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PARITY VIOLATION IN ATOMIC BISMUTH

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PARITY VIOLATION IN ATOMIC BISMUTH

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The results of the new run of measurements of the parity violation in atomic bismuth on ${}^4S_{3/2} - {}^2D_{5/2}$ MI-transition at λ = 648 nm are presented. The value $R = Im(E1/M1)$ measured on $F = 6 \rightarrow F' = 7$ and $F = 6 \rightarrow F' = 6$ hyperfine structure components is found to be $(-20.6 \pm 3.2) \cdot 10^{-8}$. The average value for all our measurements $\langle R \rangle = (-20.2 \pm 2.7) \cdot 10^{-8}$ is in agreement with the theoretical prediction obtained in the framework of the standard gauge model with $\sin^2\theta = 0.25$.

In the previous works[1,2] we reported the observation of the parity nonconservation in atomic transitions caused by the weak interaction of electrons with nucleons. In those experiments the rotation of the polarization plane of light at λ = 648 nm in bismuth vapor was observed. The results of our experiments were consistent with the theoretical predictions[3], based on the standard gauge model[4,5], and were in contradiction with null results of the experiments in Seattle[6,7] and Oxford[8].

As it was noted for the first time by Zel'dovich[9], the parity violation in the interaction of the electrons and nucleons should induce natural optical activity of the matter. The possibility to find the optical activity in atoms in real experiments was shown in the works[10-12], in which it was proposed to search for the optical activity in MI - transitions of some heavy atoms.

In Fig. 1 the scheme of the low lying atomic bismuth levels are shown. Because of the small admixture of states of opposite parity to the wave functions, the amplitude of an MI transition acquires a small admixture of an EI amplitude. As a result the interaction of right- and leftpolarized photons will be unequal and the optical activity arises. The angle of rotation of the polarization plane due to the parity nonconserving interaction between the electrons and nucleons is equal to

$$\psi_{PNC} = -4\pi(n-1)\ell R/\lambda ,$$

where n is the refraction index due to the MI transition, ℓ is the effective length of bismuth vapor, $R = Im(EI/MI)$

is the imaginary part of EI to MI amplitudes ration and λ is the wave length of the light.

In this paper the results of the new run of measurements of the optical activity in bismuth vapor at the $F=6 \rightarrow F'=7$ and $F=6 \rightarrow F'=6$ hyperfine structure components of the MI - - transition $^4S_{3/2} - {}^2D_{5/2}$ at λ = 648 nm are presented.

The scheme of the experiment is shown in Fig. 2. A Spectra-Physics 375 dye laser with an additional element, which permitted to have a single-frequency light beam and to modulate this frequency by 416.3 MHz steps was used. The frequency modulated light passed through the prism polarizer, the bismuth-vapor cell and the prism analyzer, after which space separated beams with orthogonal polarization were detected by photomultipliers. The bismuth cell was situated inside double magnetic shield so that the spurious magnetic field along the cell axis was smaller than $2 \cdot 10^{-5}$Gs. Inside the magnetic shields seven sections of the coil were placed. These coils were used to measure the Faraday rotation during the experiment for normalization of the effect and for measuring of Faraday rotation curve (see below). Moreover, the Faraday rotation from each section of the coil permitted to find out the atomic bismuth vapor pressure distribution along the cell axis. The helium buffer gas stabilized the bismuth vapor pressure and ensured the safety of the analyzer and polarizer prisms, which were used as the entrance and exit windows of the cell. The design of the support of the analyzer and the photomultipliers allowed to rotate them about initial direction of the light beam without change of the deflected beam position relative to

the multipliers. In front of the photomultipliers the cavities covered inside with white paint were placed, which ensured diffused scattering of the light before hitting the photocathodes.

The signals from the photomultipliers PMTI and PMT2 are

$$V_1 \sim I \cos^2(\theta + \psi_{PNC}) \simeq I,$$
$$V_2 \sim I \sin^2(\theta + \psi_{PNC}) \simeq I\theta^2(1 + 2\psi_{PNC}/\theta),$$

where I is the intensity of the light passed through the bismuth vapor, $\theta = \pm 4 \cdot 10^{-3}$rad is the angle between the axes of the analyzer and polarizer, ψ_{PNC} is the angle of rotation of the polarization plane due to the parity nonconserving interaction between the electrons and nucleons. As its wavelength dependence has dispersion curve shape (see Fig. 3a), during wavelength modulation near the absorption line centre ψ_{PNC} must contain the first harmonic of the scanning frequency, which in the experiment was 1 kHz. To minimize the false 1 kHz signal, two feedback circuits were used (see Fig. 2), one of which provided the symmetry of scanning position so that the signal of the first harmonic from PMT1 was more than 10^3 times suppressed. Another 2 kHz feedback circuit regulated the high voltage supply of PMT1 to provide good quality substraction of the signals from photomultipliers so that the subtracted signal had the second harmonic amplitude 10^3 times smaller than that from PMT2. Preliminarily the signals from PMT1 and PMT2 were levelled with the help of a grey filter installed before the photocathode of PMT1 and by the choice of the high voltage supply of the photomultipliers. In these conditions the subtracted signal $\Delta = V_2 - V_1 \sim I\theta\psi_{PNC}$ must contain the first harmonic of the scanning frequency only through ψ_{PNC}. It does exist if the parity is not conserved in the electron--nucleon interaction. The difference of the phase detected signals in Δ, found for $+\theta$ and $-\theta$ positions of the analyzer, served as the measure of the parity violation.

In these experiments were done on transitions $F \to F'$: $6 \to 7$, $5 \to 7$, $6 \to 6$ and on molecular line A as it shown on Fig. 3. The measurements on the quadrupole transition $F=5 \to F'=7$ and on the molecular absorption line A permitted to control the spurious magnetic field and systematic errors. During the experiment the measurements were performed alternatively on the working and control lines. Each measurement continued 30 minutes. During that time the sign of θ changed 20 times. On the $6 \to 7$, $5 \to 7$ and A lines 26 measurements were done, and only 13 on the line $6 \to 6$. At the end of each measurement the magnetic field was switched on and $d\psi_F/d\lambda$ was measured (ψ_F is the Faraday rotation angle), which was used subsequently for normalization of measured value of $d\psi_{PNC}/d\lambda$). The information about intensity of the light beam before and after the bismuth oven, about the shape of the absorption line and the value of the first harmonic of the subtracted signal was accumulated and processed with the help of the computer M-6000.

In Fig. 3a the results of the Faraday rotation measurements and the theoretical curve, calculated for null collisional broadening and the value of radial quadrupole integral $\langle r^2 \rangle = 9a_0^2$, where a_0 is a Bohr radius of hydrogen atom, are shown. Also shown in the figure is the dependence of ψ_{PNC} on λ. The theoretical curves were found on the basis of

works /3,13/ where the amplitude of MI-transition was taken/14/ to be equal to $-0{,}55\,\mu$Bohr with $\pm 2\%$ estimated error instead of the usually used value $-0{,}584\,\mu$Bohr. More precise value of R, calculated by the Novosibirsk group of theorists, was found to be $R_{theor} = -18{,}8 \cdot 10^{-8}$ for $\sin^2\theta = 0.25$. The Faraday rotation measurements were carried out in separate experiment in which a Faraday cell was placed additionally between the polarizer and the bismuth cell, and 2 Gs magnetic field was applied along the bismuth vapor cell axis. In these measurements the wavelength was scanned at 0.01 Hz frequency and at the same time the polarization plane of the laser light was modulated at 1 kHz with the help of the Faraday cell. The optical length of the atomic bismuth vapor, which was found from comparison of measured and calculated Faraday rotation, within several percent accuracy coincides with that found from measurements of the atomic bismuth vapor density distribution along the cell axis, known total pressure in the bismuth vapor cell and the partial atomic bismuth pressure taken from/15/.

The value of $d\psi_{PNC}/d\lambda$ measured on the lines $6 \to 7$, $5 \to 7$, $6 \to 6$ and A and the calculated curve $d\psi_{PNC}/d\lambda$ are presented in Fig. 3c. The results obtained on the lines $6 \to 7$ and $6 \to 6$ correspond to the value

$$R_{exp} = (-20.6 \pm 3.3) \cdot 10^{-8},$$

and the measurements on the control lines $5 \to 7$ and A show zero effect. Together with the previous results of the work/2/ we get average value for all our measurements

$$R_{exp} = (-20.2 \pm 2.7) \cdot 10^{-8}$$

and in comparison with the theoretical prediction

$$R_{exp}/R_{theor} = 1.07 \pm 0.14$$

The latest unpublished results from Oxford/16/ and Seattle/17/ show parity violation effect in atomic bismuth. However, the results of their new experiments have too poor reproducibility to make a definite conclusion about its value. The method of measurements of small angle rotation of the plane of polarization used in our experiments possesses a series of advantages. The main of them consists in the large number of measurements on different control lines. Before each run of measurements durable work on the control lines for search, artificial enlargement and then suppression of false effects had been done. Durable work on the control lines, as we are sure, allowed us to expose possible systematic errors and to get rid of them.

The result of Berkeley experiment/18/ for a measurement of the circular dichroism in the forbidden MI-transition at λ = 293 nm in thallium also shows the parity violation in atoms, however with large statistical uncertainty.

Recently some people declared doubt about the reliability of atomic calculations for such heavy atoms like bismuth/19/. From our point of view the most reliable predictions for PNC effects in heavy atoms were made by the Novosibirsk group of theorists, who succeeded in noncontradictory way to calculate a great number of known experimental atomic characteristics, using for this the theoretical scheme with a few number of phenomenological parameters. The calculations, performed recently by this group/14/, gave the value of the effect differing only by 6% from that found in 1976/3/. All this gives us confidence that the accuracy of their calculations, estimated by the authors as 15-20%, is true.

As is known/20/, in the atomic experiments and in the experiment at Stanford/21/, where the deep inelastic scattering of polarized electrons by deutrons and protons was investigated, two independent linear axial and vector constants of the weak interaction can be measured. Thus, the results of our and Stanford experiments indicate the validity of the Weinberg-Salam model.

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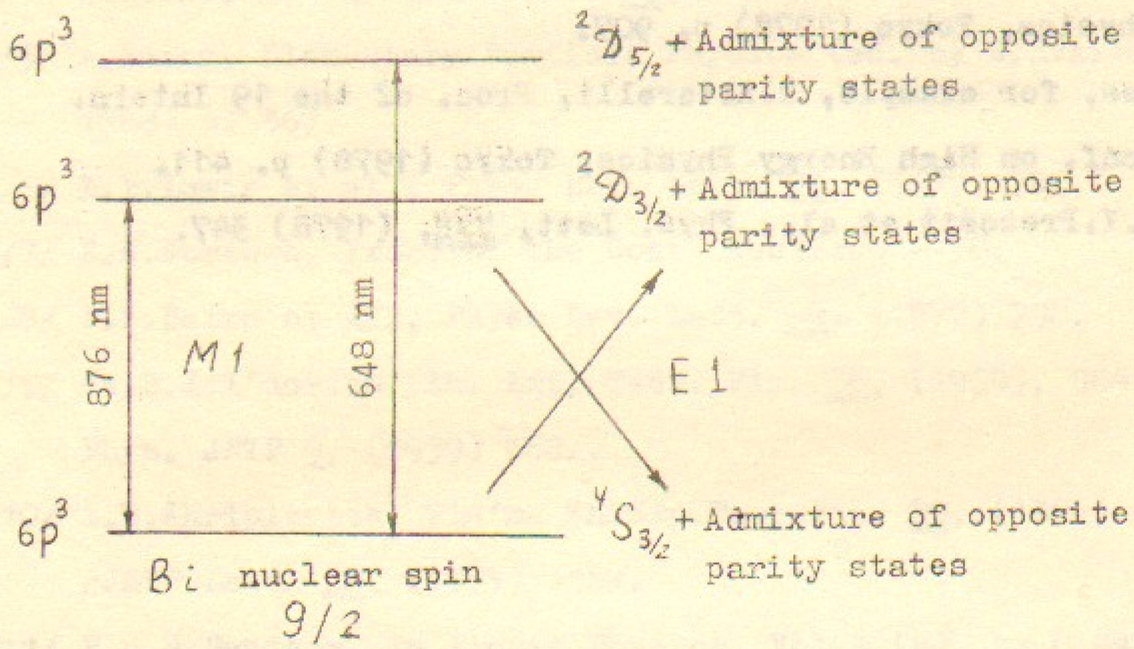

Fig. 1. Low lying atomic bismuth levels.

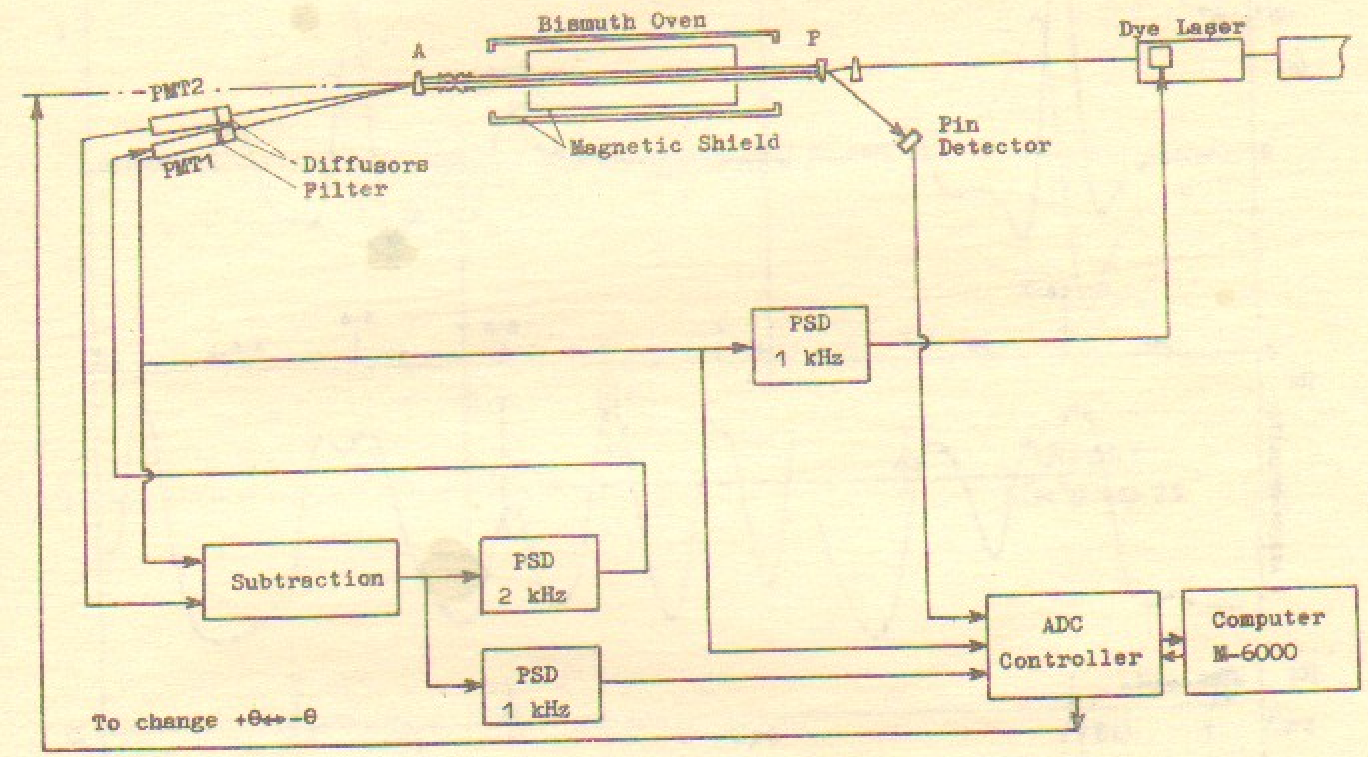

Fig. 2. The scheme of the experiment. P-prism polarizer, A-prism analyzer, PMTI and PMT2-photomultipliers, PSD-phase-sensitive detectors, ADC-analog-digital converter.

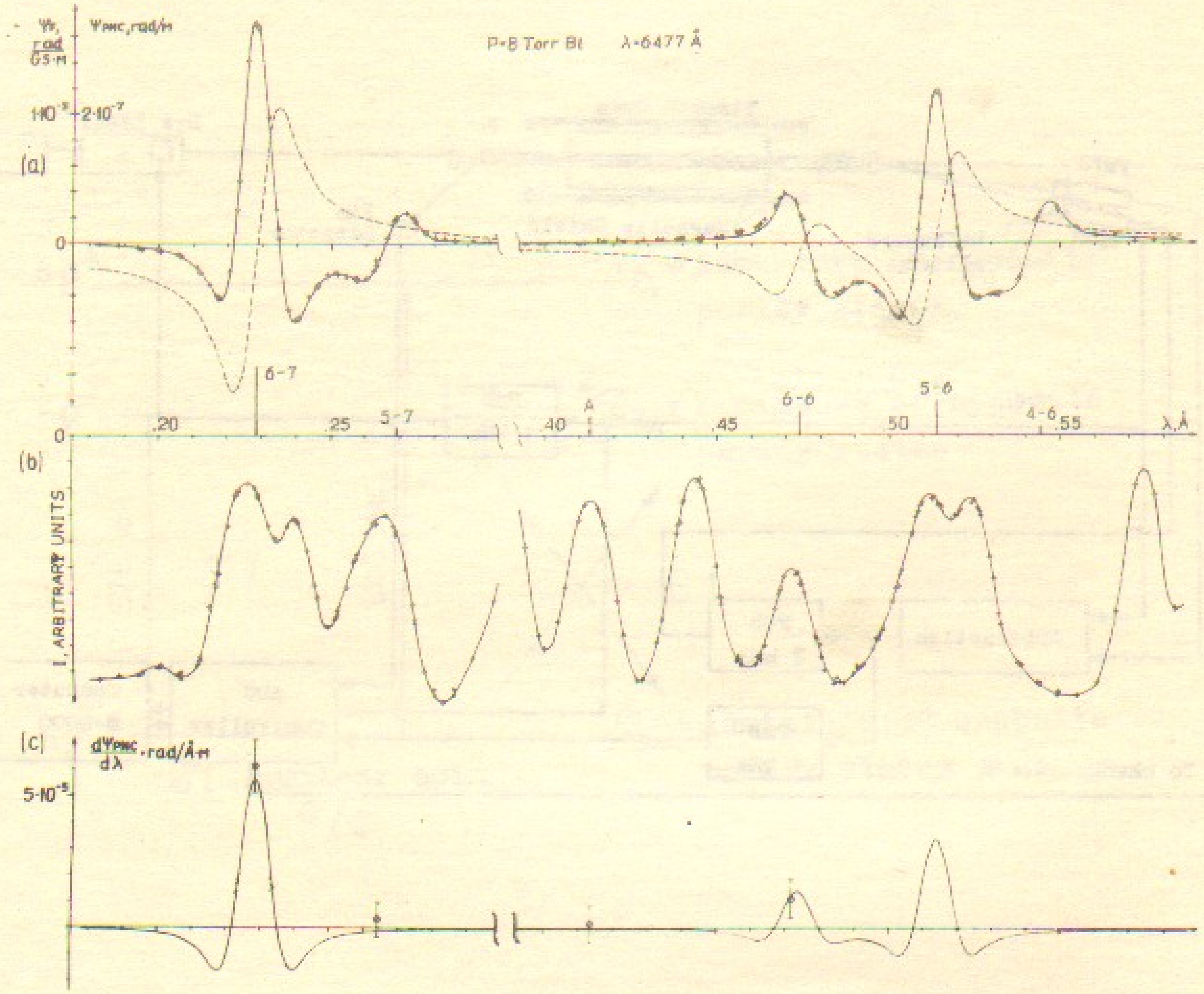

Fig. 3. a - Dashed line - the theoretical prediction for PNC optical rotation of bismuth vapor, solid line/3/. the calculated Faraday rotation; b - observed absorption spectrum; c - the calculated curve and the results of the measurements.

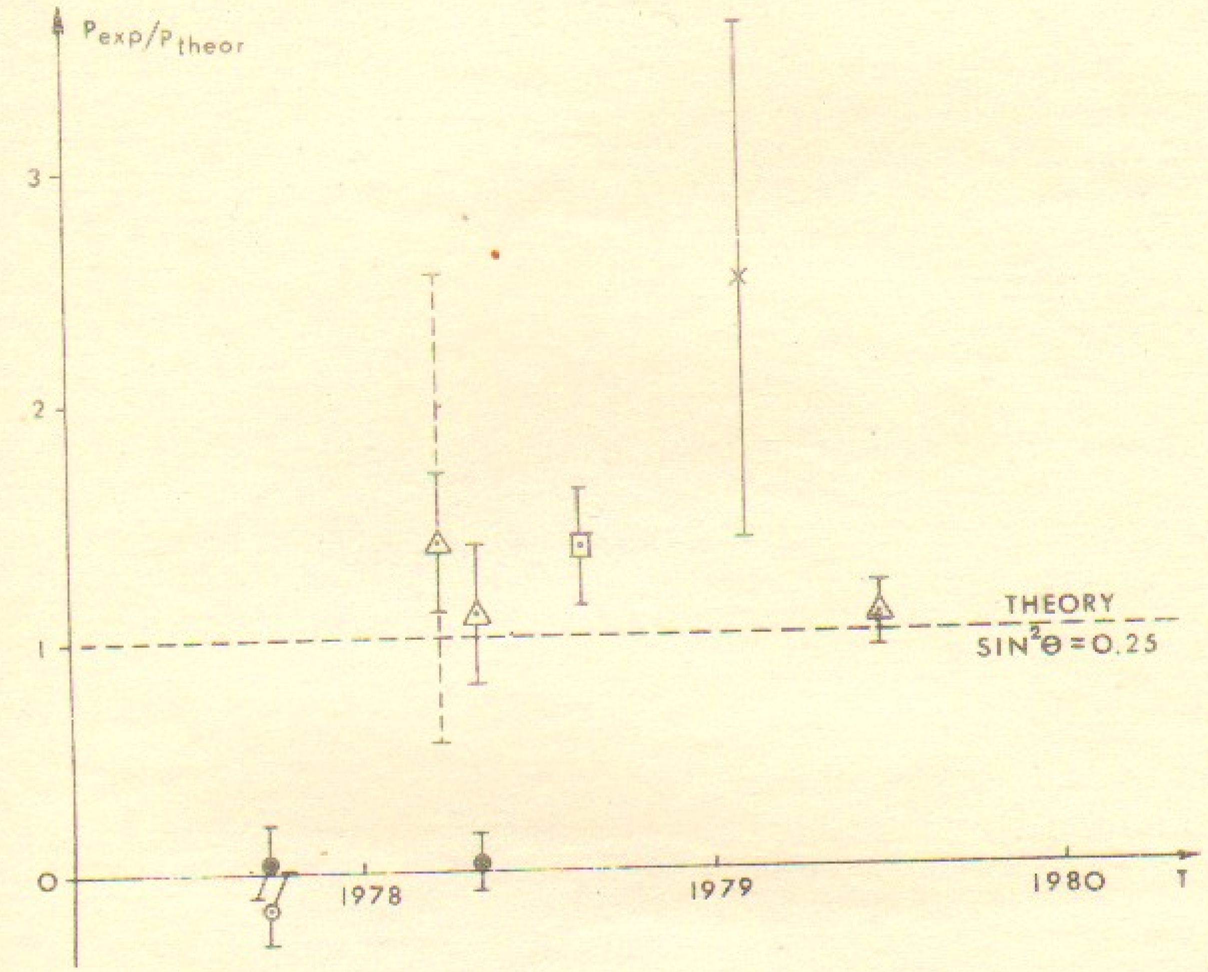

Fig. 4. Chronological sequence of the results of measurements PNC interaction of electrons and nucleons. P- parity nonconservation parameter, P_{theor}- predicted value in Weinberg-Salam model with $\sin^2\theta$ = = 0.25 ● - Seattle[6,7], ⊙ - Oxford[8], △ - Novosibirsk[1,2], ⊡ - Stanford[21], X - Berkeley[18].