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Elastic electron scattering by lead atom in the energy range from 10 to 100 eV

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Abstract. Electron scattering by lead atom is studied at energies 10, 20, 40, 60, 80 and 100 eV by applying a parameter-free complex optical potential. The real part of the complex optical potential includes the static potential $V_{st}(r)$, the polarization potential $V_{pol}(r)$ that consists of the short-range correlation and long-range polarization effects and $V_{ex}(r,k)$ term consisting of electron exchange interaction which is modeled by assuming the electron charge cloud as a free electron gas. The loss of flux into the inelastic channels is included via a phenomenological absorption potential. Our results are compared with the recent theoretical and experimental measurements.

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Key words: electron scattering, differential scattering cross sections, variable phase approach, complex optical potential

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1 Introduction

In our previous work [1-3], we reported results for theoretical investigations on elastic electron collision by Yb, Ca and Mg atoms. Here we continue our study of elastic electron collision with Pb atom. As we know, electron atom collision can be described by many theoretical approaches and that is why it is important to test the various approximations with experimental measurements. At the same time elastic electron scattering is very important in many fields such as physics of stars and plasmas [4].

Below any inelastic scattering thresholds, the scattering of electrons from atoms can be well represented as a potential scattering problem by including the static, polarization and exchange potentials. A simple way to take into account the open inelastic channels within the framework of a potential scattering problem is to use a simple computational

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approach of complex optical potential in which the imaginary part represents the absorption of flux. The more elaborate theories, such as convergent close coupling or R-matrix methods, take into account these additional channels but at the cost of very substantial increase in the complexity of the problem and the computer resources needed .

In the present work, theoretical studies of differential cross sections (DCS) of electron scattering by Pb atom have been carried out at projectile energies of 10, 20, 40, 60, 80 and 100 eV. We have employed a model complex optical potential approach. The real part of the optical potential consists of static potential, the exchange potential incorporated by treating the electron cloud as a free gas, and a polarization potential. The imaginary part of the optical potential represents the absorption potential that takes into account the loss of flux due to all energetically possible inelastic channels. The only experimental parameters required are the first ionization potential and the dipole polarizability of the target atom for the construction of the full optical potential. After generating the full optical potential of the scattering system, we treat it exactly in a partial wave analysis in terms of a set of first-order coupled differential equations for the real and imaginary parts of the complex phase shift functions under the variable phase approach [1-3] and the differential cross sections are calculated.

2 Theory

All the major interactions of electron atom scattering can be represented by a complex, energy dependent, optical potential $V_{opt}(r,k)$ as

$$V_{opt}(r,k) = V_{st}(r) + V_{ex}(r,k) + V_{pol}(r,k) + iV_{abs}(r,k), \tag{1}$$

where $V_{st}(r)$ is the static potential obtained from the DHFS function [5], $V_{ex}(r,k)$ is the exchange potential obtained from FEG model [6], $V_{opt}(r,k)$ is the polarization potential model [7] and $V_{abs}(r,k)$ is the absorption potential [8] that takes into account the loss of flux due to all energetically possible inelastic channels. The parameters used in our calculations are shown in Table 1.

Table 1. Parameters used in the present calculations for electron lead scattering.

Atom	Average dipole polarizability α_d in a_0^3	Ionization potential energy in eV
Pb	45.89	7.42

After generating the full optical potential of a given electron-atom system, we treat exactly in a partial wave analysis by solving the following set of first order coupled different equations for the real x_l and imaginary Im (x_l) parts of the complex phase shift function under the variable phase approach [1-3]

$$\chi_l'(kr) = \frac{-2}{k}[2V_R(r)(A^2 - B^2) + 2V_{abs}(r)AB], \tag{2}$$

$$\mathrm{Im}\chi_l'(kr) = \frac{-2}{k}[2V_R(r)AB - 2V_{abs}(r)(A^2 - B^2)], \tag{3}$$

where

$$A=\cos h\mathrm{Im}\chi_l(kr)[\cos\chi_l(kr)J_l(kr)-\sin\chi_l\eta_l(kr)], \tag{4}$$

$$B=\sin h\mathrm{Im}\chi_l(kr)[\sin\chi_l(kr)J_l(kr)-\cos\chi_l\eta_l(kr)], \tag{5}$$

$J_l(kr)$ and $\eta_l(kr)$ are the usual Riccati-Bessel functions [1]. Eqs. (2) and (3) are integrated up to a sufficiently large r, different for different l and k values. Thus, the final S matrix is written as

$$S_l(k)=\exp(-2\mathrm{Im}\chi_l)\exp(i2\chi_l), \tag{6}$$

and corresponding DCSs are defined as

$$\frac{d\sigma}{d\Omega}=\frac{1}{4k^2}\left|\sum_{l=0}^{l_{max}}(2l+1)[S_1(kr)-1]P_l(\cos\theta)\right|^2, \tag{7}$$

where $P_l(\cos\theta)$ is a Legendre polynomial of order l.

3 Results and discussion

We have compared our calculated results with the recent experimental and theoretical work of Tosic *et al.* [9]. The structure and change of the DCS curves are given in the following figures. The figures show how the shapes of the elastic DCS curves change as a function of electron impact energy.

For 10 eV (Fig. 1) our calculations have good agreement with the experimental measurements only up to 30° but the over all agreement in shape and magnitude between theoretical and experimental results of Tosic *et al.* [9] is better consistent with the present result. We also observe that theoretical and experimental results of Tosic *et al.* [9] give one broad minima between 90° and 100° while we get two minima at 80° and 140°.

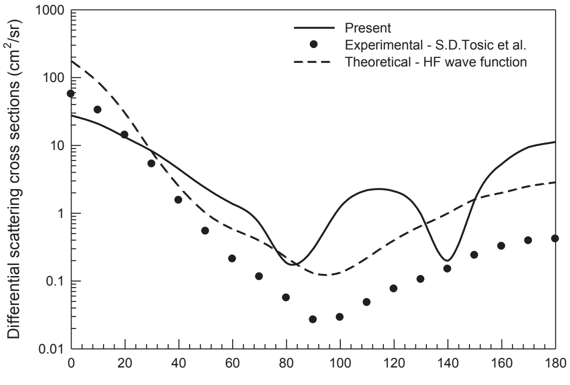

Figure 1: DCS for electron - Pb scattering at 10 eV

For 20 eV (Fig. 2), we have better agreement in shape and magnitude with theoretical and experimental results of Tosic *et al.* [9]. Our first and third minima has better agreement with the experimental value but the second minima at 90° is much sharp than Tosic *et al.* [9].

For 40 eV (Fig. 3) we have three minima. The first one is around 45°, the second one around 90° and the third one at 130°. Similar features are also observed by Tosic *et al.* [9] but their minima are at 38° , 80° and 140° respectively.

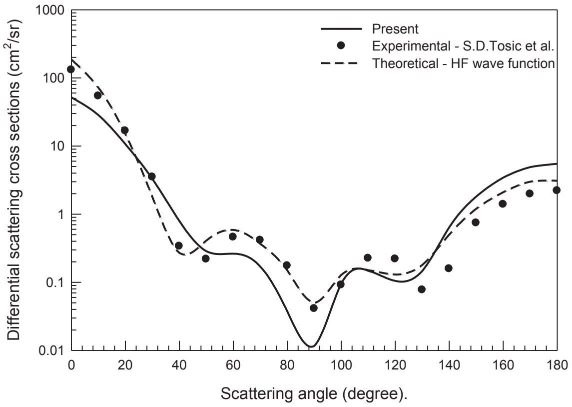

Figure 2: DCS for electron - Pb scattering at 20 eV

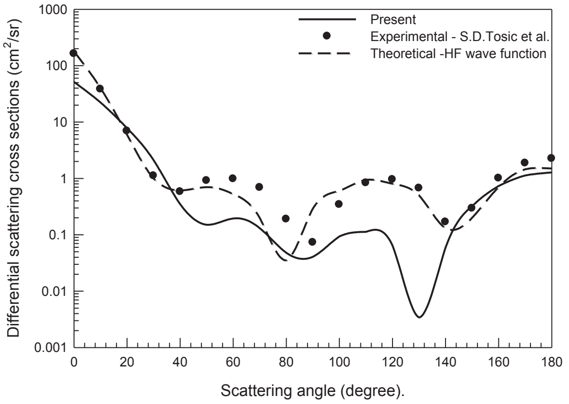

Figure 3: DCS for electron - Pb scattering at 40 eV

For 60 eV (Fig. 4), our agreement in shape and magnitude with theoretical and experimental results of Tosic *et al.* [9] is good. Our results in Figs. 3 and 4 are lower than the experiment data, which is due to the fact that the absorption potential employed is overestimating the loss of flux to the electronic excited states for large scattering angles.

For 80 eV (Fig. 5), our calculations have good agreement with the experimental measurements only up to 20° but the over all agreement in shape and magnitude between theoretical and experimental results of Tosic *et al.* [9] is better compare to the present result. In Fig. 5, our DCS are lower than experimental data up to 140°, this again may be due to an extra loss of flux. It is also to be noted that the theoretical minima predicted by

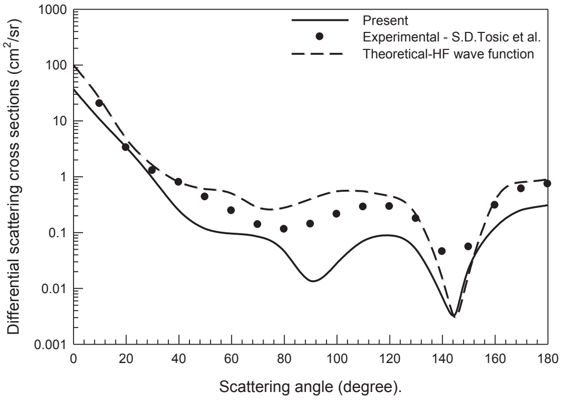

Figure 4: DCS for electron - Pb scattering at 60 eV

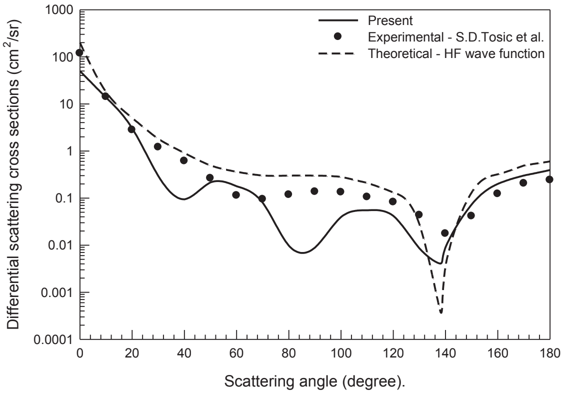

Figure 5: DCS for electron - Pb scattering at 80 eV

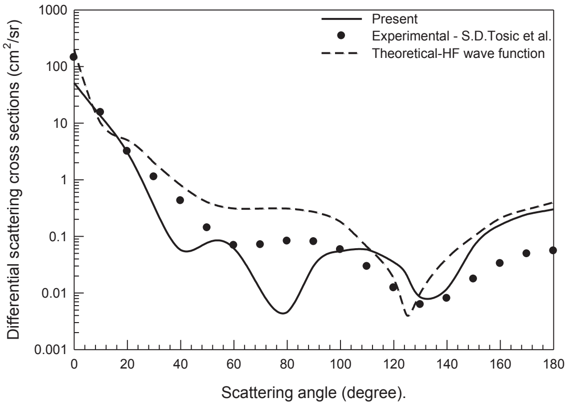

Figure 6: DCS for electron - Pb scattering at 100 eV

Tosic *et al.* [9] at 140° is much sharp than experimental result and our calculations. We have better agreement with experimental data after 140°.

Results for 100 eV are depicted in the Fig. 6. Our results are in qualitative accord with the experimental and theoretical results of Tosic *et al.* [9] except at 80° where we get a sharp minima. The DCS calculated by us and Tosic *et al.* [9] lie above experiment in magnitude after 130°.

4 Conclusions

We have calculated the elastic electron scattering by lead atom at intermediate energies by employing a complex optical potential approach. The potential $V_{opt}(r,k)$ was constructed using only two parameters, namely the spherical dipole polarizability (α_d) and the ionization potential energy of the ground state of the target atom. After generating the full optical potential of the scattering system, we treat it exactly in a partial wave analysis in terms of a set of first order coupled differential equations for the real and imaginary parts of the complex phase shift functions under the variable phase approach [1-3].

The present method is quite simple in nature and robust. The agreement between theory and experiment was observed in the general behavior, i.e., both in the shape and absolute nature of the angular distributions of the DCSs and energy dependence. There is a reasonable good agreement between the experimental and calculated DCSs. Since we have shown the figures on log scale, it is noted that even at higher energies, we have qualitative agreement with the experiment, where the cross sections are quite small. The results are encouraging.

In general the optical potential model works best for symmetrical targets, like rare gases which have closed shells. However any target with singlet S symmetry is expected to yield reasonable values. The open shell targets that have doublet or triplet spin symmetries may suffer accuracy.

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