and C. E. Tanner, Physical Review Letters **91,** 072501 (2003).

[5] A. Bartels, S. Diddams, T. Ramond, and L. Hollberg, Optics Letters **28,** 663 (2003).

[6] T. Udem, J. Reichert, R. Holzwarth, and T. Hänsch, Physical Review Letters **82,** 3568 (1999) and Atomic Physics 17, (2001), 58.

[7] J. Hensley, A. Wicht, B. Young, and S. Chu, Atomic Physics 17, (2001), 43.