DOE/ER/40282--T1

DOE/ER/40282--T1

DE90 008800

A NEW DETERMINATION OF THE FINE-STRUCTURE CONSTANT

Final Report
U.S. Department of Energy
Washington, DC 20545

by

The Electricity Division
Center for Electronics and Electrical Engineering
National Institute of Standards and Technology
Gaithersburg, MD 20899

I. Summary

This Report, submitted by the Electricity Division of NIST, is to summarize the work performed under contract DE-AI01-86ER40282 and represents a new experimental determination of the fine-structure constant α, to the accuracy of 3.7 parts in 10^8 (0.037 parts per million or ppm). The success of this experiment enabled the unequivocal testing of quantum electrodynamic theory (QED) to the same level of accuracy through the comparison of experimental and theoretical values of QED dependent quantities. These are the anomalous magnetic moment of the electron, a_e, the hyperfine splittings in muonium and positronium, and various Lamb shifts in hydrogen and helium. In view of the importance of quantum electrodynamics to our understanding of atomic, molecular, and particle physics, such critical comparisons have immense potential for confirming QED.

II. Introduction

In the NIST Electricity Division there is an extensive program to measure four physical constants which, when complete, will result in a determination of α at the 1 to 2 parts in 10^8 level by more than one method. In order to achieve such accuracy, four experiments must be done in the same physical location and close together in time so that the electrical units used in all the experiments can be realized to this same level of accuracy. This grant supported the measurement of one of those constants, namely, the proton gyromagnetic ratio γ_p'. The other three measurements are: (1) the ac Josephson effect value of 2e/h; (2) the quantized Hall resistance $R_H = h/e^2 = \mu_0 c\alpha^{-1}/2$; and (3) the determination of the absolute or SI ohm, Ω_{NBS}/Ω, via a calculable capacitor experiment. All other physical constants required to calculate α using these four constants are known to 1 part in 10^8 or better. In addition to providing one of the most stringent tests of QED, we also tested the accuracy of the quantum Hall theory and the theory of the Josephson effect. We have completed a determination of γ_p' with an uncertainty of 0.11 ppm which results in a measure of α^{-1} = 137.0359840 ± 0.037 ppm. This value of α^{-1} differs from that obtained from the electron magnetic moment anomaly experiment by (-0.054 ± 0.038 ppm) and it differs from a recent α^{-1} value determined via the NIST calculable capacitor experiment by (-0.102 ± 0.043 ppm). (See the preprints included with this report.)

III. Progress Made: 1 July 1988 - 30 June 1989

As mentioned above, the results of our research were published during this period. (See Attachment A.) The technical effort has been primarily dedicated to taking and analyzing both dimensional and NMR data of the field solenoid. We also had to spend a great deal of time assuring the accuracy of our calibrations. This required a calibration of current via transfer over a special 1.5 km cable to the Josephson volt laboratory every day that an NMR measurement was made. Electricity Division staff calibrated our current against a Josephson array voltage and a resistor that was measured via the Quantum Hall effect. The Mass and Length Division set up an iodine stabilized laser so that the laser wavelength could be calibrated in real time during the dimensional measurements.

One systematic effect took a great deal of time to investigate. We found that different results were obtained for our NMR frequency when we used NMR probes loaned to us by the English and West German National Laboratories. To investigate this we devised a way to measure the correction due to magnetic impurities in the NMR detector coils by substituting yet another coil and water sample in place of the normal water sample. The results were that our

NIST detector coils were magnetically clean while the other coils have some type of imperfections that led to the original discrepancy.

One of the most satisfying parts of our results was the excellent agreement between our latest γ_p' results and our earlier results using an entirely different apparatus. (See Fig. 10 Attachment A.) The discrepancy between our γ_p' result and the calculable capacitor experiment is disturbing because it is believed this was also a carefully executed experiment. (See Fig. 1 Attachment B.) Even with this 0.1 ppm discrepancy one can only conclude that QED theory and the quantum Hall effect are remarkably accurate theories only showing possible inconsistencies at the 0.1 ppm level or better. Of course we should continue to examine the possible reasons for the present disagreement.

Reprints removed

IV. Final Results

With the support os the DoE we have measured γ_p' five times more accurately than any other group. This has provided a new measurement of the fine structure constant α with an uncertainty of 0.037 ppm.

V. Deliverable

This is the final report describing our results for the period of this contract including references of all publications resulting from this work.

Points of Contact

Point of Technical Contact:

Edwin R. Williams
Bldg. 220, Room B258
National Institute of Standards and Technology
Gaithersburg, MD 20899
Tel: (301) 975-6555
Fax: 301-869-6188

Point of Administrative Contact:

James A. Hormuth
Bldg. 220, Room B364
National Institute of Standards and Technology
Gaithersburg, MD 20899
Tel: (301) 975-2220
Fax: 301-869-6188

Oskars Petersons 3/19/90

Oskars Petersons, Chief
Electricity Division