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POSSIBILITY TO OBSERVE PARITY VIOLATION IN ATOMIC TRANSITIONS

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POSSIBILITY TO OBSERVE PARITY VIOLATION IN ATOMIC TRANSITIONS

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The possibility to detect parity violation in atomic transitions by the rotation of light polarization plane in heavy metals vapours is discussed. The rotation angle may reach 10^{-5} rad/m at the pressure 100 mm.

The possibility to detect in principle weak interaction of electron with proton and neutron by means of observation of parity violation in atomic transitions was pointed at many years ago by Ya.B.Zel'dovich/1/ and since then was discussed repeatedly by theorists/2-5/ (see also /6-9/). Among these papers one should note specially the work by Bouchiat/3/. They have shown that the effects of parity violation in heavy atoms are enhanced to such degree that their experimental detection is on the edge of possibility. However, the concrete estimate of the degree of circular polarization of the photons in the $6s_{1/2}-7s_{1/2}$ transition in cesium presented in the work/3/ is perhaps overrated (see /5/). Therefore, the corresponding experiment seems to be more difficult than it follows from the estimates by Bouchiat.

In the present note I wish to attract attention to sufficiently real possibility to detect parity violation in atomic transitions by rotation of polarization plane of light in vapours of heavy metals. That parity violation leads to the appearance of optical activity, was first noted in the paper/1/.

The refraction coefficients for right and left polarized photons with the frequency ω close to the resonant one ω_0 write as follows

$$n_{\pm} = 1 + \frac{N\overline{|V_{\pm}|^2}}{\hbar^2\omega}\left\langle \frac{1}{\omega-\omega_0-\frac{v}{c}\omega_0+i\Gamma/2} \right\rangle \qquad (1)$$

Here N is the density of the atoms of the medium, Γ is the width of the excited level, $\overline{|V_{\pm}|^2}$ are the squares of the absorbtion matrix elements for right and left polarized photons averaged over initial polarizations and summed over intermediate polarizations of the atoms. The brackets $\langle\ldots\rangle$ denote averaging over the velocities v of the atoms.

If parity is not conserved, the matrix elements $V_{\pm}$ are distinct and may be presented as

$$V_{\pm} = V \pm \frac{\xi}{2} V_1 \qquad (2)$$

where ξ is a dimensionless small parameter and V_1 is an admixture matrix element of "wrong" parity. The angle of polarization plane rotation is equal to

$$\psi = \frac{1}{2}\frac{\omega}{c} l\, Re(n_+ - n_-) \simeq \frac{1}{2} N l \xi \frac{\overline{V^* V_1} + \overline{V V_1^*}}{\hbar^2 c} \left\langle \frac{\omega - \omega_0 - \frac{v}{c}\omega_0}{(\omega - \omega_0 - \frac{v}{c}\omega_0)^2 + \Gamma^2/4} \right\rangle \qquad (3)$$

where l is the length of the path. If the principal transition with a matrix element V is an allowed one, then the absorbtion coefficient α defined by the relation

$$\alpha = -2\frac{\omega}{c} Im\, n_{\pm} \simeq 2 \frac{N\overline{|V|^2}}{\hbar^2 c} \left\langle \frac{\Gamma/2}{(\omega - \omega_0 - \frac{v}{c}\omega_0)^2 + \Gamma^2/4} \right\rangle \qquad (4)$$

is very large. And since the path length l cannot exceed essentially α^{-1}, the accessible rotation angle ψ is then extremely small.

Therefore it is natural to turn to the case when the principal transition is M1 and correspondingly the admixture one is E1. As it is known, M1 transition proceeds (without additional suppression) only between the components of fine structure. For the observation of a small rotation angle the transition is desirable to lie in the visible part of spectrum or near it. This situation takes place for heavy metals: antimony, thallium, lead and bismuth.

For the angle ψ to be not too small, the detune $\Delta = \omega - \omega_0$ should be comparable with the Doppler width Δ_D ($\Delta_D \gg \Gamma$ is assumed). Since ψ is an odd function of Δ, it is clear that both the frequency stability and the line width of the source should be at any rate comparable with $\Delta_D \simeq 10^{-6}\omega_0$. Then both hyperfine structure and isotopic shift of a line are resolved.

Assume that parity is violated in the interaction of electron with nucleon. Being interested in the summary contribution to the effect from all the nucleons of the nucleus, average the weak interaction Hamiltonian over nucleon spin. In result the P-odd interaction of electron with nucleus looks in non-relativistic approximation as follows

$$H = -\frac{G\hbar^3}{\sqrt{2}c^2} Z q \frac{1}{2m}\left[(\vec{6p})\delta(\vec{r}) + \delta(\vec{r})(\vec{6p})\right] \qquad (5)$$

Here $G = 10^{-5} m_p^{-2}$ is the Fermi constant; m, $\vec{\sigma}/2$, $\vec{p}$ and $\vec{r}$ are the mass, spin, momentum and coordinate of electron. The quantity q depends on the concrete variant of theory. Use for definiteness the Weinberg model/10/. In it

$$q = 1 - \frac{A}{2Z} - 2\sin^2\theta \qquad (6)$$

where A is the atomic weight of the element, θ is the mixing angle that is the parameter of the model; take for computations $\sin^2\theta = 0.32$. Evidently, the Hamiltonian (5) leads to the mixing of $s_{1/2}$ and $p_{1/2}$ states only.

Consider the transition $6p_{1/2}$-$6p_{3/2}$ in thallium which lies in the near infrared region (λ =12833Å). This transition may proceed also as an electric quadrupole one. However, as simple estimates show, the matrix element of E2 transition is sufficiently small to neglect below this circumstance.

The admixture of the states of the type $6s^2 ns_{1/2}$ (n=7,8...) to the ground state $6s^2 6p_{1/2}$ is computed comparatively simply (see /3/). Taking into account relativistic effects leads for thallium to the correction factor equal to 8.8. To find the amplitudes of E1 transitions the experimental data on thallium oscillator strengths/11/ are used. The signs of these amplitudes are determined with the help of Bates-Damgaard tables/12/. The contribution of the states with n≥9 and perhaps of the continuous spectrum by itself is small. The polarization plane rotation for the transition F=1→F=2 in Tl^{205} found in this way constitutes 10^{-5} rad/m at the pressure 100 mm (which corresponds to the temperature 1196°C) and the detune $\Delta = 2.4\Delta_D$. The absorbtion coefficient α is equal then to 100 cm^{-1}.

This result for ψ is valid only by order of magnitude. The point is that here the contribution of the configurations $6s6p^2$ was not taken into account. Accurate calculation of this contribution constitutes considerable difficulties and still is not carried out. Meanwhile, one of these configurations $6s6p^2\ {}^2D_{3/2}$ almost certainly makes large contribution to the effect under discussion*). One may expect however that taking

*) Note that for cesium also the contribution of the configurations $5p^5 6s^2$ not accounted for in the work/3/ perhaps is essential.

into account of the mentioned states does not change the order of magnitude of the effect.

The polarization plane rotation will be approximately the same in the lead vapour (λ=12789Å) and the bismuth one (λ=8757Å, 6478Å, 4617Å, 3015Å). The effect by an order of magnitude smaller (due to smaller Z) should be expected in the antimony vapour (λ=11748Å, 10148Å, 6099Å, 5416Å).

The observation of the polarization plane rotation at the level 10^{-5} rad is by itself quite real. At any rate the most part of the visible diapason and the interval 8200÷8900A as well are overlapped by the existing tunable lasers with the needed characteristics. The serious problem is the elimination of a magnetic field that also leads to the rotation of polarization plane. To imitate the effect at the level 10^{-5} rad/m the mean longitudinal magnetic field 10^{-5}÷10^{-4} gs is sufficient. For most transitions the principal mechanism of imitation is the difference of resonant frequencies for right and left polarized quanta due to Zeeman splitting of the lines**).

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**) Due to inevitable difference between the laser frequency and the resonant one, the same mechanism leads in the case of experiment proposed by Bouchiat/3/ to the restrictions on the magnetic field more stringent perhaps than those pointed in their work.

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