NUCLEAR POLARIZATION EFFECTS IN THE SPECTRA OF MULTICHARGED HEAVY IONS

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Recent experimental success in the accurate Lamb shift measurements for heavy ions leads to the necessity of taking into account in the theoretical calculations the higher order QED corrections. However, the pure QED calculations are no more sufficient on the present level of accuracy ~ 0.1 eV. The nucleus size, recoil and even the nuclear polarization (NP) effects become observable. The main contribution to the NP effect for heavy nuclei arises from the collective excitations of the nucleus. In refs.[1,2], it has been developed the approach, the general idea of which is to treat NP effects perturbatively, combining the many-body approach for the nuclear excitations with QED theory for atomic electrons. In the frames of this approach, we have derived a simple analytic formula for the NP shift of energy levels in heavy high-Z ions, which seems to be a good approximation for the $L > 1$ multipole nuclear excitations [3]. For a single nuclear excitation, it looks as follows

$$\Delta E^L_{nlj} = -2\pi B(EL; L \to 0)\frac{\alpha(\alpha Z)^2 C_{nlj}}{(2L+1)R_0^{2L}}\left(\frac{2Z}{Na_0}R_0\right)^{2\gamma}\sum_{j'}(2j'+1)R_{j'}\begin{pmatrix} j' & j & L \\ \frac{1}{2} & -\frac{1}{2} & 0\end{pmatrix}^2,$$

$$R_{j'} = \frac{1}{\mu(\gamma+\mu+L+1)}\left(\frac{1}{\gamma+L+1}+\frac{2}{\mu-\gamma+L}\right)+\frac{1}{\mu(\gamma+\mu-L)}\left(\frac{2}{\gamma-\mu-L}+\frac{1}{L-\gamma}\right),$$

$$C_{nlj} = \left(n_r^2 - 2\varepsilon_{nj}n_r(N-\kappa)+(N-\kappa)^2\right)\frac{\Gamma(2\gamma+n_r+1)}{\Gamma^2(2\gamma+1)N^2(N-\kappa)n_r!}.$$

Here $N = \sqrt{(n_r+\gamma)^2+(\alpha Z)^2}, \gamma = \sqrt{\kappa^2-(\alpha Z)^2}, \kappa = (j+\frac{1}{2})(-1)^{j+l+\frac{1}{2}}, n = n_r + |\kappa|, \mu = \sqrt{(j'+1/2)^2-(\alpha Z)^2}$, a_0 is the Bohr radius, R_0 is an average radius of the nucleus, $B(EL; L \to 0)$ is the reduced electric transition probability of the nuclear excitation, and ε_{nj} is the Sommerfeld energy. Relativistic units $\hbar = m = c = 1$ with the fine-structure constant α are used.

We have also calculated numerically the NP corrections due to various nuclear excitations in $^{238}_{92}$U ion. To generate whole spectrum of the Dirac equation, B-spline method (see ref.[4] was used. The results of calculations are given in the Table. Upper half: The contributions from low-lying nuclear states are calculated using the experimental energies E_L and transition probabilities [5]. Lower half: The contributions from the isoscalar and isovector giant resonance states. Their excitation energies are estimated using an empirical formula [6]. The strength of each respective electric multipole is determined by energy-weighted sum rules [6]. Column (a) corresponds to the numerical calculations in the frames of B-spline method; (b) – analytical evaluations. Value λ is equal to 2 for the monopole excitations or multipolarity L in all other cases.

Table

E_L, MeV	L	$B(EL; L \to 0)$ (e^2b^λ)	$-\Delta E^L_{1s}$, meV		$-\Delta E^L_{2s}$, meV		$-\Delta E^L_{2p_{1/2}}$, meV	
			a	b	a	b	a	b
0.0449	2^+	2.460	131.1	125.4	25.1	23.9	2.9	2.7
0.732	3^-	0.082	1.7	1.6	0.3	0.3	0.0	0.0
0.967	2^+	0.003	0.2	0.2	0.0	0.0	0.0	0.0
0.998	3^-	0.029	0.6	0.6	0.1	0.1	0.0	0.0
1.037	2^+	0.013	0.6	0.6	0.1	0.1	0.0	0.0
1.060	2^+	0.026	1.3	1.3	0.3	0.3	0.0	0.0
1.170	3^-	0.023	0.5	0.4	0.1	0.1	0.0	0.0
1.224	2^+	0.004	0.2	0.2	0.0	0.0	0.0	
Total low-lying states			136.2	130.3	26.0	24.8	2.9	2.7
10.149	2^+	0.192	7.7	9.8	1.5	1.9	0.2	0.2
10.149	3^-	0.159	2.8	3.0	0.5	0.6	0.1	0.1
10.149	4^+	0.117	1.3	1.3	0.2	0.3	0.0	0.0
12.856	1^-	0.218	45.4		8.7		1.0	
13.533	0^+	0.721	9.6		1.9		0.2	
21.652	2^+	0.143	4.5	7.3	0.9	1.4	0.1	0.2
21.652	3^-	0.119	1.7	2.3	0.3	0.4	0.0	0.0
21.652	4^+	0.087	0.9	1.0	0.2	0.2	0.0	0.0
27.065	0^+	0.572	5.5		1.1		0.1	
Total giant resonances			79.4		15.3		1.7	
Total shift			215.6		41.3		4.6	

REFERENCES

1. *Plunien G. et al.*, //Phys.Rev., 1989. **A39**. 5428.
2. *Plunien G. et al.*, //Phys.Rev., **A43**. 5853. 1991.
3. *Labzowsky L.N., Nefiodov A.V.* //Phys.Let., 1994. **A188**. 371.
4. *Johnson W.R., Blundell S.A., Sapirstein J.* //Phys.Rev., 1988. **37A**. 307.
5. *Shurshikov E.N.* //Nuclear Data Sheets. 1988. **53**. 601.
6. *Hoffmann B., Baur G., Speth J.* //Z.Phys., 1984. **A315**. 57..