

Measurement of optical activity of bismuth vapor

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Results are presented of measurements of the angle of rotation of the polarization plane of laser light for five M1 transitions of the hyperfine splitting components of the 648 nm line of atomic bismuth, and seven control lines. The results of the measurements agree with the predictions based on the Weinberg–Salam model of neutral weak currents.

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In our preceding paper¹ reporting observation of parity nonconservation in atomic transitions, principal attention was paid to the proof of existence of optical activity of bismuth vapor. In the present communication we present new results of measurements in which, to decrease the uncertainties in the quantitative comparison of the observed effect with the predictions of theoretical calculations^{2,3} based on the Weinberg–Salam model, and also to reveal possible systematic errors, we effected partial changes in the setup and in the procedure of the measurements.

We used in the measurements the same frequency-modulation procedure as in Ref. 1. The frequency-modulated laser light passed through a cell filled with bismuth vapor and located between the polarizer and analyzer.

In the new measurements the polarizer and the analyzer (see Fig. 1) were simulta-

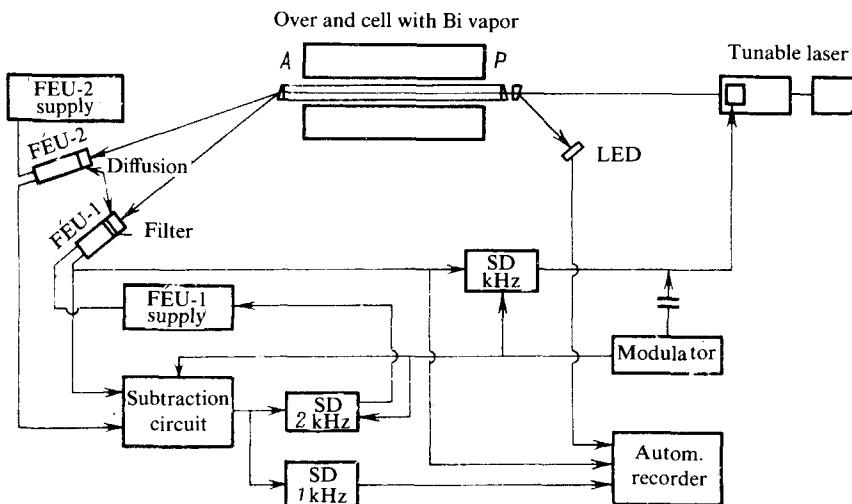


FIG. 1. Block diagram of setup.

neously the input and output windows of the cell, which was placed in a double magnetic screen. The analyzer splits the light beam into two beams with mutually

orthogonal polarizations, each of which was detected with a photomultiplier. Scanning the laser wavelength was accompanied by a synchronous rotation of the plane of polarization through an angle ψ due to the parity-nonconserving weak interaction of the electron with the nucleus. The voltage on photomultiplier FEU-1 was

$$V_1 = k_1 I_0 \cos^2(\theta_0 + \psi) \approx k_1 I_0,$$

and the voltage on photomultiplier FEU-2

$$V_2 = k_2 I_0 \sin^2(\theta_0 + \psi) \approx k_2 I_0 \theta_0^2 (1 + 2\psi/\theta_0),$$

where k_1 and k_2 are the coefficients of proportionality of the signals from the photomultiplier to the beam intensities, and θ_0 is the angle between the polarization axes of the analyzer and the polarizer and was set in the measurements in the range 10^{-3} – 10^{-2} rad. The measurements were made at a partial vapor pressure of the atomic bismuth on the order of 10 Torr, and the effective length of the cell was approximately 30 cm. These conditions corresponded to one or two absorption lengths for the hyperfine components of the 648-nm line. The scanning amplitude was chosen to be one to two Doppler line widths. In the case of symmetrical scanning of the laser wavelength relative to the center of the absorption line, the signal contains only even harmonics of the 1-kHz scanning frequency. This signal was synchronously detected by the first harmonic of the scanning frequency and was used in the feedback circuit to maintain the scanning symmetrical and to suppress the odd harmonics of the signal to a level

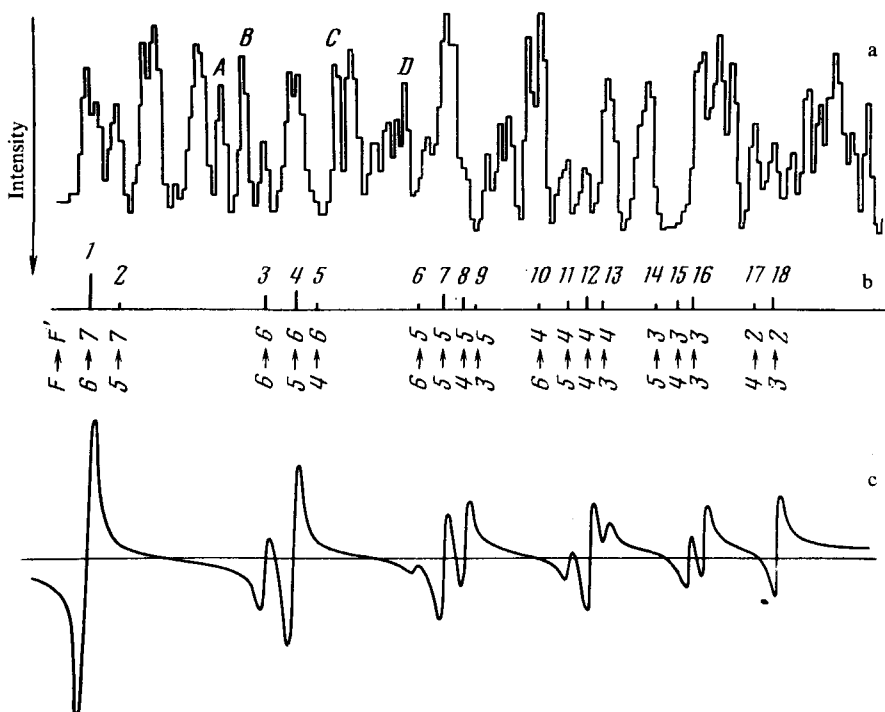


FIG. 2. a—Bismuth vapor absorption spectrum. b—position and relative intensity of the components of the hyperfine splitting of the 648-nm line of atomic bismuth, c—optical activity of bismuth vapor calculated by the Weinberg-Salam model.

$\sim 10^{-3}$. The signals V_1 and V_2 were equalized in magnitude and were subtracted to a level $\sim 10^{-3}$ by synchronous detection of the second harmonic in the difference signal in the feedback circuit that regulated the supply voltage of photomultiplier FEU-1. The difference signal $\Delta = V_2 - V_1 = 2k_2 I_0 \theta_0 \psi$ contains in this case the first harmonic of the scanning frequency only in the presence of the parity-nonconservation effect, which is proportional to the real part of the refractive index. The difference Δ of the synchronously detected signal at analyzer positions θ_0 and $-\theta_0$ served as a measure of the parity nonconservation. We note that in the preceding series of measurements¹ the polarizer was rotated.

The measurements were made on lines 1,2,3,7,10,12,17, and 18 of atomic bismuth and *A,B,C* and *D* of molecular bismuth [see Figs. 2(a) and 2(b)].

Since the bismuth nucleus has a spin 9/2, the hyperfine structure of the considered transition $^4S_{3/2} - ^2D_{3/2}$ should consist of 12 lines with $\Delta F = 0$ and $\Delta F = \pm 1$ (F is the total angular momentum of the atom) and 6 lines with $\Delta F = \pm 2$. The transitions with $\Delta F = 0$ and $\Delta F = \pm 1$ are of the magnetic-dipole type with electric quadrupole admixture, and it is in these that parity conservation should be observed. As for the

TABLE I. Results of measurements of the angle of rotation of the polarization plane in the working and control lines (in units of 10^{-8} rad).

Working lines:

Line	-	1 pass	2 pass	3 pass	Average
1	6 - 7	-6.8 + -3.1	-4.8 + -1.9	-3.7 + -2.5	-4.9 + -1.4
3	6 - 6	-1.9 + -0.8	-2.2 + -1.9	-	-1.9 + -0.7
7	5 - 5	-2.1 + -2.3	-6.3 + -4.9	-	-2.9 + -2.1
12	4 - 4	-7.2 + -2.1	-	-6.6 + -2.5	-6.9 + -1.6
18	3 - 2	-	-	-3.4 + -2.4	-3.4 + -2.4

Average over working lines

-3.1 + -0.5

Control lines

Line	-	pass	pass	pass	Average
2	5 - 7	-	3.5 + -1.6	3.8 + -3.9	3.5 + -1.5
<i>A</i>	-	3.4 + -3.4	0.8 + -1.9	-2.2 + -2.5	0.3 + -1.4
<i>B</i>	-	-	-1.6 + -1.4	-	-1.6 + -1.4
<i>C</i>	-	1.9 + -0.8	-	-	1.9 + -0.8
<i>D</i>	-	-	-	5.2 + -3.6	5.2 + -3.6
10	6 - 4	0.0 + -2.0	-	-	0.0 + -2.0
17	4 - 2	-	-3.5 + -2.4	-	-3.5 + -2.4

Average over control lines

1.0 + -0.5

electric quadrupole transitions with $\Delta F = \pm 2$, circular polarization is produced in them only by a magnetic quadrupole admixture and is therefore suppressed by an approximate factor $\alpha^2 \approx 10^{-4}$. Parity conservation on the molecular lines should also be suppressed. Since the Faraday rotation on the quadrupole transitions is not small, it was used in control experiments to monitor additionally the smallness of the magnetic field in the cell with the bismuth vapor.

A winding consisting of six sections was placed inside the magnetic screen. Measurements of the Faraday rotation with the current flowing alternately in each section made it possible to measure the effective length of the region occupied by the bismuth vapor. For an overall control of the parity nonconservation effect in the measurements process, a magnetic field was turned on at the start and end of the measurement on each line. The system in this case measured the odd part of the Faraday rotation.

To decrease the systematic error due to the inhomogeneity of the photocathodes and to the presence of modulation, in synchronism with the scanning frequency, of the spatial structure of the laser beam, special light diffusors were placed in front of the photocathode and ensured constancy of the measured signal even in the case of appreciable displacements of the photomultipliers.

Altogether there were three runs of measurements of the optical activity on five magnetic dipole, three quadrupole, and four molecular transitions with a net measurement time of approximately 30 hours. The last seven lines were used as a control. For each line we measured the average difference Δ between the values of the fundamental of the signal at the angles θ_0 and $-\theta_0$, and in the course of the measurements the sign of the angle was reversed 20 times in each pass for each line. The measurement error was determined from the deviations of the individual measurements from the mean values.

The rotation angle $\overline{\psi_{\text{exp}}}$ was $(-3.1 \pm 0.5) \times 10^{-8}$ rad averaged over the five working lines and $(1.0 \pm 0.5) \times 10^{-8}$ rad for the seven control lines. The ratio of the measured polarization-plane rotation angles to those calculated, assuming validity of the Weinberg-Salam theory at a Weinberg angle corresponding to $\sin^2 \theta_w = 0.25$ was $\overline{\psi_{\text{exp}}/\psi_{B-C}} = 1.1 \pm 0.3$ for the working lines. The averaged expected rotation angles for the control lines was 0.2×10^{-8} rad.

As seen from the foregoing data, the results agree with predictions based on the Weinberg-Salam model and disagree greatly with the measurement results obtained in Oxford⁴ and Seattle.⁵

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