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I.B.Khriplovich and V.N.Novikov

PARITY VIOLATION IN THE TRANSITIONS BETWEEN COMPONENTS OF HYPERFINE STRUCTURE IN HEAVY ATOMS

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PARITY VIOLATION
IN THE TRANSITIONS BETWEEN COMPONENTS OF HYPERFINE STRUCTURE IN HEAVY ATOMS

I.B.Khriplovich and V.N.Novikov

Institute of Nuclear Physics
Novosibirsk 90, USSR

Circular polarization of radiation in the transitions between components of hyperfine structure in heavy atoms is calculated. Possible experiment to detect this effect is pointed.

In the recent work/[1]/ the real possibility to detect parity violating weak interaction between electron and nucleons by the rotation of light polarization plane in heavy metals vapours was pointed. It was shown that one should work at the frequency close to that of the usual M1 transition between the fine structure components. This experiment would allow to detect in weak interaction of electron with nucleon the correlation between the electron spin and its momentum, i.e., the interaction of lepton axial current with the nucleon vector one.

The detection of parity violation effects depending on the nucleon spin would be of no smaller interest. They are caused by the interaction of the lepton vector current with the nucleon axial one. These effects could show up in the transitions between hfs components, the latter being the usual M1 transitions convenient for the observation of the rotation of the polarization plane.

Unfortunately, the parity violation effects are here smaller than in the transitions between the components of fine structure. All the atomic mechanisms which enhance Z^2 times the mixing of opposite parity levels, are acting here also. But since the effect is caused by the interaction of the electron with the only non-paired nucleon, and not with all the nucleons of the nucleus as it is the case with optical transitions, its magnitude is roughly speaking Z times smaller than in the optical diapason. However, the resolution possible in the present centimetre wave technique is much higher than in optics, therefore, the measurement of parity violation effects in radiodiapason seems to be sufficiently real.

Write the Hamiltonian of parity violation interaction of relativistic electron with point-like nucleus as

$$H = -\frac{G\hbar^3}{\sqrt{2}c}\,\delta(\vec{r})\left[Zq\gamma_5 + h\langle\vec{\sigma}_n\rangle\vec{\alpha}\right] \qquad (1)$$

Here $G = 10^{-5}m_p^{-2}$ is the Fermi constant of weak interaction,

m_p is proton mass, $\vec{\sigma}_n$ is the nucleon spin operator, $\vec{\alpha} = \gamma_0\vec{\gamma}$, $\gamma_5 = -i\gamma_0\gamma_1\gamma_2\gamma_3$, γ_μ are the Dirac matrices; the dimensionless constants q and h depend on the model of weak interaction.

It can be shown that the interaction (1) leads to the mixing of the $s_{1/2}$ and $p_{1/2}$ one electron states only. The corresponding matrix element is equal to

$$\langle s_{1/2}|\,H\,|p_{1/2}\rangle = +\frac{iGm^2Z^2\alpha^2}{2\pi\sqrt{2}}\,R\,\frac{me^4}{\hbar^2}\,(\nu_p\nu_s)^{-3/2}\cdot$$
$$\cdot\{\,Zq - h\,\frac{2\gamma+1}{3}\,g_i[F(F+1) - i(i+1) - 3/4]\} \qquad (2)$$

Here m is electron mass, $\gamma = \sqrt{1 - Z^2\alpha^2}$, $R = \dfrac{4(2Zr_0/a)^{2\gamma-2}}{\Gamma^2(2\gamma+1)}$, a is the Bohr radius, r_0 is the radius of the nucleus, ν_s and ν_p are the effective principal quantum numbers of s- and p-states, g_i is the ratio of $\langle\vec{\sigma}_n\rangle$ to the angular momentum of the nucleus $\vec{i}$, $\vec{F}$ is the total angular momentum of the atom. The circular polarization in the hyperfine transition is caused by the term which contains F(F+1) only.

The calculation of the degree ζ of the circular polarization was made by us for cesium and thallium. We shall not discuss it here in detail (see /[2,1]/). Note only that in thallium the contribution to the effect from the admixture to the ground state $6s^26p_{1/2}$ of the terms $6s6p^2$ with the total angular momentum J = 1/2 is almost equal to the contribution of the usual excited states $6s^2ns_{1/2}$ (here one can restrict to n = 7, 8). As to the states arising when an electron from closed shell is excited, accounting for them is certainly beyond the accuracy of our calculations. As it is shown, e.g., by the analysis of the polarizability of xenon, the corresponding dipole matrix elements are small.

Present now the results of computations.

1) Cesium (λ = 3.26 cm): $\zeta = 0.6\cdot10^{-9}h$.

2) Thallium (λ = 1.42 cm): $\zeta = -1.3\cdot10^{-8}h$.

According to the popular now Weinberg model/[3]/ (and accounting for the experimental data on the neutral currents with neutrino), h = - 0.24. However, to this prediction no great significance should be attributed. Just in the determination of this quantity h the experimental problem consists.

The existence of the circular polarization of radiation would lead to the effects of parity violation in propagation of radio waves through metal vapour. Here, however, different population of higher and lower levels of hfs is necessary. It can be achieved by means of laser excitation of one of these levels. Here the possibility of optical orientation of atoms should be excluded. If one restricts to the natural, temperature difference of populations, the effects will be smaller by some hundreds of times.

What effects do we speak about? Different radiation matrix elements for right and left quanta $M_\pm = M\,(1 \pm \zeta/2)$ lead to different refraction coefficients $n_\pm$ for these quanta near the corresponding resonance:

$$n_\pm = 1 - \frac{2\pi N|M_\pm|^2}{\hbar\,(\omega - \omega_0 + i\Gamma/2)} \qquad (3)$$

where N is the density of atoms; the population of the upper level is assumed to be small. When a linearly polarized wave propagates, its polarization plane rotates at the distance l by the angle

$$\phi = \frac{\omega l}{2c}\,\mathrm{Re}(n_+ - n_-) \qquad (4)$$

The maximum of ϕ is reached evidently at $|\omega - \omega_0| = \Gamma/2$.

Besides, due to different absorption of right and left polarization the wave becomes elliptically polarized. The ratio of small semiaxis of the ellipse to the large one constitutes

$$\zeta = \frac{\omega l}{2c}\,\mathrm{Im}(n_+ - n_-) \qquad (5)$$

At the pressure exceeding 10^{-2} mm when the Doppler width is much smaller than the collision one Γ, we obtaine the following results.

1) Cesium. The cross-section of excitation transfer by the upper level of hfs is equal to $\sigma = 2.3\cdot10^{-14}\,\mathrm{cm}^2$/[4]/. The abso-

rption length is $l_0 = (2\frac{\omega}{c}\,\mathrm{Im}\,n)^{-1} \approx 12$ m.

$\phi_{max}/l = \zeta/2l_0 \approx 0.25\cdot10^{-10}$ h rad/m.

2) Thallium. We take for σ the same value as in cesium. Then $l_0 \approx 35$ m. $\phi_{max}/l \approx -1.8\cdot10^{-10}$ h rad/m.

To work in the vicinity of the maximum of the effect in frequency is especially convenient since here the most dangerous usually mechanism of imitation of the effect due to residual external magnetic field is inessential. It arises from the difference in resonant frequencies for right and left polarized quanta due to Zeeman splitting of the lines. However, an external magnetic field leads to optical activity causing the mixing of the terms with different F. To imitate the effect under discussion an average longitudinal magnetic field $\sim 2\cdot10^{-6}$ h gs in cesium and $\sim 3.2\cdot10^{-4}$ h gs in thallium is sufficient.

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