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LETTERS TO THE EDITOR

A SIMPLE MODEL FOR PENNING IONIZATION

R. K. JANEV, D. M. DAVIDOVIĆ and A. R. TANČIĆ

Institute »Boris Kidrič«, Beograd

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The Penning ionization has been treated quantum-mechanically in the perturbed stationary state approximation[1] and Green operator as well as Fano's formalism[2].

In this note we shall present a simple model for this process based on the zero-potential approximation. The electron wave function in this approximation is of the form[3]

$$u(r) = A \frac{e^{-\alpha r}}{r}, \tag{1}$$

where $\frac{\alpha^2}{2} = -E$ is the electron binding energy and A is a constant. The effect of the atomic potential in this approximation is expressed by the boundary condition

$$\left[\frac{1}{ru} \frac{\partial}{\partial r} (r u)\right]_{r \to 0} = -K, \tag{2}$$

where K^{-1} is the scattering length. For the active electron in our process we have a superposition of the wave functions of the type (1) i. e.

$$\Psi(r_a, r_b) = A \frac{e^{-\alpha_a r_a}}{r_a} + B \frac{e^{-\alpha_b r_b}}{r_b}, \tag{3}$$

and two boundary conditions of the type (2). These two conditions give a system of two equations for the constants A and B, and the condition of existence of non-trivial solutions is:

$$(K_a - \alpha_a)\,(K_b - \alpha_b) = \frac{e^{-(\alpha_a + \alpha_b) R}}{R^2} \,. \tag{4}$$

As the state (b) is metastable it is characterized by a complex energy $E_b = E_o - i\,\frac{\Gamma}{2}$ i.e. $\alpha_b = \alpha_{bo} + i\,\gamma_b$.

Therefore from (4) we obtain two equations

$$\begin{aligned} (K_b - \alpha_a)\,(K_a - \alpha_{bo}) &= \frac{e^{-(\alpha_a + \alpha_{bo}) R}}{R^2} \cos(\gamma_b R) \,, \\ (K_b - \alpha_a) \cdot \gamma_b &= \frac{e^{-(\alpha_a + \alpha_{bo}) R}}{R^2} \sin(\gamma_b R) \,, \end{aligned} \tag{5}$$

which reduce to

$$\frac{\gamma_b}{K_a - \alpha_{bo}} = \mathrm{tg}\,(\gamma_b R) \,. \tag{6}$$

The quantities α_{bo} and γ_b as well as

$$E_o = \frac{\gamma_b^2 - \alpha_{bo}^2}{2} \,, \quad \Gamma = \alpha_{bo}\,\gamma_b$$

depend on the internuclear distance R. As the atoms approach each other, $\Gamma(R)$ spreads and at some $R = R_o$ it becomes equal to the energy difference Δ of the metastable and the ground state. At this distance the real part of E_b must be equal to the energy ε_o of the ground state. So, we have at $R = R_o$

$$\begin{aligned} \gamma_b^2(R_o) - \alpha_{bo}^2(R_o) &= 2\,\varepsilon_o \,, \\ \alpha_{bo}(R_o)\,\gamma_b(R_o) &= \Delta \,. \end{aligned} \tag{7}$$

Reaching the point $R = R_o$ atom B relaxes and the released energy ejects the electron from the atom A. So, the cross section of the process is given by πR_o^2. We can determine R_o from Eq. (6). The apparent multivaluedness in the determination of R_o by using (6) is removed by the analysis of the system (5).

As an illustration of the model, we calculated the Penning ionization of Ar, Kr, and Xe atoms in the collision with He (2^3S) metastable atom. The scattering lengths K_a^{-1} for Ar, Kr and Xe are taken from ref.[4]. The calculated

Table

	σ_{theor} $[10^{-16}\ cm^2]$	σ_{exper} $[10^{-16}\ cm^2]$
Ar	6.04	0.93 — 10
Kr	3.02	9.8 — 10.3
Xe	2.44	10 — 13.9

cross-sections are given in the Table, together with the experimental values[5]. The comparison shows that this simple model predicts the order of magnitude of the cross-sections satisfactorily.

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