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An alternative method of investigation of radiative lifetimes in atoms and ions

ABSTRACT

A method for theoretical investigation of radiative lifetimes, which does not require knowledge of the transition probabilities between the level under investigation and all the possible lower lying levels is proposed. The method is based on the analytical summation of the transition probabilities with the use of the averaged transition energy (method A), or with the correct transition energy (method B). The numerical results obtained are compared with the experimental and other theoretical data.

DESCRIPTION

The radiative lifetime τ of the level LSJ of the excited configuration, π, under investigation is given by the expression

$$\tau_{\pi LSJ}=(A_{\pi LSJ})^{-1} = \Big| \sum_{\pi'L'S'J'} A_{\pi LSJ\to\pi'L'S'J'} \Big|^{-1}. \qquad (1)$$

In practice the total transition probability is influenced only by electric dipole (E1) transitions (the numerical values of the higher multipole transition probabilities are much smaller). The direct application of (1) requires knowing the energy of lower levels, and the numerical summation of all possible transition probabilities.

METHOD A

When the configuration under investigation is highly excited one can substitute for the correct transition energy $\Delta E_{\pi LSJ\to\pi'L'S'J'}$ the average energy $\Delta \overline{E_{\pi\to\pi'}}$ as was suggested by Rajnak and Wybourne (1963) in their study of correlation effects in the term structure of configurations. In the present case use of the same approximation simplifies the expression for the total transition probability and leads to the following definition of the matrix element of the effective transition operator:

$$A_{\pi LSJ\to\pi'L'S'J'} =\overline{(\Delta E_{\pi\to\pi'})^3}(\pi LSJ|T_{eff}|\pi LSJ) = \overline{(\Delta E_{\pi\to\pi'})^3}(\pi LSJ|Q_L Q_L|\pi LSJ) = \overline{(\Delta E_{\pi\to\pi'})}(\pi LSJ|Q_V Q_V|\pi LSJ). \qquad (2)$$

An explicit expression for the radiative lifetime of the configuration under investigation $\pi\equiv(n_1l_1)^{N_1}(n_2l_2)^{N_2}$ was obtained by the use of the technique of electron creation and annihilation operators (Judd, 1967) and has the following form (units ns) (Bogdanovich et al. 1985, 1986):

$$\tau_{\pi LS}= \{21.42\ [\overline{(\Delta E_{\pi\to\pi'})^3}(\ g_1((l_1)^{N_1}(l_2)^{N_2}\ LS) + N_2(2l_2+1)^{-1}(l_2\|C^{(k)}\|l_1)^2)\langle n_1l_1\|r\|n_2l_2\rangle^2 + \sum_{\pi''}\overline{(\Delta E_{\pi\to\pi''})^3}\ N_2(2l_2+1)^{-1}(l_2\|C^{(k)}\|l_3)^2 * \langle n_2l_2\|r\|n_3l_3\rangle^2]\}^{-1}, \qquad (3)$$

where $\pi'\equiv(n_1l_1)^{N_1+1}(n_2l_2)^{N_2-1}$ and $\pi''\equiv(n_1l_1)^{N_1}(n_2l_2)^{N_2-1}\ n_3l_3$. This expression can easily be written in the velocity form by replacing the radial integral and the power of the transition energy $\overline{\Delta E^3}\to\overline{\Delta E}$.

METHOD B

In the general case of two open shells the summation can be performed without any approximation for the transition energy, but the corresponding expressions are much more complicated and contain the matrix elements of 2-,3-, and 4-body effective operators, if the transition operator in the velocity form is used ($H_{eff}\equiv Q_V Q_V$). Particular expressions for the radiative lifetimes of the configuration $(n_1l_1)^{N_1}\ n_2l_2$ (the transitions to the lower configuration $(n_1l_1)^{N_1}\ n_3l_3$ are included) have been published by Bogdanovich et al. (1988). The corresponding expression for the case of the configuration $(n_1l_1)^{N_1+1}$ being the lower one has been obtained by the author and will be published elsewhere.

RESULTS

From the comparison of the numerical results (table I) we conclude that the method proposed allows one to obtain radiative lifetimes which are in good agreement with experiment and with other theoretical data.

The formulas for the radiative lifetimes expressed in terms of the few-body effective operators allow us to apply a least-squares fitting procedure to the radiative lifetime calculations.

Table I. Comparison of the lifetimes (ns) obtained by various methods.

Ar II $3p^4(^3P)4d\ ^4P_{5/2}$

This work Q_L	Meth.(A) Q_V	ref. 1 exp.	ref. 2 exp.
3.7	4.1	3.9±0.4	4.4

Kr II $4p^4(^3P)5p\ ^4D_{5/2}$

This work(A) Q_L	Q_V	ref.3 exp.	ref.4 exp.	ref.2 exp.	ref.5 theo.	ref.6 exp.
9.89	11.19	11.2 ±0.80	10.18 ±0.40	7.6	9.6	9.55 ±0.31

Ne II $2p^4(^3P)3p\ ^4P_{5/2},\ ^4D_{7/2}$

This work(B) Q_L	Q_V	ref. 2 exp.	ref. 5 theo.	ref. 7 exp.
7.20	6.62	7.4	6.95	6.3
5.64	6.12	5.2	5.05	5.5

References

1: Blagoev 1983
2: Fink et al. 1970
3: Blagoev 1981
4: Donnelly et al. 1975
5: Koozekanani and Trusty 1969
6: Ward et al. 1985
7: Luyken 1971

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