MEASUREMENT OF THE UNPERTURBED HYDROGEN HYPERFINE TRANSITION FREQUENCY

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We report the results of a joint experiment which was aimed at the measurement of the frequency of the H^1 hyperfine transition ($F = 1$, $m_F = 0$) $\longleftrightarrow$ ($F = 0$, $m_F = 0$). The experiment was motivated by a considerable disagreement between previously determined values which amounted to several parts in 10^{12}.

The hydrogen maser frequency differs from the unperturbed atomic transition frequency because of a variety of effects including cavity pulling, spin exchange, magnetic fields, 2nd order Doppler (related to the temperature of the storage vessel), and collisions with the walls of the storage vessel. All of these effects can be measured and accounted for with fractional uncertainties of less than 10^{-13}, with the exception of the wall collision effect (wall shift). Thus, the measurement of the unperturbed hydrogen transition frequency involves primarily a measurement of the wall shift.

We used four hydrogen masers for our experiment: Model NP3 of the National Aeronautics and Space Administration (NASA)[1]; Model H2 of the National Bureau of Standards (NBS); a small packaged maser of the Smithsonian Astrophysical Observatory (SAO)[2]; and the reference maser of Harvard University. The final intercomparison and determination of the frequency was performed at NBS in terms of the NBS Atomic Time Scale AT(NBS). The rate of the AT(NBS) scale is continually calbrated by the National Bureau of Standards Frequency Standard, the NBS-III cesium beam [3].

Our result is based on two independent experiments which we outline in the following:
Experiment I: We transported the SAO maser to Harvard University where we compared its frequency with the frequency of the Harvard reference maser. Since we know the wall shift of the latter from an earlier extensive evaluation [4], we thus obtained directly the wall shift of the SAO maser. We subsequently transported this maser to the NBS Laboratory in Boulder, Colorado. Here we compared its frequency with the NASA maser which was temporarily located at NBS.
Experiment II: We equipped the NBS maser successively with 15 spherical storage bulbs of different sizes ranging from 7.5 cm (3 inches) to 20 cm (8 inches) in diameter. For each bulb we referenced the NBS maser frequency directly to the NASA maser. Figure 1 shows the beat frequency between the two masers (using a synthesizer offset) as a function of the inverse bulb diameter. The unperturbed hydrogen transition frequency was obtained by linear extrapolation of the results. Wall shift correction and absolute frequency determination thus were integral parts of the same measurement.

It is already indicated in the preceding paragraphs that we used the NASA maser as our reference standard. However, it served not only as a highly stable frequency source allowing short and long term measurements with a relative precision of a few parts in 10^{13} but also as a calibrated transfer standard. The NASA maser's frequency was constantly monitored by the NBS clock ensemble. The frequency of the NASA maser in terms of the AT(NBS) Time Scale was known, therefore, to within parts in 10^{13} which is considerably better than the measurement uncertainty to be attributed to our experiments.

The values from both experiments were corrected for all known perturbing effects and agreed to within 2×10^{-3} Hz. For their mean we obtain for the unperturbed hydrogen transition frequency

$$\nu_H = 1\ 420\ 405\ 751.768 \text{ Hz},$$

in terms of the frequency of the Cs^{133} hyperfine transition ($F = 4$, $m_F = 0$) $\longleftrightarrow$ ($F = 3$, $m_F = 0$), defined as 9 192 631 770 Hz. The uncertainty in ν_H is estimated at 2×10^{-12} (or about 3×10^{-3} Hz) with the major contribution resulting from the uncertainty in the wall shift determination.

We will describe the experimental procedures, and we will present details on experiment II including some data on the wall shift of TFE Teflon

which was used in the coating of our bulbs. We will give a detailed discussion of the applied frequency biasing corrections and the associated uncertainties. We will compare our results with previously published values and attempt an explanation of the existing differences.

[1] Peters, H. E., T. E. McGunigal, and E. H. Johnson, Proc. 23rd Annual Symposium on Frequency Control, Ft. Monmouth, N.J., p. 297 (1969).

[2] Baker, M., M. Levine, L. Mueller, and R. Vessot, Proc. 22nd Annual Symposium on Frequency Control, Ft. Monmouth, N.J., p. 605 (1968).

[3] Glaze, D. J., submitted for publication in IEEE Trans. on Instrumentation and Measurement.

[4] Zitzewitz, P. W., E. E. Uzgiris, and N. F. Ramsey, Rev. Sci. Inst. 41, p. 81 (1970).