Investigation of the optical activity of Bi vapors

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The results of an experiment on the search for nonconservation of parity in a Bi atom in the magnetic transition $6p^3\,{}^4S_{3/2}$–$6p^3\,{}^2D_{5/2}$, $\lambda = 648$ nm are reported. The expected theoretical effect was not observed in the experiment.

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In this paper we report the results of an experiment on the search for optical activity of Bi vapor, which is caused by parity nonconserving (PNC) weak interaction of atomic electrons with the nucleus (this effect was predicted by the Weinberg–Salam model for weak interactions; henceforth, we call it the PNC effect—see, for example, Refs. 1–3. We investigated the same magnetic dipole transition $\lambda = 648$ nm, $6p^3\,{}^4S_{3/2} - 6p^3\,{}^2D_{5/2}$ as that in Refs. 4, 5, and 6. The fine-structure component $F = 6$–$F = 7$ was used for the measurements. The calculated absorption spectrum—for the components 6–7 and 5–7 (quadrupole transition) and the calculated curves for the Faraday rotaton $\phi_F(\omega)$ and for the predicted effect $\phi_{\rm PNC}(\omega)$ are shown in Fig. 1(a). The normalization of $\phi_F(\omega)$ and $\phi_{\rm PNC}(\omega)$ corresponds to the following values of the characteristic parameters: magnetic field $H = 1.55 \times 10^{-4}$ G, optical thickness at the absorption peak $\kappa L = 1$, and $R = {\rm Im}(E_1/M_1) = -18 \times 10^{-8}$ cm.[7-10] Here E_1 is the matrix element of the electric dipole produced as a result of the PNC effect and M_1 is the matrix element of the magnetic dipole.

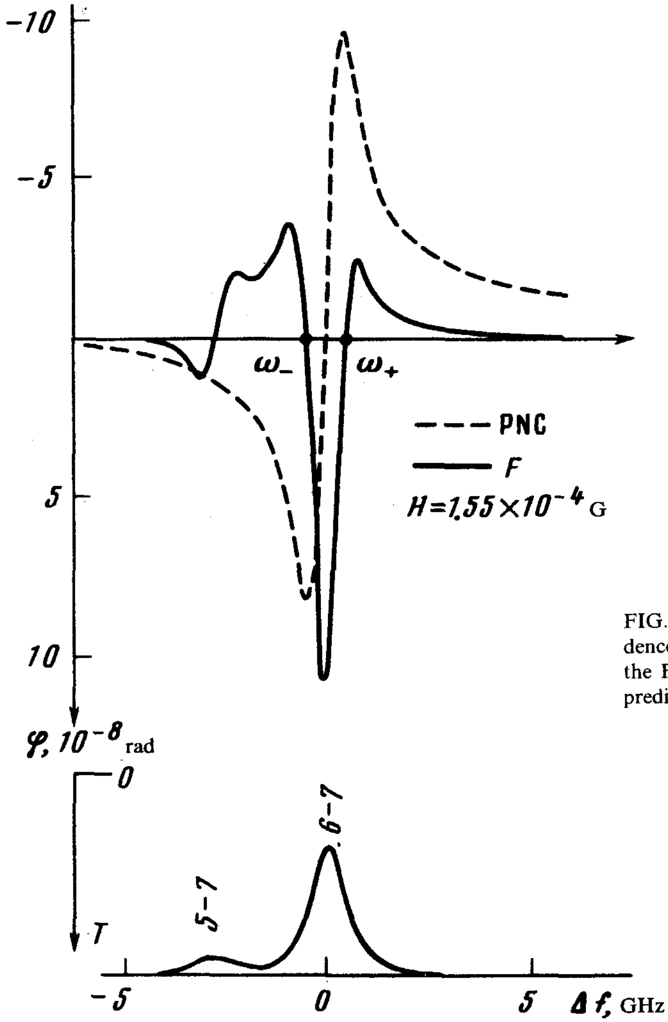

FIG. 1(a). Calculated spectral dependences of the transmission (below), of the Faraday rotation ϕ_F, and of the predicted effect ϕ_{PNC}.

For the given values of κL and R we expect the angular difference $\phi_{\text{PNC}} = -\kappa LR\,[\text{Re}(\epsilon - 1)/\text{Im}\epsilon]$, where $\epsilon(\omega)$ is the dielectric constant at the maximum and minimum points of the $\phi_{\text{PNC}}(\omega)$ curve, i.e., at the ω_- and ω_+ points in Fig. 1(a) it is $\Delta\phi_{\text{PNC}} \approx 18 \times 10^{-8}$ rad.

Figure 1(b) shows traces of the absorption spectrum (molecular bismuth lines are superimposed on the atomic spectrum) and of the Faraday rotation $\phi_F(\omega)$ in the field $H = 2.7 \times 10^{-2}$ G.

The experimental setup is shown schematically in Fig. 2. A single-frequency dye laser, a polarimeter, and a furnace with bismuth vapor are the main components of its optical part. In the measurements we used the zero-modulation method which is insensitive to the intensity variations of the laser beam. Detailed investigations of possible systematic errors of the system showed that the variation of the intensity distribu-

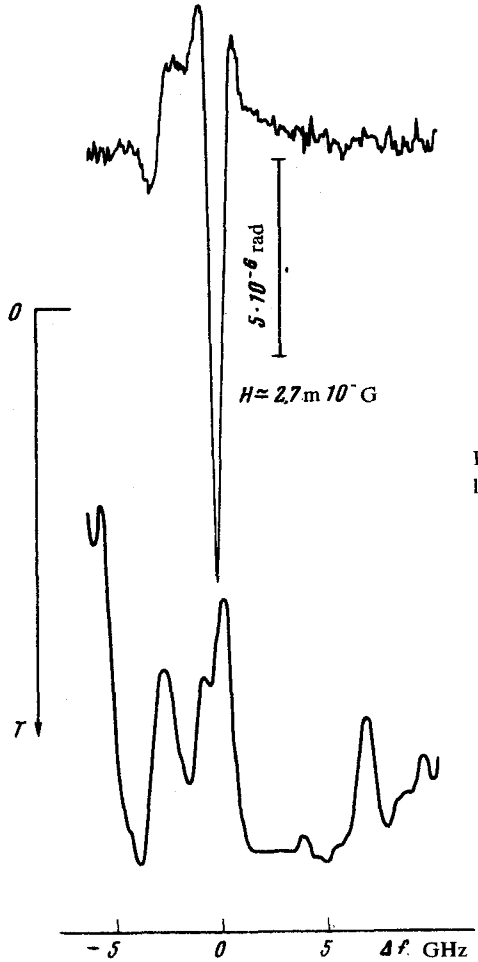

FIG. 1(b). Trace of the transmission spectrum (below) and of the Faraday rotation of bismuth vapor.

tion in the light beam due to scanning of the laser frequency and interference of the main beam with the scattered light (reflections, bright spots, scattering by the defects of the optical elements) represent the greatest danger. Both these effects can account for an additional contribution to ϕ of the same scale (several units per 10^{-7} rad) as that of the sought-for ϕ_{PNC} effect with the same type of frequency dependence as that of $\phi_{\text{PNC}}(\omega)$. The following measures were taken to reduce these errors. We placed a single-mode light pipe between the laser and the polarimeter for a stable distribution of the intensity at the exit, irrespective of the distribution of the intensity in the laser beam. The beam power in the polarimeter in this case was 0.6 mW. The surfaces of the optical elements in the measuring part of the system were clarified for the wavelength $\lambda = 648$ nm and canted in such a way as to eliminate all pairs of parallel surfaces. In addition, the polarizer and analyzer were mounted on piezoelectric ceramics, which enabled us to modulate the length of the polarimeter and to control the interference effects in it. The modulator was inserted into Hz thermostat, which enabled us either

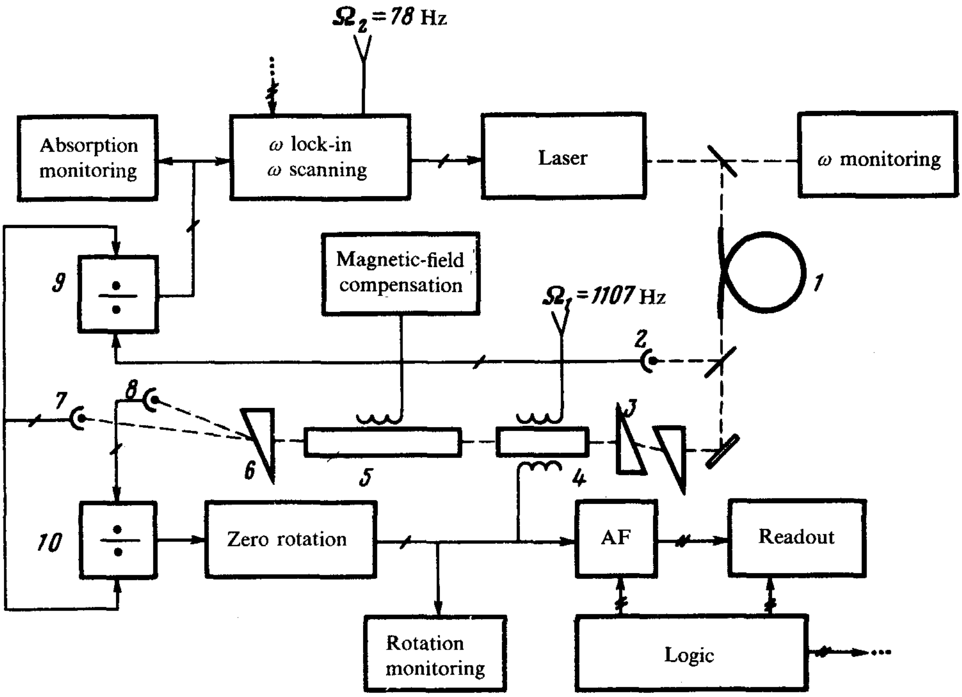

FIG. 2. Functional block diagram of the spectropolarimeter: 1, light pipe; 2, reference photodiode of the absorption channel; 3 and 6, crystal polarizer and analyzer; 4, Faraday cell; 5, furnace with bismuth vapor; 7 and 8, reference photodiode and PM of the rotation channel; 9 and 10, analog dividers.

to stabilize its length accurately or, conversely, to modulate it through the temperature expansion.

The measurements were conducted in the following way. In a relatively large magnetic field $H \approx 0.1$ G, when the Faraday rotation $\phi_F \gg \phi_{\rm PNC}$, we recorded the $\phi_F(\omega)$ curve and determined the ω_+ and ω_- points for which the rotation remains constant when the sign of the field changes—the zero points of the $\phi_F(\omega)$ function in Fig. 1(a). The ω_+ and ω_- points coincide with the minimum and the maximum of the $\phi_{\rm PNC}(\omega)$ curve. Under the conditions of the experiment $|\omega_+ - \omega_-| = 1.0$ GHz. Thus, the net magnetic field reached $H \sim 10^{-4}$ G when $\phi_F \sim \phi_{\rm PNC}$ and the rotation ϕ was measured at the ω_+ and ω_- points and at the absorption maximum ω_0. One cycle of measurements was performed in the following order. The laser was tuned to the ω_0 frequency and the rotation signal was stored for the time $T/2$; the laser frequency was then tuned to the ω_- point, the signal was stored for the time T, and then it was tuned again to the point ω_0, the signal was stored for the time $T/2$ and, finally, the signal was stored for the time T at the ω_+ point; $T = 5$ sec. This procedure was repeated 50 times automatically—one series consisted of 50 cycles and the total time was 30 min. The differences $(\phi_0 - \phi_+)$ and $(\phi_0 - \phi_-)$ were printed out for each cycle, from which the difference $\phi_- - \phi_+$ was determined, i.e., the sought-for $\Delta\phi_{\rm PNC}$ effect. In all, six series of measurements were performed. To monitor the instruments these measurements were

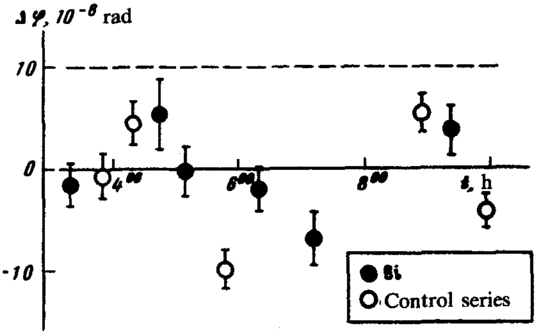

FIG. 3. Results of measurements of $\Delta\phi_{\mathrm{PNC}}$ for individual series. The doubled standard deviation for the average $\Delta\phi_{\mathrm{PNC}}$ is represented by the vertical sections.

ed with the control series of measurements (50 cycles each); at a lowered temperature of the furnace the absorption at the maximum $[1-\exp(-\kappa L)]$ decreased by a factor of 8–10. The furnace design made it possible to go from one mode to another in several minutes. The value of κL was determined from the absorption and from the Faraday rotation in a sufficiently large and hence accurately determined magnetic field. The experiment was performed at $\kappa L = 0.55 \pm 0.05$. After five main series of measurements, we checked the value of κL according to the Faraday rotation, and also the accuracy with which the laser frequency followed the ω_- and ω_+ points.

We obtained the following results. The averaging over all six main measurement series (300 cycles) gives

$$\Delta\phi_{\mathrm{PNC}} = \phi_- - \phi_+ = (-0{,}22 \pm 1{,}0)\times 10^{-8}\ \mathrm{rad}. \tag{1}$$

For each series in units of 10^{-8} rad,

$$\Delta\phi_{\mathrm{PNC}} = (-1{,}52 \pm 2{,}1);\quad (+5{,}41 \pm 3{,}5);\quad (-0{,}16 \pm 2{,}4);\quad (-1{,}96 \pm 2);$$
$$(-6{,}76 \pm 2{,}6);\quad (+3{,}70 \pm 2{,}4) \tag{2}$$

For the five control series (241 cycles at a reduced temperature),

$$\Delta\phi'_{\mathrm{PNC}} = (-1{,}19 \pm 1)\times 10^{-8}\ \mathrm{rad}. \tag{3}$$

The results of all these measurements are shown in Fig. 3.

According to Eq. (1), the spread $\Delta\phi_{\mathrm{PNC}}$ for the individual series, which substantially exceeds the rms error in Eq. (1), apparently characterizes the time-dependent instrumental errors.

Under the conditions of the experiment $\kappa L = 0.55$. Therefore, for the value $R = -18\times 10^{-8}$ indicated above, the predicted theoretical value of the PNC effect, which is slightly smaller than that in Fig. 1(a), is $\Delta\phi_{\mathrm{PNC}} = 10^{-7}$ rad.

As can be seen, the expected effect was not observed in the performed measurements. This is consistent with the results of the initial studies of the optical activity of Bi vapor[4,11] and is inconsistent with the results of Refs. 5 and 6, in which the effect predicted by the theory was observed.

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1)It should be noted that the authors of Refs. 4 and 11 do not assume that all possible systematic errors were eliminated.

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