85

ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ
СО АН СССР

Yu.I.Skovpen'

THE HYPERFINE STRUCTURE OF HEAVY ATOMS AND MULTIPOLE NUCLEAR MOMENTS

ПРЕПРИНТ ИЯФ 79 - 152

Новосибирск

THE HYPERFINE STRUCTURE OF HEAVY ATOMS AND MULTIPOLE NUCLEAR MOMENTS

Yu.I.Skovpen'

Institute of Nuclear Physics,
630090, Novosibirsk, USSR

A b s t r a c t

The quadrupole moments for the bismuth and antimony nuclei and also the octupole moment of the bismuth nucleus are calculated, using the experimentally known quanrupole and octupole hyperfine splitting. The magnetic dipole hyperfine structure of indium, tin, and antimony is calculated as well.

1. INTRODUCTION

Multipole nuclear moments serve as a source of information on a nuclear structure. These moments may be determined, using the hyperfine structure. In the present paper, following from the experimentally known quadrupole and octupole splittings the quadrupole nuclear moments for Bi and Sb, and also the octupole moment for a Bi nucleus are calculated. An interest to this problem is also due to the fact that the value for the quadrupole constant of the state $^2D_{\frac{5}{2}}(6p^3)$ obtained in the experiment on parity violation in atoms (Novosibirsk) /1/ as a by-result, and the value obtained in Ref./2/ are much more accurate than the results of the previously works (see the Table in Ref./2/). Calculation of the quadrupole and octupole hyperfine structure enables one to verify the calculation procedure for the parity violation effects in heavy atoms /3-5/. The magnetic-dipole hyperfine structure in In, Sn, and Sb is calculated as well. This calculation is similar to that carried out in Ref./6/ for thallium, lead, and bismuth.

A Hamiltonian of electron-nucleus interaction has the form:

$$H = -eV + e\vec{\alpha}\vec{A} \qquad (1)$$

where $\vec{\alpha}$ is the Dirac matrix, V and $\vec{A}$ are the scalar and vector potentials. V and $\vec{A}$ can be represented as follows:

$$V = \sum_{\kappa,m} r^{-\kappa-1}\sqrt{\frac{4\pi}{2\kappa+1}}\, Y_{\kappa m}(\theta,\varphi)\, Q^n_{\kappa m} = \sum_{\kappa,m} Q^e_{\kappa m} Q^n_{\kappa m}$$

$$\vec{A} = \sum_{\kappa,m} \frac{-i}{\kappa}\sqrt{\frac{4\pi}{2\kappa+1}}\, r^{-\kappa-1}\,(\vec{l}\, Y_{\kappa m}(\theta,\varphi))\, M^n_{\kappa m} \qquad (2)$$

$$\vec{\alpha}\vec{A} = \sum_{\kappa,m} M^e_{\kappa m} M^n_{\kappa m}$$

where $\vec{L} = -i[\vec{r} \times \vec{\nabla}]$, Q_κ and M_κ are the electric and magnetic multipole moments. The first term of the Hamiltonian (1) is an electric multipole interaction, $\kappa = 2$ is the electric quadrupole interaction. The second term of the Hamiltonian is a magnetic multipole interaction; $\kappa = 1$, $\kappa = 3$ are the magnetic dipole and octupole interactions, respectively. The standard definitions of the magnetic dipole, electric quadrupole, and magnetic octupole nuclear moments are:

$$\mu = \langle II | M^{n}_{10} | II \rangle$$
$$eQ = 2\langle II | Q^{n}_{20} | II \rangle$$
$$\Omega = -\langle II | M^{n}_{30} | II \rangle$$

The constants of the corresponding splittings are given by the following formula:

$$A = \frac{e}{IJ} \mu \langle JJ | M^{e}_{10} | JJ \rangle$$
$$B = -2e^2 Q \langle JJ | Q^{e}_{20} | JJ \rangle \qquad (3)$$
$$C = -e\Omega \langle JJ | M^{e}_{30} | JJ \rangle$$

where I is the nuclear moment, J the total electric moment.

The matrix elements Q^{e}_{20} have the form:

$$Q'_{nm} = \langle np_{\frac{1}{2}}, \tfrac{1}{2} | Q^{e}_{20} | mp_{\frac{3}{2}}, \tfrac{1}{2} \rangle = \frac{\sqrt{2}}{5} \frac{Z}{a^3 \nu_n^{\frac{3}{2}} \nu_m^{\frac{3}{2}}} \times$$
$$\times \frac{4 \sin[\pi(\gamma_3 - \gamma_1)]}{3\pi(Z\alpha)^2} \frac{15 - 4Z^2\alpha^2}{15 - 16Z^2\alpha^2} \kappa'$$

$$Q''_{nm} = \langle np_{\frac{3}{2}}, \tfrac{3}{2} | Q^{e}_{20} | mp_{\frac{3}{2}}, \tfrac{3}{2} \rangle = \qquad (4)$$
$$= -\frac{2}{5} \frac{Z}{a^3 \nu_n^{\frac{3}{2}} \nu_m^{\frac{3}{2}}} \frac{(15 + Z^2\alpha^2)}{\gamma_3(\gamma_3^2 - 1)(4\gamma_3^2 - 1)} \kappa''$$

where Z is the charge of a nucleus, a the Bohr radius, ν the effective principal quantum number, $\gamma = \sqrt{\varkappa^2 - Z^2\alpha^2}$, $\varkappa = (-1)^{j+\frac{1}{2}-l}(j+\frac{1}{2})$, j is the total moment, and l is the orbital moment.

The matrix element M^{e}_{30} has the form:

$$R = \langle p_{\frac{3}{2}}, \tfrac{3}{2} | M^{e}_{30} | p_{\frac{3}{2}}, \tfrac{3}{2} \rangle =$$
$$= \frac{112\, a\, Z^3}{7 a^4 \nu^3 \gamma_3 (\gamma_3^2 - 1)(4\gamma_3^2 - 1)(4\gamma_3^2 - 9)} \kappa \qquad (5)$$

The coefficients κ', κ'' and κ in (4) and (5) are determined in such a way that at $\kappa' = \kappa'' = \kappa = 1$ these expressions coincide with the matrix elements calculated by means of the quasiclassical wave functions presented in Ref./7/. The quantities κ', κ'', κ are the ratios of the matrix elements calculated with use of the wave functions derived by numerical solution of the Dirac equations with a potential /8/

$$V(r) = -\frac{e^2}{r}\left[\frac{Z-1}{H(e^{r/d}-1)+1} + 1\right] \qquad (6)$$

to the qiasiclassical ones. For In, Sn, and Sb the parameters H and d were chosen to be the following:

$H_{In} = 20.085$ $\quad H_{Sn} = 15.081$ $\quad H_{Sb} = 11.075$

$d_{In} = 2.4\, a$ $\quad d_{Sn} = 1.984\, a$ $\quad d_{Sb} = 1.6046\, a$

and for Bi they are known from Ref./6/:

$H_{Bi} = 12.049$ and $d_{Bi} = 1.401\, a$

Let us proceed now to calculation of the quadrupole structure for the states of Bi related to the ground configuration $6p^3$. It is clear that $B(^2P_{\frac{1}{2}}) = 0$.

2. THE QUADRUPOLE STRUCTURE OF THE Bi STATES $6p^3$, $J = \frac{3}{2}$.

It is convenient to perform these calculations with use of the secondary quantization representation. The wave functions of Bi in the jj -scheme calculated in the paper /9/ have the following form:

$$
\begin{aligned}
|^4S_{\frac{3}{2}}\rangle &= -0.930\left(\tfrac{3}{2}\tfrac{1}{2}\tfrac{1}{2}\right)_{\frac{3}{2}} + 0.323\left(\tfrac{3}{2}\tfrac{3}{2}\tfrac{1}{2}\right)_{\frac{3}{2}} - 0.179\left(\tfrac{3}{2}\tfrac{3}{2}\tfrac{3}{2}\right)_{\frac{3}{2}} \\
|^2D_{\frac{3}{2}}\rangle &= -0.357\left(\tfrac{3}{2}\tfrac{1}{2}\tfrac{1}{2}\right)_{\frac{3}{2}} - 0.940\left(\tfrac{3}{2}\tfrac{3}{2}\tfrac{1}{2}\right)_{\frac{3}{2}} + 0.053\left(\tfrac{3}{2}\tfrac{3}{2}\tfrac{3}{2}\right)_{\frac{3}{2}} \\
|^2D_{\frac{5}{2}}\rangle &= \left(\tfrac{3}{2}\tfrac{3}{2}\tfrac{1}{2}\right)_{\frac{5}{2}} \qquad (7) \\
|^2P_{\frac{1}{2}}\rangle &= \left(\tfrac{3}{2}\tfrac{3}{2}\tfrac{1}{2}\right)_{\frac{1}{2}} \\
|^2P_{\frac{3}{2}}\rangle &= 0.151\left(\tfrac{3}{2}\tfrac{1}{2}\tfrac{1}{2}\right)_{\frac{3}{2}} - 0.109\left(\tfrac{3}{2}\tfrac{3}{2}\tfrac{1}{2}\right)_{\frac{3}{2}} - 0.982\left(\tfrac{3}{2}\tfrac{3}{2}\tfrac{3}{2}\right)_{\frac{3}{2}}
\end{aligned}
$$

where $(j_1 j_2 j_3)_J$ are the wave functions for three p - electrons with moments j_1, j_2, j_3, and with the total moment J, which are presented in the secondary quantization representation in Ref./6/. Using Eqs.(3) and (7), we get:

$$
\begin{aligned}
B(^4S_{\frac{3}{2}}) &= 2Qe^2\left[-0.832\,G'' + 0.217\,G'\right] \\
B(^2D_{\frac{3}{2}}) &= 2Qe^2\left[-0.110\,G'' - 0.327\,G'\right] \qquad (8) \\
B(^2P_{\frac{3}{2}}) &= 2Qe^2\left[0.942\,G'' + 0.111\,G'\right]
\end{aligned}
$$

The contribution to the quadrupole splitting comes from the Columb admixture to $6s^2 6p^3$ of the configurations $6s6p^3nd$ and $6s^2 6p^2 np$ and also from the second order of perturbation theory over the magnetic dipole interaction. It follows from numerical calculations that this contribution

is less than 5% and we do not taken account of it.

From numerical calculation $K' = 1.501$ and $K'' = 1.319$. The best approximation of experimental values of the constants is achieved at

$$Q = -0.41\,b.$$

An accuracy in calculation of the constant is determined by the mixing of configurations and equals about 5%. The results are given in Table 1. In the Table and in what follows, the direct experimental results are given without taking into account the second order of perturbation theory. The found value of Q coincides with the results of the paper /12/. Note, that the latter result is $Q = 0.385(40)\,b$. The calculation procedure used in the present paper differs from that used in Ref./12/. In that paper, when calculating a quadrupole moment the radial integral is used which was found with respect to the magnetic dipole structure with introduction of various relativistic corrections.

3. QUADRUPOLE SPLITTING OF THE LEVEL $^2D_{\frac{5}{2}}$.

The state $^2D_{\frac{5}{2}}$ is a pure LS-state with the half-filled shell, so that the constant B arises in it both due to the mixing of configurations and also to the second order of perturbation theory over the magnetic dipole interaction. Therefore, the constant $B(^2D_{\frac{5}{2}})$ is very small.

$$
\begin{aligned}
B &= B_1 + B_2 \\
B_1 &= -4e^2 \sum_{n \neq 7} \frac{Q}{E_{6p^3} - E_{6p^2 np}} \left[\frac{1}{25} F^2_{np_{\frac{3}{2}} 6p_{\frac{1}{2}}, 6p_{\frac{3}{2}} 6p_{\frac{1}{2}}} Q''_{n6} + \right. \\
&\left. + \frac{2\sqrt{2}}{25} F^2_{np_{\frac{1}{2}} 6p_{\frac{3}{2}}, 6p_{\frac{3}{2}} 6p_{\frac{3}{2}}} Q'_{n6}\right] \qquad (9) \\
B_2 &= -\frac{120}{63} W_6
\end{aligned}
$$

$$F^2_{ij,\kappa\ell} = \int \frac{r_<^2}{r_>^3} R_i(r_1) R_j(r_1) R_\kappa(r_2) R_\ell(r_2)\, dr_1 dr_2$$

$$W_F = \sum_{J'} \frac{\langle F,J|H^{hfs}|F,J'\rangle\langle F,J'|H^{hfs}|F,J\rangle}{E_J - E_{J'}}$$

H^{hfs} is the Hamiltonian of magnetic hyperfine interaction; B_1 is the contribution owing to the Columb mixing of $6s^26p^3$ with $6s^26p^2np$; B_2 is the contribution owing to the second order of perturbation theory. Numerical calculations yield B_1 = 17.8 MHz. Uncertainty in calculation of $B(^2D_{\frac{5}{2}})$ is determined by the calculation accuracy of the exchange Columb integrals. The exchange Columb integral found *numerically* differs by 30-40% from that known from calculation of the scheme of the levels of configuration $6p^3$ in the intermediate coupling approximation. In connection with this, the calculation accuracy (*at n≥7*) can be expected to be 30-40% as well. The quantity B_2 was previously calculated in the paper /2/, B_2 =-9.2 MHz. Whence,

$$B(^2D_{\frac{5}{2}}) = 8.5 \pm 7 \text{ MHz}.$$

The experimental results are:

14 ± 11 MHz /2/

2 ± 13 MHz /13/

The other references to experimental papers can be found in Ref./2/.

4. THE OCTUPOLE STRUCTURE OF Bi

Using Eqs.(3) and (7), we have

$$\begin{aligned} C(^4S_{\frac{3}{2}}) &= -0.813\,\Omega\,Re \\ C(^2D_{\frac{3}{2}}) &= 0.591\,\Omega\,Re \\ C(^2D_{\frac{5}{2}}) &= 2\,\Omega\,Re \\ C(^2P_{\frac{1}{2}}) &= 0 \\ C(^2P_{\frac{3}{2}}) &= -0.978\,\Omega\,Re \end{aligned} \qquad (10)$$

By numerical calculation κ = 1.05. The results are quoted in Table 2. The calculation accuracy determined by the mixing of configuration and also by the contribution of the second order of perturbation theory is equal to 5-10%. The found value

$$\Omega = 0.56\ \mu n b$$

does not coincide with the results of Ref./10/ and coincide with those of Ref./12/. The calculation procedure in the present paper is another than that used in Refs./10,12/. The result of Ref./12/ is: Ω = 0.55(3) $\mu n b$. Note, that different procedure used in that paper give the results varying within 20%. The result of the paper /10/ is: Ω = 0.0086 $\mu n b$. In the latter paper once more two values Ω = 0.0135 $\mu n b$ and Ω = 0.043 $\mu n b$ are given, depending upon the relativistic corrections being used. Our calculation is exempt from such a non-uniqueness.

5. THE QUADRUPOLE STRUCTURE OF Sb

The wave functions of Sb in the p^3 -scheme are:

$$\begin{aligned} |^4S_{\frac{3}{2}}\rangle &= -0.632\left(\tfrac{3}{2}\,\tfrac{1}{2}\,\tfrac{1}{2}\right)_{\frac{3}{2}} + 0.687\left(\tfrac{3}{2}\,\tfrac{3}{2}\,\tfrac{1}{2}\right)_{\frac{3}{2}} - 0.360\left(\tfrac{3}{2}\,\tfrac{3}{2}\,\tfrac{3}{2}\right)_{\frac{3}{2}} \\ |^2D_{\frac{3}{2}}\rangle &= 0.678\left(\tfrac{3}{2}\,\tfrac{1}{2}\,\tfrac{1}{2}\right)_{\frac{3}{2}} + 0.714\left(\tfrac{3}{2}\,\tfrac{3}{2}\,\tfrac{1}{2}\right)_{\frac{3}{2}} + 0.174\left(\tfrac{3}{2}\,\tfrac{3}{2}\,\tfrac{3}{2}\right)_{\frac{3}{2}} \\ |^2D_{\frac{5}{2}}\rangle &= \left(\tfrac{3}{2}\,\tfrac{3}{2}\,\tfrac{1}{2}\right)_{\frac{5}{2}} \end{aligned} \qquad (11)$$

$$|^2P_{\frac{1}{2}}\rangle = \left(\tfrac{3}{2}\,\tfrac{3}{2}\,\tfrac{1}{2}\right)_{\frac{1}{2}}$$

$$|^2P_{\frac{3}{2}}\rangle = -0.376\left(\tfrac{3}{2}\,\tfrac{1}{2}\,\tfrac{1}{2}\right)_{\frac{3}{2}} + 0.134\left(\tfrac{3}{2}\,\tfrac{3}{2}\,\tfrac{1}{2}\right)_{\frac{3}{2}} + 0.917\left(\tfrac{3}{2}\,\tfrac{3}{2}\,\tfrac{3}{2}\right)_{\frac{3}{2}}$$

With use of Eqs.(3) and (11), we get:

$$B(^4S_{\frac{3}{2}}) = 2Qe^2[-0.270\,Q'' + 0.167\,Q']$$
$$B(^2D_{\frac{3}{2}}) = 2Qe^2[-0.429\,Q'' - 0.322\,Q'] \qquad (12)$$
$$B(^2P_{\frac{3}{2}}) = 2Qe^2[0.700\,Q'' + 0.155\,Q']$$

From numerical calculations $\kappa' = 1.313$ and $\kappa'' = 1.261$. The constant $B(^4S_{\frac{3}{2}})$ is very small, and this is not accident. In the LS-scheme the function $|^4S_{\frac{3}{2}}\rangle$ will be a nearly pure $^4S_{\frac{3}{2}}$ LS-state. The matrix element of Q_{20}^e over any pure LS-state with the half-filled shell is equal to zero. Due to orthogonality, $\langle {}^4S_{\frac{3}{2}}|Q_{20}^e|{}^2D_{\frac{3}{2}}, {}^2P_{\frac{3}{2}}\rangle = 0$. A single non-zero contribution $\langle {}^2D_{\frac{3}{2}}|Q_{20}^e|{}^2P_{\frac{3}{2}}\rangle$. Therefore, the constant $B(^4S_{\frac{3}{2}})$ is a quantity of the third order over the spin-orbital interaction. The accuracy in calculation of the wave functions (11) is equal to about 10%. Thus, the calculation accuracy of $B(^4S_{\frac{3}{2}})$ constitutes $\sim$ 100%. The uncertainty in calculation of the constants B for $^2D_{\frac{3}{2}}$ and $^2P_{\frac{3}{2}}$ is determined by the accuracy of calculation of the wave functions (11) and is equal tp $\sim$ 10%, however, the experiment accuracy is not high in this case.

The constants B for the Sb^{121} and Sb^{123} isotopes are known from the experiment. From the best approximation of the experimental values of $B(^2D_{\frac{3}{2}})$ and $B(^2P_{\frac{3}{2}})$ we find that

$$Q_{121} = -0.40\ b$$
$$Q_{123} = -0.59\ b$$

The results are illustrated in Table 3. The accuracy of the values found for Q is determined by that of experimental data. They do not coincide with the results of the paper /14/ and are consistent with those of the paper /15/. The results of /14/ are the following: $Q_{121} = -0.20(3)\ b$, $Q = -0.26(4)\,b$. The results of the paper /15/ are: $Q_{121} = -0.36(4)\,b$, $Q_{123} = -0.49(5)\ b$. The expression for $B(^2D_{\frac{5}{2}})$ is analogous to that derived for B_i. The changes in B_L are obvious. For Sb^{121} $B_2 = -\frac{4}{3}W_4$, for Sb^{123} $B_2 = -\frac{50}{63}W_5$.

6. THE HYPERFINE STRUCTURE OF In, Sn, AND Sb

Let us proceed now to calculation of the hyperfine magnetic structure of In, Sn, and Sb. As has already been mentioned, this calculation is analogous to that carried out in Ref./6/ for thallium, lead, and bismuth. The matrix elements of the hyperfine interaction Hamiltonian in /6/ have the form:

$$\langle p_{\frac{1}{2}}|H|p_{\frac{1}{2}}\rangle = \frac{8}{9}\frac{\Omega}{v_p^3}R_1K_1N_1\vec{I}_N\vec{J} \qquad R_1 = \frac{3}{\sqrt{1}(4j_1^2-1)}$$

$$\langle p_{\frac{3}{2}}|H|p_{\frac{3}{2}}\rangle = \frac{8}{45}\frac{\Omega}{v_p^3}R_3K_3N_3\vec{I}_N\vec{J} \qquad R_3 = \frac{30}{\sqrt{3}(4j_3^2-1)}$$

$$\langle p_{\frac{3}{2}}, j_z, I_{N,z}|H|p_{\frac{1}{2}}, j_z, I_{N,z}\rangle = \frac{1}{9\sqrt{2}}\frac{\Omega}{v_p^3}R_{13}K_{13}N_{13}I_{N,z} \qquad (13)$$

$$R_{13} = -\frac{4\sin[\pi(\delta_3-\delta_1)]}{\pi Z^2\alpha^2}$$

$$N_1 = 1 - \frac{v_p^3}{K_1}x_1, \quad N_3 = 1 + 5\frac{v_p^3R_1}{K_3R_3}x_3,$$

$$N_{13} = 1 - 16\frac{v_p^3R_1}{K_{13}R_{13}}x_{13}$$

where $\mathcal{K}_i$ are expressed via the exchange Columb integrals, $\Omega = \frac{\mu_N}{I_N} Z\alpha^2 \frac{m_e}{m_p} \frac{m_e e^4}{2\hbar^2}$, μ_N is the magnetic nuclear moment, m_e and m_p are the electron and proton masses, κ_i is the ratio of the precise matrix element to the quasiclassical one. According to /6/, $\mathcal{K}_1 \approx \mathcal{K}_3 \approx \mathcal{K}_{13} = \mathcal{K}$, where $\mathcal{K}$ is chosen from the beat approximation of experimental data.

I_n^{115} has the magnetic moment μ_N = 5.5083 /16/ and ν_{5p} = 1.558. According to numerical calculations, the quantities κ_i are the following: κ_1 = 1.229 and κ_3 = 1.1286. The best fit of the hyperfine splitting is achieved at $\mathcal{K}$ = = -0.01187. The results are given in Table 4.

The wave functions of the $5p^2$-configuration of Sb in the jj -coupling approximation are the following:

$$|^3P_0\rangle = 0.908\,(\tfrac{1}{2}\tfrac{1}{2})_0 - 0.420\,(\tfrac{3}{2}\tfrac{3}{2})_0$$
$$|^3P_1\rangle = (\tfrac{3}{2}\tfrac{1}{2})_1$$
$$|^3P_2\rangle = 0.793\,(\tfrac{3}{2}\tfrac{1}{2})_2 - 0.609\,(\tfrac{3}{2}\tfrac{3}{2})_2 \qquad (14)$$
$$|^1D_2\rangle = 0.609\,(\tfrac{3}{2}\tfrac{1}{2})_2 + 0.793\,(\tfrac{3}{2}\tfrac{3}{2})_2$$
$$|^1S_0\rangle = 0.420\,(\tfrac{1}{2}\tfrac{1}{2})_0 + 0.908\,(\tfrac{3}{2}\tfrac{3}{2})_0$$

The wave functions of the two p -electrons are presented in Ref./6/. The quantities $\mathcal{K}_i$ are: $\mathcal{K}_1$ = 1.2676, $\mathcal{K}_3$ = 1.16, $\mathcal{K}_{13}$ = 1.2347. The magnetic moment of Sn^{117} is μ_N = 0.9949 /16/ and ν_{5p} = 1.416. According to /6/, the values of $\mathcal{K}$ for Tl, Pb, and Bi are equal with an accuracy not worse than 5%. For this reason, for Sn we assume that $\mathcal{K}$ = -0.012. There exist a few papers where the hyperfine structure of Sn was measured. The results are given in Table 5. They are in a good agreement with those of Refs./18/ and /19/.

The magnetic moment of Sb^{121} is μ_N =3.343 /16/. According to numerical results, κ_1 = 1.3319, κ_3 =1.2555, and κ_{13} = = 1.3042. Here $\mathcal{K}$ is assumed to be equal to -0.012. The results are presented in Table 6.

The level $^3P_1$ will be admixed to the $^3P_0$ and $^1S_0$ levels because of the hyperfine interaction, i.e. the magnetic nuclear moment will be different from the magnetic moments of the nucleus in these states.

$$\delta^{-1} M_{^3P_0} = -0.0264\,\mu_p, \quad \delta^{-1} M_{^1S_0} = 0.0002\,\mu_p$$
$$\mu_p = \frac{|e|\hbar}{2m_p c}$$

The author is grateful to O.P.Sushkov, V.V.Flambaum, and I.B.Khriplovich for numerous discussions and also for a significant part of the computer programs.

Table 1. Quadrupole splitting (MHz) in Bi.

	$B\,^4S_{3/2}$	$B\,^2D_{3/2}$	$B\,^2P_{3/2}$
Calculation	-314.3	-647.2	961.5
Experiment	-304.654(2) /10/	-652.5(30) /11/	978.569(9) /12/

Table 2. Octupole splitting (MHz) in Bi

	$C\,^4S_{3/2}$	$C\,^2D_{3/2}$	$C\,^2P_{3/2}$	$C\,^2D_{5/2}$
Calculation	0.0170	-0.0124	0.0205	-0.0419
Experiment	0.0165(1) /10/		0.0207(5) /12/	

Table 3. Quadrupole splitting (MHz) in Sb

	$B\,^4S_{3/2}$	$B\,^2D_{3/2}$	$B\,^2P_{3/2}$	$B\,^2D_{5/2}$
Calculation Sb^{121}	-2.2	382	385	14 ± 6
Experiment Sb^{121}	-3.68(2)	-360(90)	414(36)	
Calculation Sb^{123}	-3.2	-554	558	22 ± 9
Experiment Sb^{123}	-4.67(3) /14/	-525(90) /15/	600(45) /15/	

Table 4. Hyperfine splitting (MHz) in In

	$A\,^2P_{1/2}$	$A\,^2P_{3/2}$
$\kappa = 1$ $x = 0$	1735	283
$x = 0$	2133	319
Final result	2211	241
Experiment /17/	2282	242

Table 5. Hyperfine splitting (MHz) in Sn

	$A\,^3P_1$	$A\,^3P_2$	$A\,^1D_2$
$\kappa = 1$ $x = 0$	187	-1003	-1063
$x = 0$	321	-1220	-1282
Final result	519	-1021	-1265
Experiment	552.608(4) /19/	-1212.956(3) /19/	-1269.652(3) /18/
Experiment /17/	1649	-5216	-4737

Table 6. Hyperfine splitting (MHz) in Sb

	$A_{^4S_{3/2}}$	$A_{^2D_{3/2}}$	$A_{^2D_{5/2}}$	$A_{^2P_{1/2}}$	$A_{^2P_{3/2}}$
$\varkappa = 1$ $x = 0$	-6	531	1115	3403	567
$x = 0$	-57	642	1445	4530	699
Final result	-324	672	1388	4620	624
Experiment	-299.034 (4) /14/	584(15) /15/	1466(9) /15/	4950(9) /15/	673(4) /15/

References

1. L.M.Barkov, M.S.Zolotarev. Pis'ma v ZhETF, 26, 379, 1978; 27, 544, 1978; Phys.Lett. 85B, 308, 1979.
2. J.Dembczynski, B.Arcimawicz, K.Wisniewski, J.Phys. B: Atom. Molec.Phys., 10, 2951, 1977.
3. V.N.Novikov, O.P.Sushkov, I.B.Khriplovich, ZhETF 71, 1665, 1976.
4. O.P.Sushkov, V.V.Flambaum, I.B.Khriplovich, Pis'ma v ZhETF 24, 502, 1976.
5. V.V.Flambaum, Sov. J. Nucl.Phys. 24, 383, 1976.
6. O.P.Sushkov, V.V.Flambaum, I.B.Khriplovich, Opt. and Spectr. 44, 3, 1978.
7. A.N.Moskalev, P.M.Ryndin, I.B.Khriplovich, Uspekhi Fiz. Nauk, 118, 409, 1976.
8. A.E.S.Green, D.L.Sellin, A.S.Lachez, Phys.Rev. 184, 1, 1969.
9. O.P.Sushkov, V.V.Flambaum, I.B.Khriplovich. Report at Conf. on Thery of Atoms and Molecules. Vil'nyus , 1979.
10. R.J.Hull, G.O.Brink. Phys.Rev. A1, 685, 1970.
11. J.Dembczynski, M.Frackowiak, Acta Phys.Pol. A48, 139, 1975.
12. D.A.Landman, A.Jurio, Phys.Rev. A1, 1330, 1970.
13. M.S.Zolotarev, Thesis,Novosibirsk , 1979.
14. P.C.B.Fernando, G.R.Rochester, I.J.Spalding, K.F.Smith. Phil.Mag. 5, 1291, 1960.
15. B.Buchholz, H.-D.Kronfeldt, G.Müller, M.Voss, R.Winkler. Z.Physik A228, 247, 1978.
16. B.S.Dzhelepov, L.K.Peker, V.O.Sergeev. Schemes of decay of radioactive nuclei. Moscow-Leningrad, 1962.
17. Zandolt-Bornstein. "Zahlenwerte und Funktionen ans Physik, Chemie, Astronomie, Geophysik und Technik", 1952.

18. Childs W.J. Phys.Rev. 4A, 439, 1971.

19. Childs W.J., Goodman L.S. Phys.Rev. 137, A35, 1965.

Работа поступила - 24 сентября 1979 г.

Ответственный за выпуск - С.Г. ПОПОВ
Подписано к печати 5.12-1979 г. МН 16625
Усл. 1,1 печ.л., 0,9 учетно-изд.л.
Тираж 200 экз. Бесплатно
Заказ № 152

Отпечатано на ротапринте ИЯФ СО АН СССР