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PARITY VIOLATION IN STRONGLY FORBIDDEN M1 TRANSITIONS IN THALLIUM AND LEAD

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abstract

The transitions in thallium and lead, promising from the point of view of the search for neutral currents, are considered. The effects of parity violation in these transitions are calculated.

The first sufficiently real experiment on the detection of parity violation in atomic transitions was suggested by Bouchiat/1/. The search for circular polarization of photons in the strongly forbidden M1 transition 6s-7s in cesium is meant. This polarization arises if the parity violating weak interaction of nucleon and electron neutral currents exists. Up to now the magnetic moment of the transition is measured/2/ and the limit on the degree of circular polarization is obtained/3/: $|P| < 2.6\cdot 10^{-2}$. In the Weinberg model one should expect in this transition/3/ $P = 2.2\cdot 10^{-4}$.

Soonly after the work/1/ it was noted that circular polarization larger by an order of magnitude may be expected in strongly forbidden M1 transitions in thallium/4,5/ and lead/5/. The corresponding transitions lie in the region accessable for tunable lasers with frequency doubling. Now when the experiment with thallium is going on/6/ and has lead already to the determination of the magnetic moment of the transition

$$\langle 7p_{1/2}|M_z|6p_{1/2}\rangle = -(2.11 \pm 0.30)\cdot 10^{-5}|\mu_B| \qquad (1)$$

the detailed calculation of parity violation in strongly forbidden M1 transitions[*] in thallium and lead is timely. Its results are presented in this note.

The technique of computations of E1 amplitudes in thallium and lead due to parity violation is considered rather in detail in the work/7/ where the optical activity of heavy metal vapors near usual M1 transitions is calculated. Therefore we present here only some details of calculations.

The matrix element of P - odd electron - nucleus interaction looks as follows/8/:

$$\langle s_{1/2}|H_W|p_{1/2}\rangle = i\,\frac{Gm_e^2\alpha^2 Z^2 R}{\pi\sqrt{2}}\cdot\frac{m_e e^4}{2\hbar^2}\cdot\nu_s^{-3/2}\cdot\nu_{p_{1/2}}^{-3/2}\cdot\left[Zq + \frac{2\gamma+1}{3} g_I 2 I_n i_e\right] \qquad (2)$$

where $G = 10^{-5}/m_p^2$ is the Fermi constant, $\gamma = \sqrt{1 - Z^2\alpha^2}$, ν_s, $\nu_{p_{1/2}}$ are the effective principal quantum numbers of electron, R is relativistic enhancement factor ($R_{Tl}= 8.5$; $R_{Pb}= 8.9$), $\underset{\sim}{I}_n$ and $\underset{\sim}{j}_e$ are the angular momenta of nucleus and electron correspondingly. In the Weinberg model at $\sin^2\theta = 0.32$ $q_{Tl}= q_{Pb}= - 0.9$; assuming shell model of nucleus as well, $g_I(Pb^{207}) = 0.12$.

In the simplest way the effect is calculated for the transitions $6p_{1/2}\rightarrow mp_{1/2}$ in thallium. In this case the contribution of the second term in the square brackets in (2) is small ($\sim Z^{-1}$) in comparison with the first one and therefore the constant q describing the interaction of nucleon vector neutral current and electron axial one is measured. Usual levels of opposite parity $ns_{1/2}$ ($n \geqslant 7$) including continuous spectrum and the excitations of the type 6s6pmp of the internal $6s^2$ subshell are admixed to initial and final states. The radial integrals necessary for the computations we extract from experimental data or, if they are absent, from numerical calculations/2,9/. The most essential radial integrals are presented in the table 1.

The results of our calculations for the amplitudes of E1 transitions are given in the table 2. For the transition $6p_{1/2}\rightarrow 7p_{1/2}$ this quantity was calculated previously by Bouchiat/10/. Their result ($D_z= 0.78\cdot10^{-10}i|e|a_o$) differs from ours since they did not take into account the contribution to the effect from the excitations of the type 6s6p7p. The value of the degree of circular polarization found by us for this transition*)

$$P = - 2\frac{\mathrm{Im}\langle 7p_{1/2}|D_z|6p_{1/2}\rangle}{\langle 7p_{1/2}|M_z|6p_{1/2}\rangle} = - 2.5\cdot10^{-3} \qquad (3)$$

agrees with the estimate by **Neuffer** presented in the work/6/. Since the magnetic moments of the transitions $6p_{1/2}\rightarrow mp_{1/2}$ decrease perhaps with the growth of m, in the two other transitions (see the table 2) one may expect the same or even somewhat larger circular polarization.

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*) We assume here that the sign of the experimental result (1) is given under the convention that the radial wave functions are positive at the origin.

Pass now to lead. Here we shall consider the transitions $6p^2({}^3P'_0)\rightarrow 6p7p({}^3P'_1, {}^3D'_1)$ where the constant q can also be measured. The analysis of lead spectrum shows that both upper levels are almost pure jj states: $6p_{1/2}7p_{1/2}$ and $6p_{1/2}7p_{3/2}$ correspondingly*). Radial integrals used in calculations are given in the table 1. Our results for the amplitudes of E1 transitions are presented in the table 2. In both transitions the circular polarization $\sim 3\cdot10^{-3}$ can be expected.

Since the contributions of different states to the effect are mutually compensating considerably, the inaccuracy of our calculations may be rather large. Unlike the authors of/4/, we think that due to inaccuracy of atomic calculations the isotopic structure of neutral currents can hardly be found by comparison of parity violating effects in thallium and cesium even at high experimental accuracy. The investigation of optical activity of vapors of different isotopes of thallium and lead are perhaps more promising from this point of view/8,11/.

Discuss now M1 transitions in the odd isotope of lead going via hyperfine mixing of electronic states with angular momenta 0 and 1. In their work/4/ Bouchiat pointed that the observation of circular polarization in the transition $6p^2({}^3P'_0)\rightarrow 6p^2({}^1S'_0)$ would allow to detect another type of weak interaction - that of nucleon axial and electron vector currents (i.e., to find the constant g_I in the formula (2)).

In our work/11/ the matrix element of this transition is computed:

$$\langle {}^1S'_0|M_z|{}^3P'_0\rangle = 0.81\cdot10^{-6}|\mu_B| \qquad (4)$$

(Bouchiat/4/ give for the numerical factor the value $(0.27 \div 0.69)\cdot10^{-6}$). Found by us the dipole moment of E1 transition is presented in the table 2. Note that here the calculation is somewhat more reliable than those discussed above since the prin-

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*) These functions we define in such a way that in the second quantization formalism they are correspondingly $b^+_{6,1/2}b^+_{7,1/2}|0\rangle$ and $\left[\frac{\sqrt{3}}{2}b^+_{6,1/2}c^+_{7,3/2} - \frac{1}{2}b^+_{6,1/2}c^+_{7,1/2}\right]|0\rangle$ (see/7/).

cipal contribution to the effect is given here by the admixture of one configuration 6p7s($^3P'_0$). Our result for the degree of circular polarization in this transition $P = -0.65 \cdot 10^{-4}$ is almost by an order of magnitude smaller than the corresponding estimate in/4/.

We have considered also the analogous transition $6p^2\ ^3P'_0 \to 6p7p\ ^3P'_0(6p_{1/2}7p_{1/2})$. Larger circular polarization can be expected in it due to smaller value of $\langle M_z \rangle$. The important advantage is in this case evidently the presence of an allowed transition from the excited state which makes the observation of the process more easy.

Note in conclusion that the effects similar to the considered above could be observed in analogous transitions in indium and tin.

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	Tl				Pb		
	$6p_{1/2}$	$7p_{1/2}$	$8p_{1/2}$	$9p_{1/2}$	$6p_{1/2}$	$7p_{1/2}$	$7p_{3/2}$
6s	− 1.8	− 0.13	− 0.06	− 0.04	− 1.6	− 0.09	− 0.2
7s	2.22	− 7.62	− 0.90	− 0.40	1.75	− 7.10	− 6.67
8s	0.67	7.38	−14.7	− 1.77	0.66	6.65	8.10
9s	0.37	1.58	14.3	−23.8	0.37	1.49	1.35
10s	0.28	0.79	2.74	23.5	0.25	0.79	0.68

Radial integrals in the units of Bohr radius

Table 1

	initial state	final state	λ, Å	$\frac{\langle f \vert M_z \vert i \rangle}{\vert \mu_B \vert}$	$\frac{\langle f \vert D_z \vert i \rangle}{i \vert e \vert a_0}$	P
Tl	$6p_{1/2}$	$7p_{1/2}$	2927	$-2.11 \cdot 10^{-5}$	$-0.95 \cdot 10^{-10}$	$-2.5 \cdot 10^{-3}$
		$8p_{1/2}$	2417		$-0.53 \cdot 10^{-10}$	
		$9p_{1/2}$	2253		$-0.40 \cdot 10^{-10}$	
Pb	$6p^2(^3P'_0)$	$6p7p(^3P'_1)$	2330		$1.07 \cdot 10^{-10}$	$-6.5 \cdot 10^{-5}$
		$6p7p(^3D'_1)$	2238		$-1.25 \cdot 10^{-10}$	
		$6p^2(^1S'_0)$	3394	$0.81 \cdot 10^{-6}$	$0.95 \cdot 10^{-13}$	
		$6p7p(^3P'_0)$	2252		$-0.95 \cdot 10^{-13}$	

Table 2

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