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Inelastic Scattering of Positrons with Sodium

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Abstract

The two potential approach is used to study the resonant 3s-3p excitation of sodium atom by positrons of energy 40 and 54.4ev.The angular variation of coherence and correlation parameters is presented. Comparison with the corresponding parameters in electron scattering is given to see the role of various interaction potentials in electron and positron scattering.

1 Introduction

The development of positron beams of well defined energy has led to several experimental studies on the scattering of positrons with atomic and molecular systems. Measurement of total and differential cross-sections for various excitation and ionization processes are in progress at several laboratories. In comparison to the total and differential cross-sections, the study of angular correlation parameters provides a much deeper insight into the dynamics of atomic and molecular collision process. Such studies have now become possible with electron beams. With the rapid development in positron beam technology it is expected that in near future angular correlation and polarization correlation measurements with positrons will become feasible. The positron scattering differs from electron scattering in many ways, such as the absence of exchange in positron scattering and absence of positronium formation in electron scattering. The nature of the static potential is different in the two cases. It is repulsive for positrons and attractive for electrons. This coupled with attractive polarization in both the cases leads to totally different distortion of the incident positron and electron wavefunctions. A relative comparison of electron and positron scattering therefore leads to significant information on the nature of the interaction potential.

Since sodium atomic targets are most suitable for experiments, we report here a theoretical study on the resonant 3s-3p excitation of sodium atom by positrons at intermediate energies of 40 and 54.4ev, where positronium formation cross-section would be negligible. The theoretical approach we follow is based on the two potential formalism[1], which has been found to yield reliable results at intermediate energies in our earlier work on electron scattering[1,2]. We present here the angular variation of the correlation parameters $(\lambda, \chi, < L_Y >)$ and the polarization parameters $(P1, P2, P, \gamma)$ for positron impact. Relative comparison with electron scattering is also given.

2 Theory

The T matrix for positron scattering, in the framework of the two potential approach, is given (to the first order) by[3],

$$T =< \phi_f \mid U \mid \chi_i^+ > + < \chi_f^- \mid W_f \mid \chi_i^+ > \quad (1)$$

where the total positron sodium interaction potential V in a channel j is divided as,

$$V = U_j + W_j \quad (2)$$

The distorted waves are the solution of Schroedinger equation,

$$(H_0 + U_{i,f})\chi^+_{i,f} = E\chi^+_{i,f} \tag{3}$$

The distorting potentials U_j are chosen as

$$U_j = V^j_S + V^j_P + V_C \tag{4}$$

where the static, polarization and core potentials for sodium are of the same form (except for the change of sign of static and core terms) as given in our earlier work[2] on electron sodium scattering. The differential cross-sections are given by,

$$\sigma = \sigma_0 + 2\sigma_1 \tag{5}$$

$$\sigma^{i\to f}_m = (1/4\pi^2)(k_f/k_i) \mid T^{i\to f}_m \mid^2 \tag{6}$$

The alignment and orientation parameters are defined as,

$$\lambda = \sigma_0/\sigma_1 \tag{7}$$

$$\chi = \arg(a_1/a_0) \tag{8}$$

$$< L_Y > = -2\sqrt{2} Im < a_0 a_1 > /\sigma \tag{9}$$

a_0 and a_1 are the excitation amplitudes for m=0 and m=1 magnetic substates. $<>$ denotes spin average.

The polarization of radiation emitted perpendicular to the scattering plane is given by,

$$P1 = [I(0^0) - I(90^0)]/[I(0^0) + I(90^0)] \tag{10}$$

$$P2 = \frac{[I(45^0) - I(135^0)]}{[I(45^0) + I(135^0)]} \tag{11}$$

$$P3 = \frac{[I(RHC) - I(LHC)]}{[I(RHC) + I(LHC)]} \tag{12}$$

The alignment angle of the charge cloud with respect to the incident positron direction is given by,

$$\gamma = 0.5 \arg(P1 + iP2) \tag{13}$$

The coherence of excitation is determined by the reduced polarization vector $\mid P \mid$ (which takes into consideration the depolarizing influence of unresolved fine and hyperfine structure of excited state of sodium[4],

$$\mid P \mid = [\mid P1/c_1 \mid^2 + \mid P2/c_1 \mid^2 + \mid P3/c_2 \mid^2]^{1/2}, \tag{14}$$

where $c_1 = 0.141$ and $c_2 = 0.558$. The angular distribution of the above parameters provides information about the shape and rotation of the excited state.

3 Results

Figure 1 shows the differential cross-sections for positron (solid curve) and electron impact (dashed curve) excitation of sodium to the 3p state at 40 and 54.4ev energies. We find that in the low angle region the positron and electron cross-sections are nearly equal. This is expected also, since the low angle scattering is dominated by polarization potential which is identical in the two cases. In the large angle region the differences come primarily due to the absence of exchange in positron scattering, and due to the different nature of static interactions in the two cases.

Figure 2 gives the angular variation of the λ parameter for positron and electron scattering at the two energies. We find that for positron impact only one minima is obtained while for electron impact two minimas are obtained. The position of the first minimum in electron scattering nearly coincides with that of positron scattering.

Figure 3 gives the angular variation of the expectation value of the angular momentum transferred during the collision in perpendicular direction by positrons and electrons. We see that the positron and electron orientation is of opposite sign for low and intermediate angles while for large angles it is of the same sign. This behavior of orientation in positron and electron scattering is also found in our earlier work on lithium[3].

Figure 4 gives the angular variation of polarization and alignment in positron and electron scattering at the two energies. It is seen that for positron scattering the alignment angle γ is negative in the whole angular range, thus showing that the charge cloud is always aligned away from the positron. The alignment in positron and electron scattering is nearly identical at low and at large angles.

The reduced polarization $|P|$ is almost unity in the entire angular region leading to coherent excitation by positrons.

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4 References

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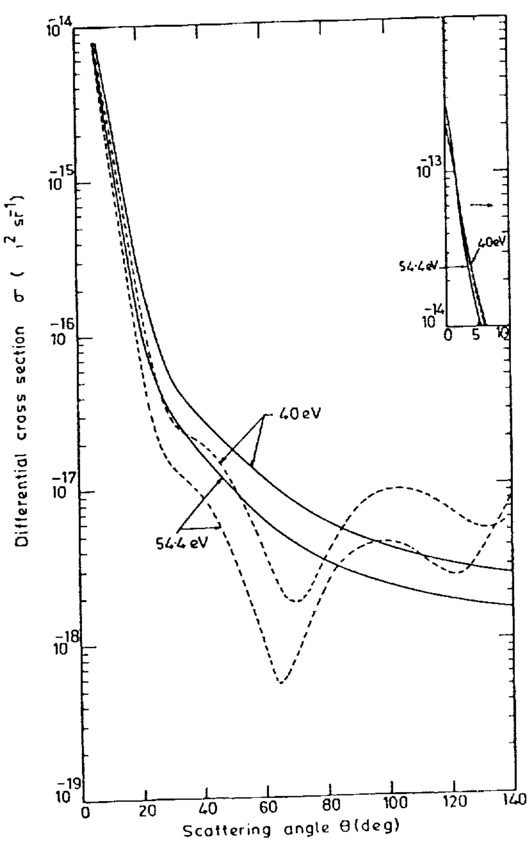

Figure 1

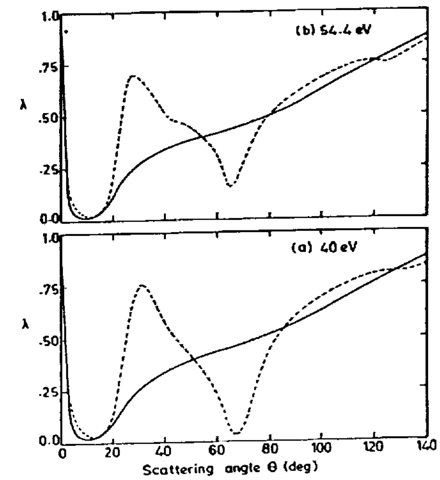

Figure 2

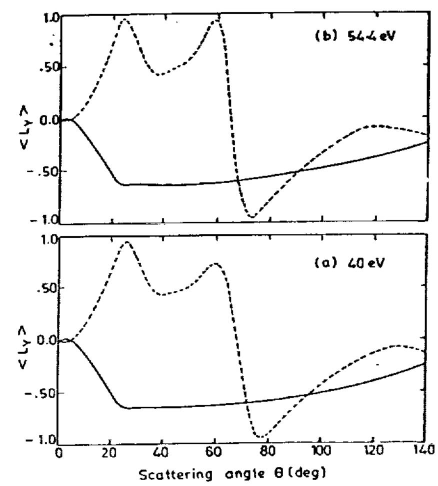

Figure 3

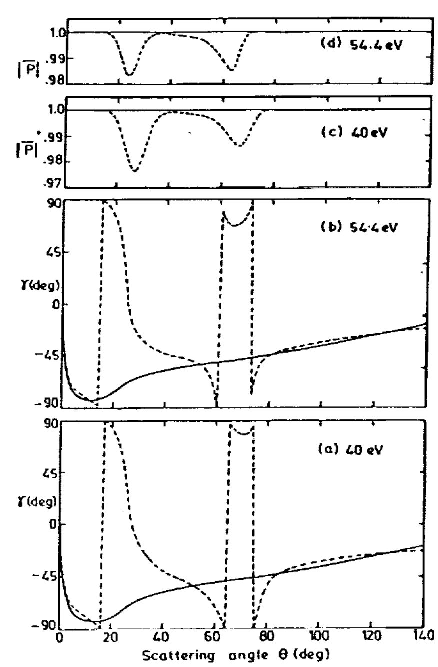

Figure 4