Diamagnetic effect on intensities of atomic lines

V.D. Ovsiannikov, and V.V. Chernushkin

Physics Department, Voronezh State University
Universitetskaya pl. 1, 394693, Voronezh, Russia
Tel +7-0732-789756, Fax +7-0732-789755
E-mail: vit@ovd.vsu.ru

The variation of atomic line intensities in a magnetic field provides essential information both for determining the basic laws of atom-field interaction and for detection and measurement of the field. The influence of the diamagnetic interaction on intensities has been studied in detail for hydrogen atoms. The field-induced corrections to the radiation matrix elements have been presented in analytical form for the dipole transitions between Zeeman diamagnetic manifolds [1]. In a manielectron atom the states with low orbital momentum are separated from the degenerate Zeeman manifold, so the perturbation theory for nondegenerate states may be effectively used in the range of fields $B \ll B_0/\nu^3$, where $B_0 = 2.35 \times 10^5\,T$ is the atomic unit field and $\nu = 1/\sqrt{-2E}$ is the effective principal quantum number of the upper level.

We consider the first-order diamagnetic corrections to the dipole matrix elements, caused by the field-induced modification of the initial-state $|1\rangle = |nlm\rangle$ and final-state $|0\rangle = |n'l'm'\rangle$ wave functions. The matrix element is presented in the form of power series of the magnetic field:

$$d_{if}(B) = d_{10}\left(1 + \sum_{s=1}^{\infty} q_{10}^{(s)} B^{2s}\right). \tag{1}$$

where d_{10} is the field-free matrix element and $q_{10}^{(s)}$ is the field-independent atomic factor. The first-order term ($s = 1$) may be presented in the form of ratios between the second-order and first-order matrix elements. After integration over angular variables the linear combination of corresponding radial matrix elements may be written as

$$q_{10}^{\mu}(nlm) = \sum_{p=0,\pm2} A_p^{\mu}(l,m;l')a_p(nl;n'l') \tag{2}$$

— for the contribution of the field-induced variation of the initial state,

$$q_{10}^{\mu}(n'l'm') = \sum_{p=0,\pm2} A_p^{-\mu}(l',m';l)a_p(n'l';nl) \tag{3}$$

— for the contribution of the field-induced variation of the final state. Here $A_p^{\mu}(l,m;l')$ is the ratio of the angular matrix elements; $\mu = 0\,(\pm1)$ for the polarization of photons along (perpendicular to) the magnetic field vector $\mathbf{B}$,

$$a_p(nl;n'l') = \frac{\langle nl|r^2 g_{l+p}^{(nl)} r|n'l'\rangle}{\langle nl|r|n'l'\rangle} \tag{4}$$

is the ratio of the radial matrix elements.

In addition to modification of dipole matrix elements, the magnetic field induces dipole transitions between states with difference between angular momenta $\Delta l = \pm 3, \pm 5$, etc. The field-induced dipole matrix element may be written to the lowest order in B^2 as $d_{n_3 n} B^2$. The expressions for the field-independent factor $d_{n_3 n}$ are quite similar to those given in equations (2)–(4) for the factor q. Thus, the intensity of the field-induced line may be presented in terms of intensity for the field-free emission, as follows

$$I_{n_3 l+3 \to nl} = \eta I_{n_1 l+1 \to nl} B^4, \qquad (5)$$

with atomic parameter η determined by the ratio of frequencies and matrix elements of induced and field-free transitions:

$$\eta = \left(\frac{\omega_{n_3 n}}{\omega_{n_1 n}}\right)^4 \left(\frac{d_{n_3 n}}{d_{n_1 n}}\right)^2 . \qquad (6)$$

An important feature of this factor is its rapid increase which exceeds essentially the increase of the field-induced shift and splitting of the line frequencies with the principal quantum number of the upper level. Thus, the dependence of the factor η on ν_3 as estimated on the basis of the hydrogen-like model, is:

$$\eta = a_\beta \nu_3^\beta, \qquad (7)$$

where $\beta \approx 11 \div 12$. The numerical computations have demonstrated β to be rather 12. Such a rapid increase of the field-induced radiation matrix elements provides possibilities to develop new spectroscopic methods with the use of moderate magnetic fields, specifically the magnetically-induced access to highly excited Rydberg F-states appears in one-photon transitions from the ground atomic level.

The numerical values of the factor η corresponding to the ratio of intensities for the transitions to the ground and metastable states of helium and ground states of alkali atoms from some first F-states and from the first P-state are given in the table. Corresponding asymptotic factor a_{12} is presented in the last column of the table. The data demonstrates in particular, that the intensity of transition $8^1F_3 \to 2^1S_0$ in helium will achieve a quarter of intensity for the strongest resonant line of the $2^1P_1 \to 2^1S_0$-transition in the field of $B = 10\,T$.

Atom	$4F \to nS$	$5F \to nS$	$6F \to nS$	$7F \to nS$	a_{12}
He $1S$	9.64(8)	2.38(10)	3.92(11)	9.64(12)	3.3(2)
He $2\,^1S$	1.27(11)	3.60(12)	6.34(13)	1.62(15)	6.0(4)
He $2\,^3S$	2.12(8)	4.55(9)	4.26(10)	2.52(11)	1.2(2)
Li $2S$	2.30(7)	5.24(8)	5.57(9)	3.67(10)	27
Na $3S$	7.40(4)	1.17(5)	7.60(5)	6.71(6)	3.4(-2)
K $4S$	1.13(4)	1.13(6)	1.77(7)	1.41(8)	1.6(-1)
Rb $5S$	4.00(3)	6.31(4)	2.58(6)	2.77(7)	5.2(-2)
Cs $6S$	5.98(3)	5.16(4)	2.48(6)	2.72(7)	5.3(-2)

[1] V. D. Ovsiannikov and V. V. Chernushkin, *JETPh* **89** 618 (1999).