Constancy of the fundamental constants

Yu. S. Domnin, A. N. Malimon, V. M. Tatarenkov, and P. S. Shchumyatskiĭ
All-Union Scientific-Research Institute of Physicotechnical and Radiotechnical Measurements

(Submitted 2 January 1986)
Pis'ma Zh. Eksp. Teor. Fiz. **43**, No. 4, 167–169 (25 February 1986)

A time variation of the ratio of the frequencies of quantum standards for the optical and rf ranges has been observed experimentally. With respect to the frequency of the standard transition of the Cs atom, the frequencies of He–Ne/CH_4 lasers stabilized on the basis of the F_2^2 and E components of methane decreased by 4.7 ± 0.7 and 4.3 ± 1.7 kHz, respectively, over an interval of 4 years, 8 months. The hypothesis of a time variation of the fundamental constants is discussed as a possible reason.

Over the years since Dirac[1] suggested a possible inconstancy of the fundamental constants, several experiments have been proposed as tests. In the present letter we report an experiment carried out to measure the ratio of the frequencies of quantum standards based on quantum transitions of different natures. This experiment was discussed in Refs. 2 and 3.

In April 1981 and December 1985, we carried out the most accurate absolute measurements ("absolute" here means with respect to the standard hyperfine transition in the Cs atom) of the frequencies of He–Ne/CH_4 infrared lasers stabilized on the basis of the F_2^2 and E components of the $\nu_3 P(7)$ vibrational-rotational transition of methane.[4] The ratio of the frequencies ν_{Cs} and ν_{CH_4} is proportional to a combination of fundamental constants:

$$\frac{\nu_{Cs}}{\nu_{CH_4}} \propto g_I \alpha^2 \left(\frac{m_e}{m_p} \right)^{1/2}, \tag{1}$$

where g_I is the gyromagnetic ratio of the proton, $\alpha = e^2/\hbar c$ is the fine structure constant, and m_e and m_p are the electron and proton masses, respectively.[5]

In 1981, measurements were carried out for a transportable He–Ne/CH_4 laser stabilized on the basis of the F_2^2 component, with a frequency reproducibility $\sim 1 \times 10^{-11}$, with respect to the standard transition of the Cs atom. The frequency of this laser at the time of the measurements was 88 376 181 600.4 $\pm$ 0.5 kHz. This laser was used to measure the frequency of a stationary He–Ne/CH_4 standard stabilized on the basis of E component of methane. In this case the reproducibility of the transition frequency is[7] $\sim 5 \times 10^{-13}$. The frequency of this standard turned out to be 88 373 149 033.3 $\pm$ 1.7 kHz. These measurements and the limiting factors are described in detail in Refs. 4 and 6.

In December 1985, we repeated the frequency measurements of the same He–Ne/CH_4 lasers. These measurements showed that the frequencies of the lasers using the F_2^2 and E components were 88 376 181 595.7 $\pm$ 0.5 kHz and 88 373 149 029.00 $\pm$ 0.07 kHz, respectively. The experimental results thus show that the frequency of the laser stabilized on the basis of the F_2^2 component decreased 4.7 $\pm$ 0.7 kHz, and that stabilized on the basis of the E component decreased 4.3 ± 1.7 kHz, over this time interval of 4 years, 8 months.

The apparatus used for the frequency measurements in 1985 was of basically the same structure as the apparatus used in 1981 (Ref. 4), but significantly more accurate and more reliable. Three series of measurements were carried out over the course of 2 weeks. Each series consisted of about 500 readings with an averaging time of 10 s. The standard deviation σ in all the series of measurements was ~100 Hz.

In the 1985 measurements, we also used a newly developed, transportable He–Ne/CH_4 laser using the F_2^2 component and having improved accuracy characteristics. The reproducibility of the frequency of this laser over a year is about 1×10^{-12}. In the course of the measurements, we monitored the frequency difference between the old and new lasers. The frequency of the new laser is 88 376 181 602.15 ± 0.06 kHz. This laser and the laser using the E component will be used to "store" the frequency for future measurements.

A test of the measurement circuit and an analysis of its operation in 1985 revealed no sources of systematic errors which might explain the observed shift of frequencies of the optical standards.

One possible reason for the observed frequency shift might be a time variation of the combination of constants in (1). Wolfe *et al.*[8] have found on the basis of astrophysical measurements that the change in a combination K of the same constants,

$$K = g_I \alpha^2 \frac{m_e}{m_p}, \qquad (2)$$

does not exceed 2×10^{-14}/yr. Expression (2) differs from (1) by a factor of $(m_e/m_p)^{1/2}$. If (2) is constant, the change in (1) might have been caused by a change in the ratio m_e/m_p.

We are preparing for a new measurement in about a year, to obtain more accurate and more reliable data. Over a year, the possible effect of a change in the frequency of the He–Ne/CH_4 lasers would be ~1 kHz according to the results which we found, and the error in the measurements will be lowered to ~50 Hz.

We now have at our disposal a unique instrument consisting of a cesium standard, laser standards, and a frequency-measurement apparatus for comparing their frequencies—all highly accurate. This instrument makes it possible to detect possible changes in the fundamental constants with a resolution of 1×10^{-12} under laboratory conditions.

We wish to thank S. N. Ovchinnikov for assistance in fabricating the transportable He–Ne/CH_4 standards, N. B. Koshelyaevskiĭ for assistance in equipping these standards with systems for automatic frequency control, A. N. Titov for furnishing the He–Ne laser stabilized on the basis of the E component of methane, and Yu. M. Malyshev and Yu. G. Rastorguev for assistance in making the comparisons of the transportable laser and the laser stabilized on the basis of the E component of methane.

[1]P. A. M. Dirac, Phys. Rev. Lett. **A165**, 199 (1938).
[2]R. H. Dicke, Quantum Electronics (C. H. Townes, ed.), Columbia Univ. Press, New York, 1960, p. 572.

[3]N. G. Basov and V. S. Letokhov, Usp. Fiz. Nauk **96**, 625 (1968).
[4]Yu. S. Domnin, N. B. Koshelyaevskiĭ, V. M. Tatarenkov, and P. S. Shumyatskiĭ, Pis'ma Zh. Eksp. Teor. Fiz. **34**, 175 (1981) [JETP Lett. **34**, 167 (1981)].
[5]Yu. S. Domnin, N. B. Koshelyaevskiĭ, V. M. Tatarenkov, P. S. Shumyatskiĭ, O. N. Kompanets, A. R. Kukudzhanov, V. S. Letokhov, and E. L. Mikhaĭlov, Pis'ma Zh. Eksp. Teor. Fiz. **30**, 269 (1979) [JETP Lett. **30**, 249 (1979)].
[6]Yu. S. Domnin, N. B. Koshelyaevskiĭ, Yu. M. Malyshev, Yu. G. Rastorguev, V. M. Tatarenkov, and A. N. Titov, Metrology in Radioelectronics. Proceeding of the Fifth All-Union Scientific Conference, VNIIF-TRI, Moscow, 1981.
[7]Yu. M. Malyshev, S. N. Ovchinnikov, Yu. G. Rastorguev, V. M. Tatarenkov, and A. N. Tutov, Kvantovaya Elektron. (Moscow) **7**, 655 (1980) [Sov. J. Quantum Electron. **10**, 376 (1980)].
[8]A. M. Wolfe, R. L. Brown, and M. S. Roberts, Phys. Rev. Lett. **37**, 179 (1976).

Translated by Dave Parsons