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*LIMITS OF QUANTUM ELECTRODYNAMICS AND ACCURACY OF GLOBAL CONSTANTS**

GLOBAL CONSTANTS*

Ya. A. SMORODINSKIĬ

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THE new measurement of the fine-structure constant is a major accomplishment on the part of the experimenters. The described experiments are very beautiful in their conception and are splendid in their performance. These experiments taught the physicists an instructive and to some degree severe lesson.

First, however, a few remarks concerning the method. The Josephson effect used in these experiments has been described in the article by Parker, Taylor, and Langenberg (see also the 9-th issue of the "Feynman Lectures," Ch. 19). This effect is based on the remarkable fact that the state of a superconductor is described by a wave function (a complex one, as should be the case for a quantum state with current). The wave function is defined over macroscopic distances, so that different regions of the sample are rigorously correlated with one another. When two superconductors are separated from each other by a narrow gap and are at different potentials V_1 and V_2, their state can be described in a manner similar to that used in quantum mechanics to describe a system with two levels $2eV_1$ and $2eV_2$ (2e, since electron pairs participate in the superconductivity). Since the potential difference is maintained by an external source, there will occur in such a two-level system transitions with a frequency determined by the Bohr condition $\hbar\omega = 2eV$, where V is the potential difference. If the junction between the two superconductors is "illuminated" with microwave radiation and the current is measured at a given potential difference, the problem reduces to a measurement of the dc component in a system with phase modulation. If the radiation used to illuminate the sample has a frequency ω_1, then an alternating current will flow through the gap. The phase of this current will consist of two parts:

$$\frac{2e}{\hbar}\int V\,dt = \frac{2eV}{\hbar}\,t, \tag{1}$$

which is connected with the transitions between levels, and

$$\frac{2ev}{\hbar}\int \cos\omega_1 t\,dt = \frac{2ev}{\hbar\omega_1}\sin\omega_1 t, \tag{2}$$

which is connected with the radiation (v—amplitude).

The current is proportional to

$$\cos\frac{2e}{\hbar}\left(Vt + \frac{v}{\omega_1}\sin\omega_1 t\right).$$

The instrument records the average value of this current (the zeroth Fourier component). This value differs from zero if (n is an integer)

$$n\omega_1 = \frac{2eV}{\hbar}$$

and is equal to

$$\frac{1}{\omega_1} J_n\left(\frac{2ev}{\hbar\omega_1}\right).$$

If V is varied, then the current will increase jumpwise if the foregoing condition is satisfied. We have added, so to speak, one more quantum to the superconductor. This is precisely the step observed in the experiment.

The new value of the fine-structure constant, $1/\alpha = 137.0359$, has eliminated the disparity between theory and experiment in the value of the Lamb splitting. The theoretical value of this splitting, using the new value of α, is (in MHz)

$$1057.57 \pm 0.08;$$

whereas experiment yields

$$1057.77 \pm 0.10.$$

Recent experiments by Robiscu gave for the Lamb shift somewhat larger values. However, according to the latest data, the reduction of Robiscu's results is not fully reliable.

The most interesting is the situation with the hyperfine splitting of the ground state of hydrogen. Hydrogen can have a spin equal to zero or one. The transitions between these two levels give rise to the 21-cm line, which is well known to radio astronomers. The triplet state is very stable, and its lifetime in vacuum is approximately 30 years. Therefore the 21 cm hydrogen line has an exceptionally small natural width. Under laboratory conditions, the line width is determined by the collisions of the hydrogen atoms with the walls of the vessel. This calls for a high accuracy of measurement of the frequency of this line. It has been measured with eleven (!) reliable significant figures

$$\nu = \underline{1420\,405}\,751.800 \pm 0.028 \text{ Hz}.$$

The underscored six figures constitute the value that can be calculated by modern theory (there is full agreement with respect to these figures). A challenge to the theoreticians are the additional five figures, with respect to which no one can say whether they agree with modern theory or not. To calculate the effect accuracy it is necessary to know the field "inside" the proton and to be able to calculate exactly the recoil effect.

The lesson referred to above consists in the fact that the experimenters, at the request of the theoreticians, sought the possible limits of applicability of quantum electrodynamics. Many recent communications report that discrepancy between experiment and quantum electrodynamics has been finally observed; every time, however, a refinement (of either the experiment or the

*Comments on the article "Measurement of 2e/h Using the ac Josephson Effect and Its Implications for Quantum Electrodynamics" by W. H. Parker, B. N. Taylor, and D. N. Langenberg, Phys. Rev. Lett. 18, 287 (1967).

theory) restored the status quo.* The hyperfine splitting in hydrogen also remained unchanged. But in this case experiment turned out to be much more accurate than theory, and the experimenter is now fully justified in asking how an experiment aimed at verifying quantum electrodynamics should be set up in order to be effective. What is to be done with the five extra digits in the hydrogen line, which contain, in principle, information concerning interactions at distances smaller by a million times than those at which quantum electrodynamics is now regarded as verified (~ 0.1 F). Is it possible at all to formulate correctly at present the very question of verifying quantum electrodynamics? I do not know.

*A good review of such verifications was presented by D. R. Jennie at International Conference on Electromagnetic Processes in Dubna (February, 1967).

Translated by J. G. Adashko