RESONANCES IN LOW-ENERGY POSITRON–ALKALI SCATTERING

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ABSTRACT

We have performed close-coupling calculations with up to five target states at energies in the excitation threshold region for positron scattering from Li, Na and K. We have discovered resonances in the $L = 0$, 1 and 2 channels in the vicinity of the atomic excitation thresholds. The widths of these resonances vary between 0.2 and 130 meV. As well we have found evidence for the existence of positron–alkali bound states in all cases.

INTRODUCTION

Our previous calculations of the total and excitation cross sections[1-3] for e^+- alkali scattering are in reasonable agreement with experiment[4-7] and similar to electron scattering calculations. We have concentrated recently on the detailed study of phase shifts and eigenphase sums in the region of very low energies.[8]

One interesting observation is that for all three alkali atoms under study, namely Li, Na and K, the s-wave phase shifts start at a positive multiple of π rad. This is to be contrasted with similar electron scattering calculations where the phase shift approaches zero at zero energy.[9] The behaviour, just below the first excitation theshold, of our s-wave phase shifts for Na and K is, however, similar to that observed in relativistic R matrix calculations of e^--Cs scattering.[10] If Levinson's theorem holds for these systems (it is not valid for electron scattering due to exchange) then this implies that there are stable (e^+-alkali) bound states. However, since positronium formation is energetically allowed at zero energy, these states may be embedded in the continuum of the Ps–alkali$^+$ system.

RESULTS

The $L = 0$, 1 and 2 resonances found in our calculations are summarized in table 1. It is not clear how these resonances will be affected by the inclusion of positronium channels in the close-coupling expansion. A study of the possibility of e^+-alkali bound states ideally would be performed using either the complex coordinate method[11] or the hyperspherical coordinate method.[12,13] It is expected that, due to the $ns-np$ level degeneracy of positronium, additional resonances associated with excited positronium configurations will appear.[14]

TABLE 1. Resonance parameters for positron scattering from Li, Na and K in the close-coupling approximation. Resonance positions are given in eV, full widths in meV.

	Li		Na		K	
	E_{res}	Γ	E_{res}	Γ	E_{res}	Γ
S(1)	1.86 *	35	1.985	0.4	1.5	1.7
S(2)	3.01	40	3.195	0.2	2.45	0.54
S(3)	3.365	1	3.62	4		
P(1)	3.11	130	2.065	6	1.57	1.8
P(2)			3.124	32		
D(1)	3.19	110	3.2	30		

* This resonance features a variation in the eigenphase sum of only 2 rad.

Below the $ns-np$ threshold we observe s-wave and p-wave resonances in both Na and K with widths in the meV range. The inclusion of the 3d as well as the $(n+1)s$ states is crucial in order to obtain these resonances. Since the e^+-alkali system has not been studied in detail for bound states, it is difficult to classify the resonances. The necessity of including the above mentioned states in the close-coupling expansion indicates that the dipole polarization potential alone is not sufficient but that contributions from the quadrupole polarization potential are also important in order to obtain resonances. Since more than one state in the close-coupling expansion contributes to the development of these resonances it is also evident that the electronic wavefunction for these quasi-bound Ps–alkali$^+$ states consists of a superposition of several target states. Similarly the positronic wavefunction is expected to be complicated.

In figure 1 we show the contributions to the elastic cross section for e^+-Na scattering from the lowest four partial waves below the "resonant" 3s–3p excitation threshold. It is clear that the s-wave resonance which is situated over 0.1 eV below this threshold will be hard to measure due to its small width and the small overall contribution of that partial wave to the total cross section at this energy. The p-wave resonance, however, with its relatively broad width should be detectable once positron scattering measurements achieve energy resolutions which are comparable to those of electron scattering.
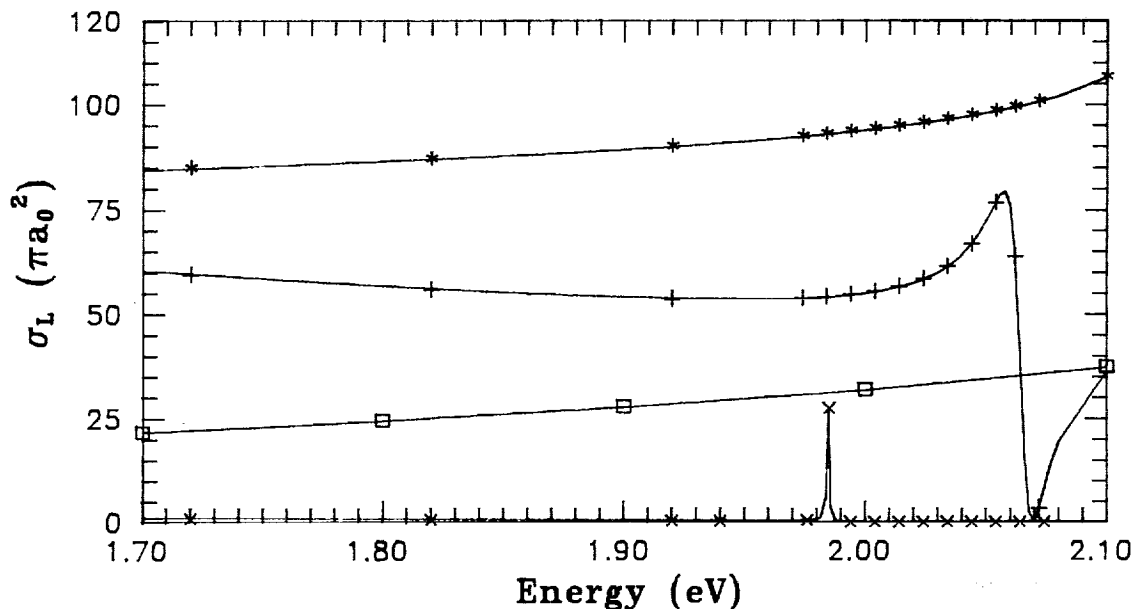

FIG. 1. Partial wave elastic cross sections (in πa_0^2) for $L = 0$, $\times$; $L = 1$, $+$; $L = 2$, $*$ and $L = 3$, $\square$, e^+-Na scattering in the (3s–3p–4s–3d–4p) model potential close-coupling approximation.

The shape of this resonance is somewhat different from the corresponding one in the e^+-K system; there the p-wave resonance appeared as a fully destructive resonance due to the fact that in the vicinity of the resonance the contribution of the p-wave to the cross section was close to its maximum possible value.

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