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Electron and Positron Collision with Neon at Intermediate Energies

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Abstract

In present paper differential scattering cross section and total scattering cross section for the first excited state of neon by electron as well as positron are reported and comparison is made with different available theoretical and experimental data. The present calculation is done with R matrix theory. We have chosen a complex type potential, a part of which is directly calculated from the target charge density and other part is taken from Baluja and Jain. The present work yields a satisfactory result for differential cross section while previously large discrepancies were found in theoretical and experimental data. More positron results are required for the best judgment of present calculation.

Key Words: R-matrix, Complex Potential, Electron, Positron

Introduction

The interaction of matter with antimatter is a burning as well as interesting field of atomic and molecular physics. One of the simplest of these types of interactions is collision between positron and an atom or molecule or ion. Such interactions are proved to be important in atomic physics and surface science [1]. They have great potential technical applications such as mass spectrometry. Apart from fundamental significance, the positron impact studies with matter have also an importance in the origin of astrophysical sources of annihilation radiation, as well as in the field of medicines, characterization of material [2] and so on. Thus understanding of basic physics behind positron interaction is knowledgeable for the development of aforesaid areas.

Since the positron is distinguishable from the electron in the target atoms, there are no exchange interactions for positrons. Meanwhile, the static interaction is repulsive for positrons, while it is attractive for electron. The polarization interaction is attractive for both particles. These differences and similarities provide in some interesting ways when comparison are made between the scattering of positrons and electrons by atoms. Therefore it is of interest to compare the positron scattering from a target with the scattering of electron for which more extensive theoretical and experimental data are available. During recent years there has been remarkable interest in measuring differential as well as total cross section for the scattering of positron by simpler inert gas atoms to provide test of various theoretical approximations. Neon is so chosen for the study because it is simplest gaseous atom in which observations are feasible due to decay radiations from many excited states. It possesses wavelengths in the visible region which are easily detected and their polarizations are measurable. Neon swarm (swarm is an ensemble of neon particle which do not interact with each other) collision with atom provide the important data applicable in modeling of low temperature neon plasmas. Also, neon is of interest for studies of gas laser, neon lamps and various problems in plasma physics, in addition data demands from astrophysicists. The aim of this investigation is to provide reliable cross section data for the excitation of neon by positron impact.

J. L. S. Lino [3] has reported differential cross section for electron neon collision using Schwinger variational principle in the energy range 130-500eV. His results were found in reasonable agreement with existing measurements. In the same year a large group of California [4] measured successfully differential scattering cross section (DCS) and cross sectional ratio for electron impact excitation of neon $2p^5 3s$ configuration. They have also calculated DCS with various theoretical approximations such as R-Matrix, distorted wave Born approximation, relativistic distorted wave etc. Apart from electron collision, positron impact excitation, ionization and positronium formation in noble gases are studied by various theoreticians as well as experimentalists. Marler *et al* [5] presented absolute measurement for positron impact cross section for direct ionization and positronium formation of noble gas atoms in the range of energies from threshold to 90eV. Recently Sullivan *et al* [6] have provided the experimental results of their measurements of low energy positron interaction with neon atom. An important theoretical investigation is done recently by Kothari and Joshipura [7]. They have reported total cross section (TCS) at incident energy above ionization threshold using complex potential formulism method.

The present study has several goals: first, to our knowledge, no theoretical using R-Matrix, close coupling method have yet been published for positron neon collision; second, to test the relevance of exchange effect at intermediate energies and large scattering angle by comparison of present result with the corresponding electron collision.

Theory

In this paper the dynamics of positron neon scattering are calculated under R-Matrix formulism. Throughout we shall use atomic units in which ħ=m_e=e=1.Denoting the position vector of i^{th} positron relative to atomic nucleus the Hamiltonian H for this system may be written as

$$H = -\frac{1}{4}\nabla_R^2 + H_{PS}(\bar{t}) + H_A(\bar{r}_1, \ldots \ldots \bar{r}_N) + V(r_p, r_0; r_1 \ \ldots . r_N) \quad \ldots. (1)$$

Where $\bar{t} = \bar{r}_p - \bar{r}_i, \quad i = 0,1,2, \ldots .. N$

H_{ps} is the positronium Hamiltonian

$$H_{PS}(\bar{t}) = -\nabla_t^2 - \frac{1}{t}$$

H_A is the atomic Hamiltonian

$$H_A(\bar{r}_1, \ldots \ldots \overline{r_N}) = \sum_{i=1}^{N}\left(-\frac{1}{2}\nabla_t^2 - \frac{Z}{r_i} + \sum_{j<i} \frac{1}{|\bar{r}_i - \bar{r}_j|}\right) \quad \ldots.. (2b)$$

and V is the interaction potential

$$V(r_p, r_0; r_1 \ldots \ldots r_N) = \left(\frac{Z}{r_P} - \sum_{i=1}^{N} \frac{1}{|r_p - r_i|}\right) - \frac{Z}{r_0} - \sum_{i=1}^{N} \frac{1}{|\bar{r}_0 - \bar{r}_i|} \quad \ldots. (2c)$$

We have taken the collision wave function for the system φ as

$$\varphi = \mathcal{A} \sum_a G_a(\bar{R}_0) \phi_a(\bar{t}_0) \chi (S_0) \varphi_0(\bar{X}_1, \ldots \ldots \ldots \ldots . . \bar{X}_n). \quad \ldots (3)$$

Here $\mathcal{A}$ is the electron antisymmetrization operator.

The one electron radial function are represented by a linear combination of Slater type orbitals

$$P_{nl} = \sum_{j=1}^{k} C_{jnl}\, r^{I_{jnl}} \exp\left(-\xi_{jnl}\, r\right) \quad \ldots. (4)$$

Where the parameters C_{jnl}, I_{jnl} and ξ_{jnl} also determined variationally.

The potential is so choosen which is a complex type potential and given by

$$V(r, E_i) = V_{st}(r) + V_{Pol}(r) + iV_{abs}(r) \quad \ldots. (5)$$

The static potential $V_{st}(r)$ is directly calculated from the target charge density. $V_{Pol}(r)$ is taken from Baluja and Jain [8] and given by

$$V_{Pol}(r) = \begin{cases} V_{corr}(r), & r \le r_c, \\ -\frac{\propto_d}{2r^4}, & r \ge r_c, \end{cases} \quad \ldots. (6)$$

Where r_c is the radial distance of first crossing of correlation term V_{corr}(r) and the asymptotic form $-\propto_d / 2r^4$. The imaginary part of complex potential is absorption potential $V_{abs}(r)$. It is used to account for all inelastic channels with incident positrons. The absorption potential depends on incident positron energy as well as target charge density. The scattering amplitude is obtained from the phase shift by

$$f(\theta) = \frac{1}{2iK}\sum_{l=0}^{l_{max}}(2l+1)[\exp(2i\delta_l) - 1]P_l(\cos\theta) + f_4(\theta) \quad \ldots. (7)$$

The function f_4 is the higher l contribution from the Born phase shifts for the dipole (~ $1/_{r^4}$) Part of the polarization potential. For this function, the closed form expression is

$$f_4(\theta) = -\pi k \alpha_d\left(\frac{\sin(\theta/_2)}{2} + \sum_{l=0}^{l_{max}} \frac{P_l(\cos\theta)}{(2l+3)(2l-1)}\right) \quad \ldots. (8)$$

The differential and total cross sections are obtained from the scattering amplitude in the usual manner

$$\frac{d\sigma}{d\Omega} = |f(\theta)|^2 \quad \ldots. (9)$$

$$\sigma_{tot} = \frac{4\pi}{k} I_m[f(0)] \quad \ldots. (10)$$

Results and Discussion

Using equations (9) and (10), we have calculated DCS and TCS respectively for positron neon excitation. For comparison purpose we have also computed these results for electron collision. The present results are also compared with other available theoretical results and experimental data in figure [1] and figure [2].

(a) Differential scattering cross section for neon

Figure [1] shows the Differential scattering cross section (DCS's) for positron and electron scattering of Neon [$2p^5$ 3s] at intermediate energy range using R matrix theory. In this figure we have plotted two theoretical calculations of Zuo *et al* [9]. One is (SC) represented by single configuration ground state calculation while other (MC) is multi configuration ground state. The only available experimental data of Khakoo *et al* [4] is also shown in this figure. Present curve (P_1) for positron scattering have good agreement in the range $45^0 \le \theta \le 90^0$ with the experimental data of Khakoo *et al* [4] as well as other theoretical results. At small angle, our calculated DCSs are higher than experimental value and it is smaller for high value of θ. The electron impact result (P_2) is very close but little higher with the experimental data of Khakoo *et al* [4] as well as MC and SC. They have calculated their results by considering the relativistic distorted wave approximation approach. In this figure, however we have observed that both maxima as well as minima are at almost angle as that of data and theoretical calculations.

(b) Total scattering cross section for neon

Figure [2] shows the variation of total scattering cross section (TCS) of neon [$2p^5$ 3s] with various incident energies. For comparison purpose we have plotted two experimental data *viz.* Griffith *et al* [11] and Kauppila *et al* [12] and a theoretical result of Dewangan and Walters [10]. Our positron total scattering cross sections have similar nature as that of experimental data of Griffith et al and Kauppila *et al*. The present calculated theory for positron (P_1) is higher than both data. It is significant that our present positron results are in a close agreement with theoretical result of Dewangan and Walter [10]. The electron impact total scattering cross section (P_2) result show a good agreement with experimental data.

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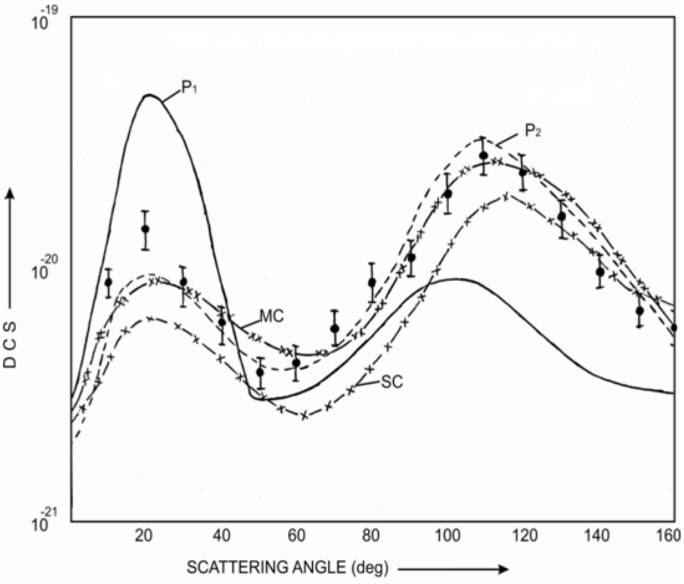

Fig. 1: Positron (electron) impact excitation of Neon at 100eV

: Present Positron results (P_1)
: Present Electron results (P_2)
: Experimental data of Khakoo *et al* [4]
: RDWA Zuo *et al* (SC) [9]
(SCGS - single configuration ground state)
: RDWA Zuo *et al* (MC) [9]
(MCGS - multi configuration ground state)

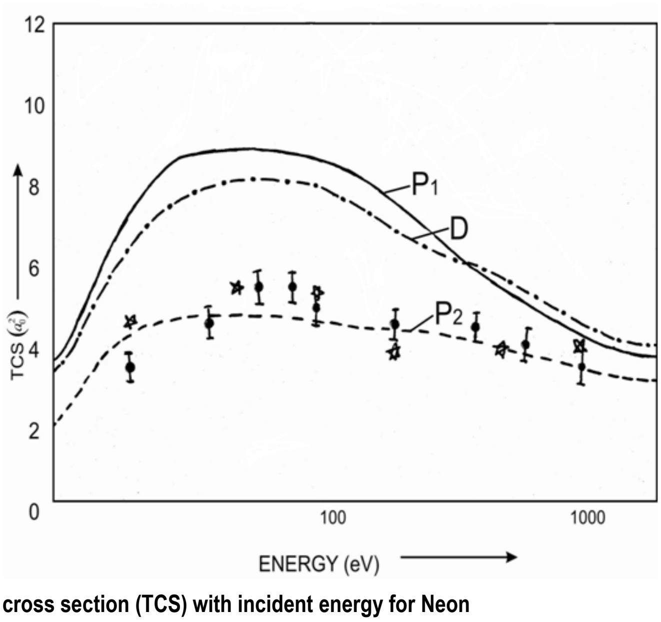

Fig. 2: Variation of total cross section (TCS) with incident energy for Neon

: Present Positron results (P_1)
: Present Electron results (P_2)
: Theoretical result of Dewangan and Walter (D)[10]
: Experimental data of Griffith *et al* [11]
: Experimental data of Kaupilla *et al* [12]

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