LETTER TO THE EDITOR

Position and width of the resonance in electron–potassium scattering from self-broadening of Rydberg states

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Abstract. The parameters of the resonance in electron scattering by potassium ground-state atoms are obtained by the use of experimental data on the self-broadening of the Rydberg states. These parameters are close to the results of a variational calculation. The possibility of the extension of the method to other atoms and molecules is discussed.

It has long been recognised (Fermi 1934, Firsov 1951, Alekseev and Sobel'man 1965) that electron–atom and electron–molecule interactions can be studied on the basis of experiments on the broadening and shift of a high-Rydberg series perturbed by neutral species. Later Matsuzawa (1975, 1977), Kaulakys et al (1979) and Kaulakys (1980) have pointed out theoretically that in such a way one can detect and investigate an isolated resonance in the elastic scattering of an extremely slow electron by an atom or molecule. The supposition (Kaulakys et al 1979, Kaulakys 1980) that there is a ^{3}P resonance in the scattering of a slow electron by an alkali-metal atom allowed us to explain the oscillations in the dependence of the widths and shifts of Cs(np) levels as a function of n in self-broadening experiments (Mazing and Serapinas 1971). From a comparison of the theory with the experimental data the energy E_p and width Γ of such a resonance in the scattering of an electron by a caesium ground-state atom were obtained. Later the oscillations of the widths of Rb(ns) levels in rubidium self-broadening experiments were observed (Stoicheff and Weinberger 1980) and the parameters of the ^{3}P resonance for Rb were obtained (Kaulakys and Serapinas 1980, Rabin and Rebentrost 1982).

The purpose of the present letter is to calculate the resonance parameters for electron scattering by potassium ground-state atoms with the help of the data on the pressure broadening and shift of the K(ns) and K(nd) series in self-broadening experiments (Stoicheff et al 1981) and then to compare these parameters with the results of a variational calculation (Sinfailam and Nesbet 1973). Potassium is the first element we know of for which such a comparison is possible. In addition, the possibility of extending the method to the detection and investigation of the resonances in the scattering of very slow electrons by other atoms and molecules and the validity criteria of the method are discussed.

The resonance parameters for scattering of a low-energy electron by a ground-state atom or molecule can be obtained from a comparison of the experimental oscillating components of the line widths and shifts as a function of n with the theoretical expressions (Matsuzawa 1975, 1977, Kaulakys et al 1979, Kaulakys 1980). The

oscillating components of the width, γ_{osc}, and shift, Δ_{osc}, of the nl Rydberg levels are related to the parameters E_p and Γ of the resonance according to (Kaulakys 1980):

$$\gamma_{osc} = -(-1)^l 2B \cos[4n^* \tan^{-1}(q_p n^*)] \tag{1}$$

$$\Delta_{osc} = (-1)^l B \sin[4n^* \tan^{-1}(q_p n^*)] \tag{2}$$

where

$$B = \frac{2\pi N(2L_p+1)(2S_p+1)\Gamma n^*}{(2S+1)q_p^2(1+q_p^2 n^{*2})^2} \exp\left(-\frac{2\Gamma n^{*2}}{q_p(1+q_p^2 n^{*2})}\right). \tag{3}$$

In equations (1)–(3), n^* is the effective quantum number, q_p is the electron momentum at resonance $(E_p = q_p^2/2)$, L_p and S_p are the resonance angular momentum and spin, S is the perturbing atom spin and N is the perturber density. In equation (3) an approximation

$$\left(\frac{1+q_p^2 n^{*2}-\Gamma n^*/q_p}{1+q_p^2 n^{*2}+\Gamma n^*/q_p}\right)^{n^*} \simeq \exp\left(-\frac{2\Gamma n^{*2}}{q_p(1+q_p^2 n^{*2})}\right) \tag{4}$$

is used.

The resonance energy E_p can be estimated from a comparison of the period of the measured γ_{osc} and Δ_{osc} against n^* with the period of the oscillations described by equations (1) and (2). The damping behaviour of the oscillations yields the value of Γ. Note, that the amplitude of the oscillations B as a function of n^* achieves its maximum value B_{max} at $n^*_{max} = \frac{1}{2}(q_p/\Gamma)^{1/2}$ and if $q_p n^* \ll 1$

$$B_{max} = \frac{\pi N(2S_p+1)(2L_p+1)}{(2S+1)q_p}\left(\frac{\Gamma}{eq_p}\right)^{1/2}. \tag{5}$$

However, under the conditions of the impact approximation for collision broadening the oscillations of the line widths and shifts as a function of n cannot be observed if $2\sigma' \geq \sigma_g$, where σ' is the broadening cross section $(\gamma = 2\langle\sigma'v\rangle N)$, v is the relative velocity of collision and σ_g is the geometrical cross section defined by:

$$\sigma_g = \pi\langle r_e^2\rangle = \frac{1}{2}\pi n^{*2}[5n^{*2}+1-3l(l+1)]. \tag{6}$$

For collisions with alkali atoms $2\sigma' > \sigma_g$, if $n^* < n_0^* \approx 20$. Therefore, under the condition of $n^*_{max} < n_0^*$ the resonance width Γ cannot be estimated from equation (5), but can be estimated from the damping behaviour of the oscillations at $n^* > n_0^*$.

In figure 1 the plots of the theoretical γ_{osc} and Δ_{osc} (equations (1)–(3)) with E_p and Γ calculated by Sinfailam and Nesbet (1973) and found by comparing the theory with experimental data are shown together with the experimental results for potassium (Stoicheff *et al* 1981). The theory, as we see, describes well the oscillation of the line widths and shifts in the potassium self-broadening. The parameters of the resonance in electron–potassium scattering, E_p and Γ, obtained from a comparison of the theory with the experimental data are close to the parameters calculated by Sinfailam and Nesbet (1973). This testifies that, on the one hand, the reason for the oscillations in the line widths and shifts of the Rydberg states of the alkali-metal atoms is indeed the existence of the resonances in the slow electron scattering by alkali-metal ground-state atoms and the parameters of such resonances can be obtained reliably from the experimental data; on the other hand, the calculation of the scattering of slow electrons from complex atoms by Sinfailam and Nesbet (1973) is rather accurate. Table 1
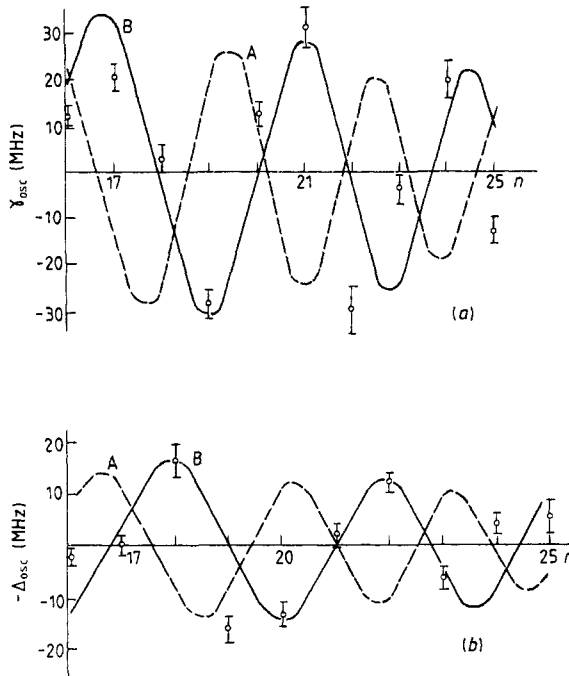
Figure 1. Oscillating components of the line widths (a) and shifts (b) of $4S \rightarrow nS$ transitions as a function of n for $K^{**} + K$ (pressure, 30 mTorr). Experiment: $\bigcirc$, Stoicheff *et al* (1981); theory: equations (1)–(3), curve A, with $E_p = 2.4$ meV, $\Gamma = 0.58$ meV (Sinfailam and Nesbet 1973), curve B, with $E_p = 1.7$ meV, $\Gamma = 0.47$ meV (present work).

Table 1. Energy E_p and width Γ of the ^3P resonance in electron scattering by alkali atoms in meV

	Theoretical[a]		Experimental[b]	
	E_p	Γ	E_p	Γ
Li	60	57		
Na	83	85		
K	2.4	0.58	1.7[c]	0.47[c]
Rb			1.3[d]	0.40[d]
			1.7[e]	0.50[e]
Cs			0.75[f]	0.30[f]

[a]Sinfailam and Nesbet (1973).
[b]Based on theory of Kaulakys *et al* (1979), Kaulakys (1980).
[c]Theory: present work; experimental data: Stoicheff *et al* (1981).
[d]Theory: Kaulakys and Serapinas (1980); experimental data: Stoicheff and Weinberger (1980).
[e]Theory: Rabin and Rebentrost (1982); experimental data: Stoicheff and Weinberger (1980).
[f]Theory: Kaulakys *et al* (1979); experimental data: Mazing and Serapinas (1971).

presents the parameters of the ^3P resonances for alkali-metal atoms calculated theoretically (Li, Na, K) and obtained from experimental data (K, Rb, Cs).

From equation (3) one can estimate the amplitudes of the oscillations in the widths and shifts of the Rydberg states which are dependent on a resonance with given parameters, if $n^* > n_0^*$. Thus, if the parameters of the resonance for Na are close to those presented in table 1, the amplitudes of the oscillations of the width and shift of the Rydberg states of Na for self-broadening will be about four orders smaller than for K. On the other hand, the validity criterion of the impact approximation in collision broadening theory $4\sigma'n^{*2}N \ll 1$ restricts the perturber density N used in experiments. Therefore this method of detection and investigation of the resonances in electron scattering by atoms and molecules can only be applied to the search for the narrow resonances with widths $\Gamma \leq 10^{-3}$ eV.

For a full verification of the theory it is of interest to measure the broadening and shift of the Rydberg states of atoms of one alkali, for example sodium, perturbed by atoms of another alkali, for example rubidium. It follows from the theory that the result must depend on the species of perturbing atoms only and be independent of the species of Rydberg atoms. It would be of interest to measure Rydberg line widths and shifts of atoms in an atmosphere of various species of atoms and molecules with the purpose of detecting resonances in the electron–atom and electron-molecule scattering.

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