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Scattering of Electrons from (Curium, Europium and Ytterbium) Atoms at Energy range (10 - 10000) eV

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ABSTRACT

This study covers the calculation of the differential cross sections (DCS's), total cross sections(TCS's), momentum transfer cross sections (MTCS's) and spin polarization parameters S(Θ),T(Θ),U(Θ) for electron scattered by [Curium (Cm) ,Europium(Eu) and Ytterbium(Yb)] atoms. The aim of such calculations is to represent the interaction between electron and target atoms in the range (10- 10000) eV by using optical potential.

The theoretical method was conducted based on the combination of the static potential with the polarization potential at long distances and the correlation potential of Perdew - Zunger at short distances. Overall, the results show a close agreement when compared to the experimental and theoretical findings that reported by the others.

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استطارة الالكترونات من ذرات (Cm , Eu , Yb) عند مدى طاقه (١٠ - ١٠٠٠٠) إلكترون فولت

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الكلمات المفتاحية:

النسبية
الالكترونات المستطارة
ذرات (Cm،Yb,Eu)
معادلة ديراك
استقطاب البرم

الـــخُـــلاصـــة

تمت دراسة المقاطع العرضية التفاضلية والمقاطع العرضية الكلية وزخم الانتقال للمقاطع العرضية ومعاملات استقطاب البرم U(Θ), T(Θ) , S(Θ) لاستطارة الالكترونات من ذرات الهدف (Cm ,Eu ,Yb) عند المدى (١٠-١٠٠٠٠) إلكترون فولت باستخدام الجهد البصري .

لقد اعتمدت طريقة الحسابات النظرية على ربط الجهد المستقر مع جهد الاستقطاب للمديات الطويلة وجهد الارتباط للباحثين بردو - زنكر عند المديات القصيرة . وجدنا توافق جيد مع القياسات العملية والحسابات النظرية للعديد من الباحثين.

1. INTRODUCTION

Basically, the relative interaction plays an important role in understanding and interpreting the scattering electron by heavy atomic target, due to the great progress which has recently occurred in the development of the efficiency of polarized electronic resources and accurate polarization measures. In this context, a number of studies have identified the differential cross sections (DCS's), total cross sections (TCS's), momentum transfer cross section (MTCS's) and the spin polarization parameters of electronic S(Θ), T(Θ), U(Θ) for the elastic scattering process for heavy atomic systems. Experimental measurements of complex atoms have been completed [1-3], such as mercury, Tilerium, lead, Bizmouth atoms [4-6], together with the Thallium, Zinc, Cadmium and Indium [7-9]. Theoretically, Walker [10] and Sin Fai Lam [11] were studied the scattering of electrons from atoms, where they relied on a non-relativistic form of Schrodinger equation. In addition, Neerja et al. [12, 13] calculated the differential cross sections (DCS's), total cross section (TCS's) and momentum transfer cross section (MTCS's) for scattering electrons by Yb at incident energy (2-500) eV. This study was conducted based on relativistic Dirac equation by using the optical potential which consists of two parts (Real potential and imaginary potential). It was noted that the real part consists of the static potential Vst and semi-classical exchange potential $V_{ex}(\bar{r})$, also the second part (complex term), which includes absorption potential $V_{abs}(\bar{r})$ [12].

Moreover, many researchers have also studied the Europium (Eu) and Ytterbium (Yb) atoms, which belong to Lanthanide series of periodic table. A specific attention has been paid to the scattering of electrons by these atoms, especially Yb-atom that has been studied theoretically [14-20] and experimentally [19-21]. At the same time, Eu-atom has been studied but there is no data about these atoms. Sabad et al. [22] were able to study Curium, Europium and Ytterbium theoretically with energies (0.1-100) eV by using optical potential, where the interaction of exchange depends on the mutual direction of falling electron spin and atom target. These authors studied the cross sections of scattering electrons and parameters of spin polarization by semi-Relativistic approximate by using complex optical potential method for incident electron of different incident energies (2-500) eV [23]. Also, Felfli et al. in 2009 [24] calculated differential cross sections for Eu-atom at low energies; less than 1eV. Remeta et al. in 2010 [25] studied differential cross sections for elastic scattering electron process; they used spin-polarized approximation at 10 eV. In 2011 Kelemen et al. [26] also conducted investigation for the scattering process of Eu and Yb atoms at range energy more the 2 keV. Also they studied differential cross sections, total cross sections and momentum transfer cross sections in 2013 [27]. The scattering of electrons by Cm-atom at different energy range (100, 500, 1000, 10000) eV was investigated by Jablonski et.al [28], using two kinds of potentials. Thomas-Fermi-Dirac (TFD) and Dirac-Hartree-Fock (DHF) are evaluated the differential cross sections for Cm-atom, The results of the two types of potentials were close but it found that the DCS's decreases with increasing the energy of incident electrons.

In the present paper the calculating method is described in the next section, whereas a comparison among our results, demonstrating experimental and theoretical results.

2. Theoretical approach

The contraction of scattering potential is an important issue that affecting the parameters of calculated scattering in which there exist a complex potential as optical potential. Consequently the process of contraction of scattering potential studied and determined.

Basically, the structure of optical potential $V_{opt}(r)$ consist of three terms, the static $V_{st}(\bar{r})$, exchange $V_{ex}(r)$, and the correlation-polarization potential $V_{copl}(r)$, where the electro static interaction energy between the projectile and target atom is obtained by [29].

$$V_{st} = Zoe\ \phi(r) \qquad (1)$$

Where, Zo e is the charge of incident particles (Zo = -1 for election and Zo =1 for positron). $\phi(r)$ is the electrostatic potential function of the target atom which express as the sum of contributions from the nucleus and the electron cloud, $\phi_n(r')$ and $\phi_e(r')$, respectively

$$\phi(r) = \phi_n(r) + \phi_e(r) . \qquad (2)$$

$$\phi_n(r) = e\left[\frac{1}{r}\int_0^r 4\pi r'^2 \rho_n(r')\,dr' + \int_r^\infty 4\pi r'\ \rho_n(r')\,dr'\right] \qquad (3)$$

Also,

$$\phi_e(r) = -e\left[\frac{1}{r}\int_0^r 4\pi r'^2 \rho_e(r')\,dr' + \int_r^\infty 4\pi r' \rho_e(r')\,dr'\right] \qquad (4)$$

Where **r** is the radian distance from centre of nucleus, $\rho_n(r')$ and $\rho_e(r')$ denote the space densities (particles per unit volume) of protons in the nucleus orbital electrons, respectively, while the exchange potential is defined as [29] :

$$V_{ex} = \frac{1}{2}\left[E - V_{est}(r')\right] - \frac{1}{2}\left[\left(\left[E - V_{est}(r')\right]\right)^2 + 4\pi a_\circ e^4 \rho(r)\right] \qquad (5)$$

where E is the total energy of the projectile, which depends on the density of electronic charge $\rho(r)$, also the correlation-polarization potential $V_{copl}(r)$ has two components; the short-range $V_{SR}(r)$ and the long-range $V_{LR}(r)$ (for more details about the definitions of both components see [29], [31], [32], [33]. In this context, the correlation-polarization potential is given by

$$V_{copl}(r) = \begin{Bmatrix} V_{cor}^{SR} & , r < r_c \\ V_{pol}^{LR} & , r < r_c \end{Bmatrix} \qquad \textbf{(6)}$$

Where, r_c is the intersection point between V_{cor}^{SR} and V_{pol}^{LR}.

In the present calculation the two complex scattering amplitudes $f(k,\theta)$ (the direct amplitude) and $g(k,\theta)$ (the spin-flip amplitude) are defined as [10]

$$f(k,\theta) = \frac{1}{2ik}\sum_{l=1}^{\infty}\{(l+1)[\exp(2i\delta_l^+)-1] + l[\exp(2i\delta_l^-)-1]\}p \qquad (7)$$

And

$$g(k,\theta) = \frac{1}{2ik}\sum_{l=1}^{\infty}[\exp(2i\delta_l^-)\ \exp(2i\delta_l^+)]\quad p_l{}'(\cos\theta) \qquad (8)$$

Where θ is the scattering angle and $p_l(\cos\theta)$ and $p_l{}'(\cos\theta)$ are the Legendre polynomial and the Legendre associated function, respectively.

The elastic differential cross section for scattering of the un polarized incident electron beam is given by [34]

$$\rho_u = \frac{d\rho}{du} = |f|^2 + |g|^2 . \qquad (9)$$

and the spin polarization parameter $S(\theta)$ had the form [12]

$$S(\theta) = \frac{i(f g^* - f^* g)}{\rho_u(\theta)} . \qquad (10)$$

The spin polarization (Sherman function) S(Θ) describes the spin polarization parameter of the scattered electrons if the incident electron beam is un polarized.

Also, we can calculate the parameters [29] :

$$T(\theta) = \frac{|f|^2 + |g|^2}{\rho(\theta)} , \qquad (11)$$

and

$$U(\theta) = \frac{f\,g^* - f^*\,g}{\rho(\theta)} \quad . \qquad (12)$$

3. Results and Discussion:

Generally, it should be noted that the experimental measurements and theoretical calculations for electron scattering from curium (Cm) atom (Z=96) were very little. In this situation, figure (1) shows the differential cross sections at the range energies (100, 500, 1000, 10000) eV. For energy 100 eV one can conclude that, the results are not compatible with theoretical calculation of Jablonski et al. [28], while when the energy increases, our results agreed with the work of Jablonski [28]. Figure (2 - a) illustrates the total cross sections of Cm atom. In this case, there is no data available for this atom, by contrast, for momentum transfer cross sections the data is available (see figure (2-b)). From the profiles, the results are entirely consistent with findings reported by Jablonski et al [28].

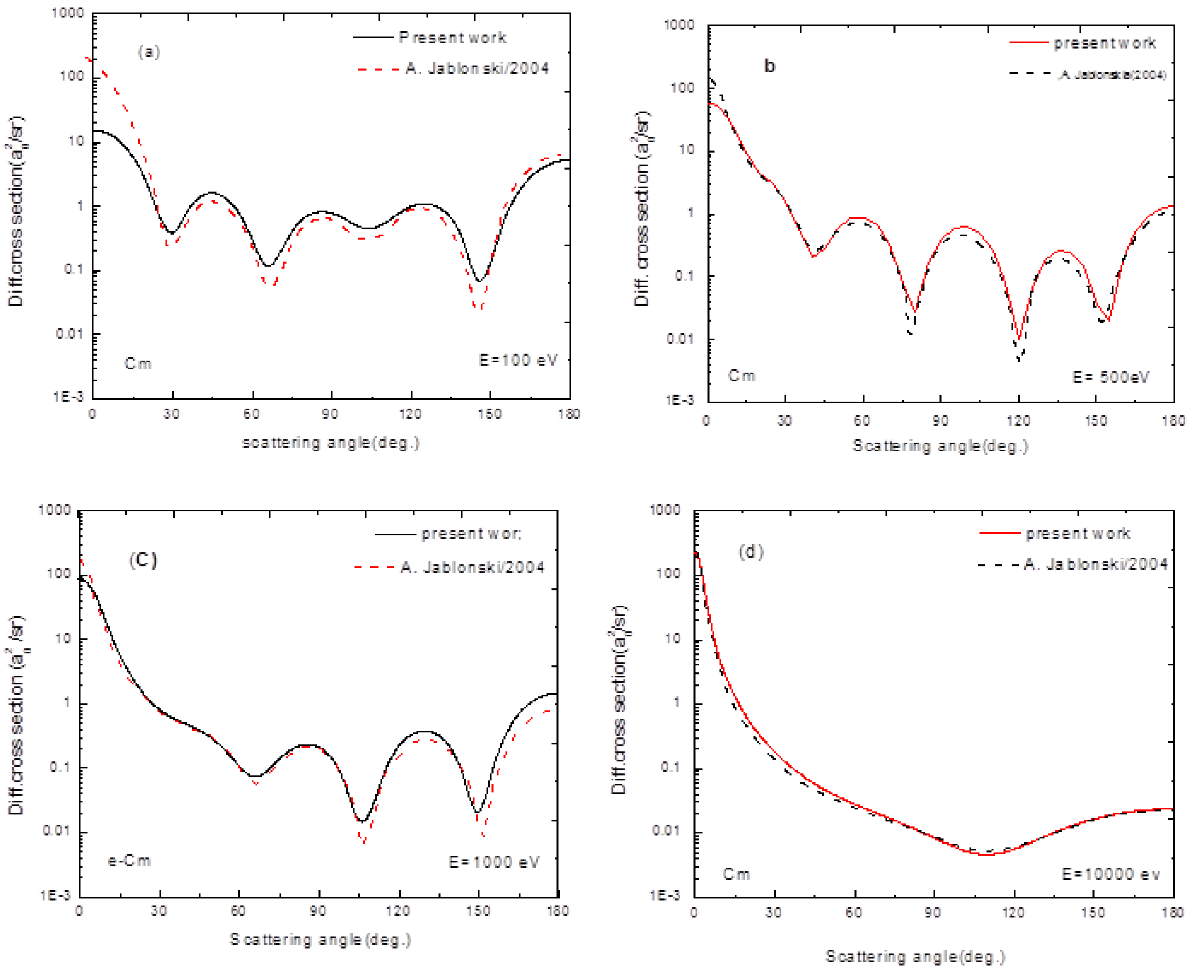

Figure (1): Differential cross-sections (a_o^2/sr) for the Scattering of electron s from Cm- atoms for an incident electron energy (a)100 eV ,(b) 500 eV,(c) 1000 eV , and (d) 10000 eV.

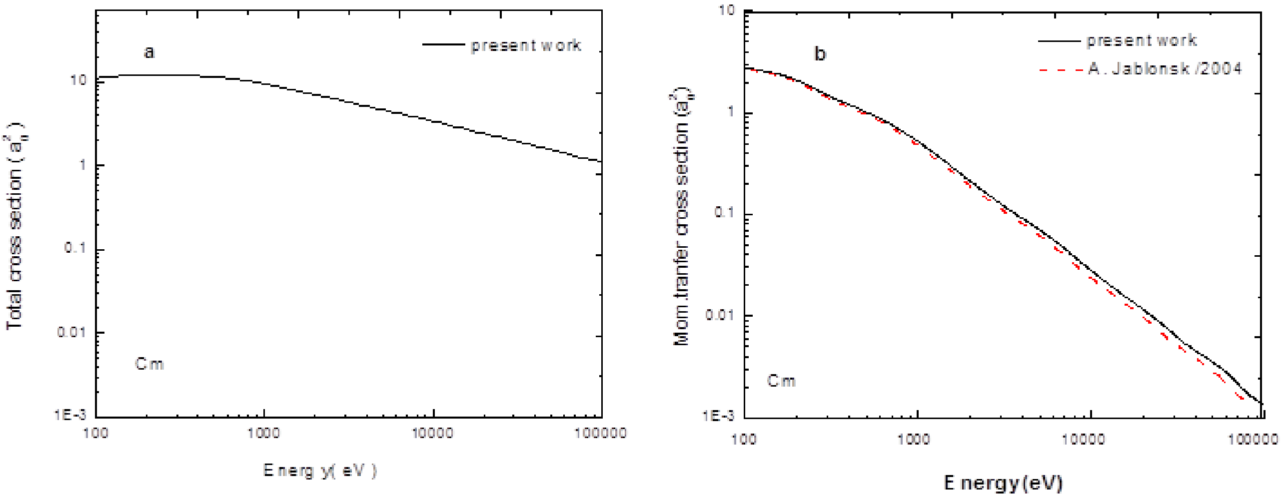

Figure (2): The Scattering of electrons (a_0^2) from Cm-atoms (a) TCS`s (b) MTCS`s

Two atoms from Lanthanide series of periodic table were chosen ; Europium (Eu) atom (Z=63) and Ytterbium (Yb) atom (Z=70). In Figure (3), a comparison between our results and other investigators results are shown. These results are given for the differential cross sections for scattering electron form Yb atom at different range of energies (10, 20, 40, 50, 60, 80) eV, and found that these results are consistent with others for some energies due to the user potential difference.

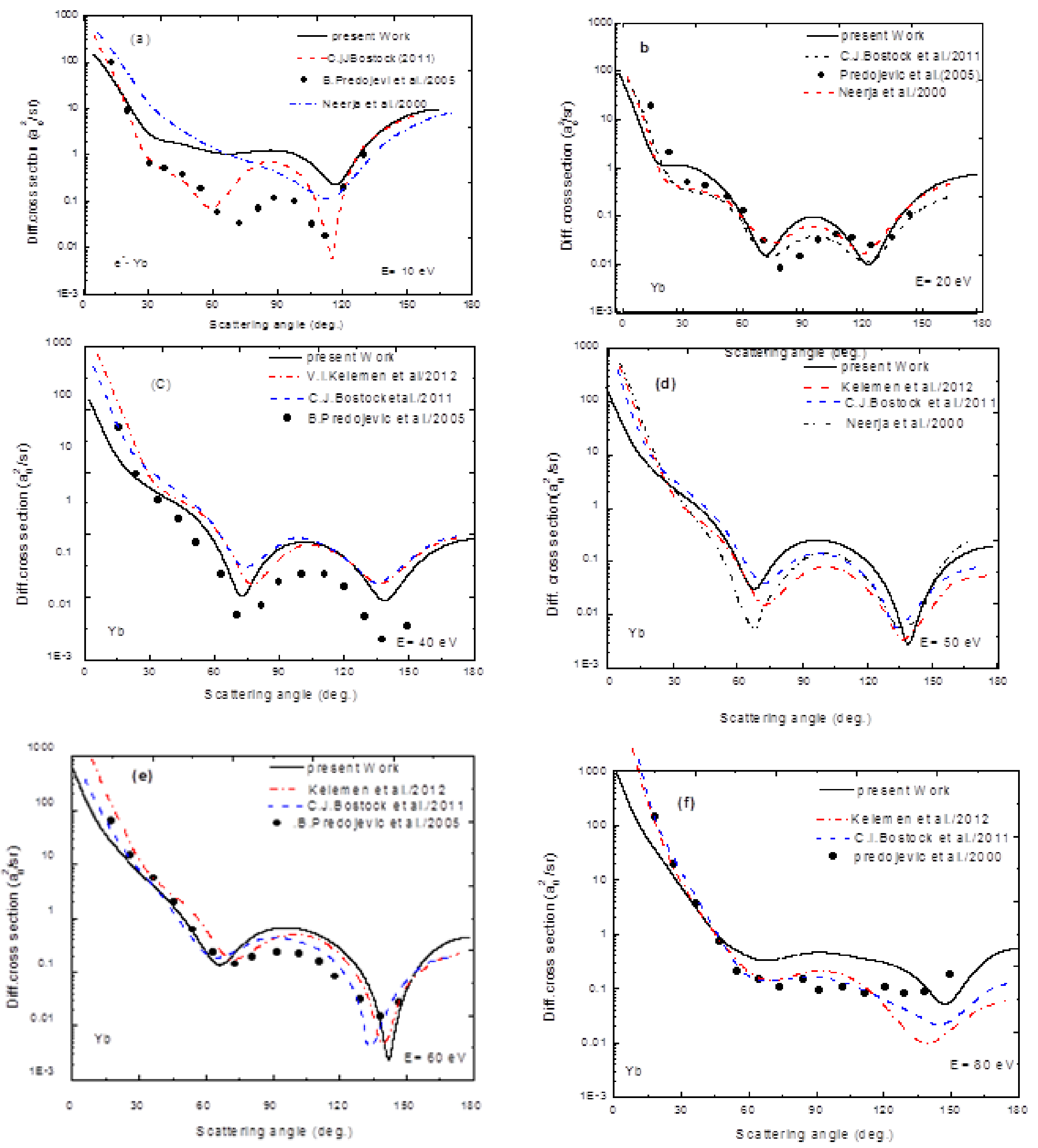

Figure (3): Differential cross-sections (a^2_0 /sr) for the Scattering of electron s from Yb- atoms for an Incident electron energy (a)10 eV ,(b)20 eV,(c) 40 eV , (d) 50 eV, (e) 60 eV and (f) 80 eV.

Similarly, Figure (4 - a) explains the total cross sections, but there is not data available, in contrast a comparison with other researchers in term of the momentum transfer cross sections are presented in figure (4 - b). In addition, the measurement of the differential cross sections for scattering electrons by Eu-atom is shown Figure (5). In experimental measurements and theoretical calculations the findings are agreed between results of present study and that conducted by others at low level of energies. In contrast, for the higher level of energy the results are incompatible due to optical potential, thus the mismatch can be attributed the inelastic scattering of electrons.

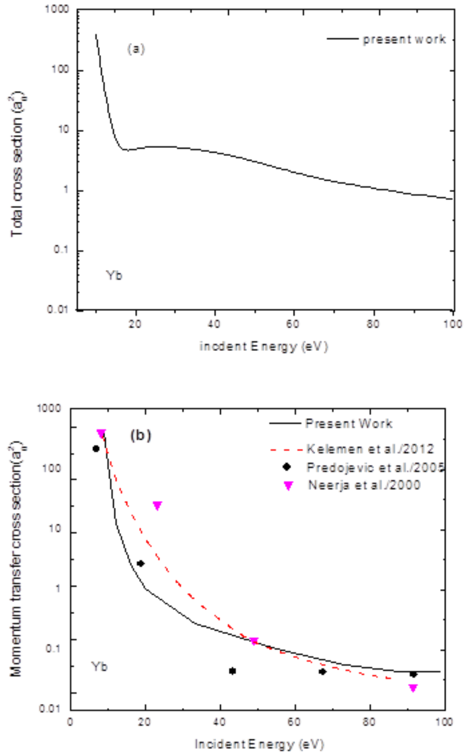

Figure (4): The Scattering of electrons (a_0^2) from Yb -atoms

(b) MTCS`s (a) TcS`s

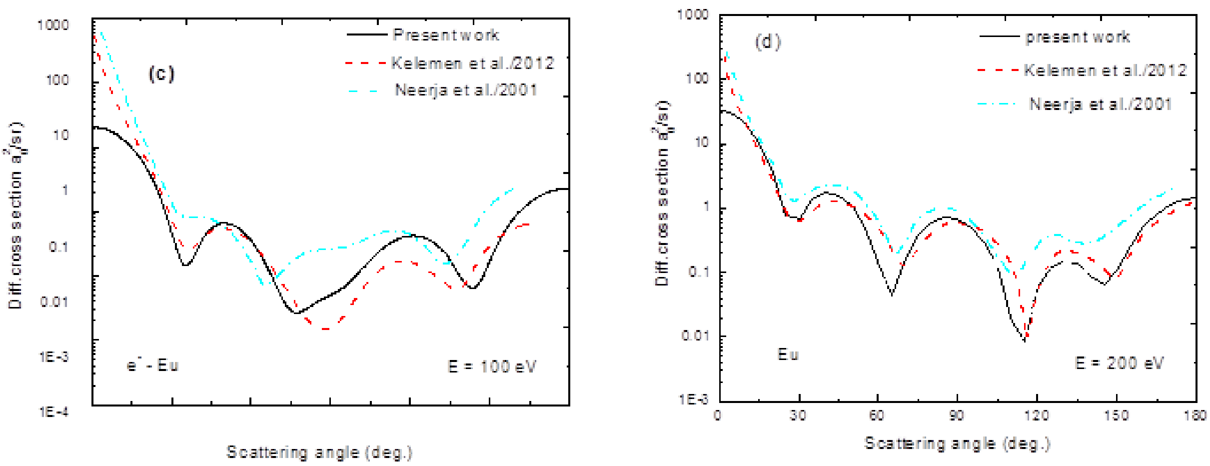

figure (5): Differential cross-sections (a0² /sr) for the Scattering of electron s from Eu- atoms for an Incident electron energy (a)10 eV ,(b)50 eV,(c) 100 eV

Figure (6- a) illustrates the total cross sections, which are compared to other researchers and given a good agreement in the energies range of (1-10) eV, while incompatibility was noted out of this range. Also ,Figure(6 – b) illustrates the momentum transfer cross sections, a good agreement with the observations of theoretical calculations and experimental work was found. Thus we can see that, the atoms Eu and Yb are played an essential role in increasing the knowledge of the process of electronic scattering in heavy atomic elements of electronic structures with multiple orbits.

Furthermore, the parameters of spin polarization for electrons S(θ),T(θ) ,U(θ) for different atoms (Cm, Eu ,Yb) were evaluated. The comparison is made between our findings and that reported by others, whereas some atoms did not compare because there is no data about these atoms, and therefore our calculations can be considered as the first in this field. In this context, the relativistic Dirac equation with optical potential consistory of three type of potential is used in this study.

The Sherman function was calculated for scattering electrons from Cm atom at incident energies (10, 15, 20, 100) eV (see Figure (7)). Also, we were calculated the spin polarization parameters S (θ), T (θ), U (θ) by Cm-atom at incident energies (10, 100) eV, as shown in Figure (8). The comparison is not observed here, because there is no comparable data. So, our findings provide a suitable basic for others.

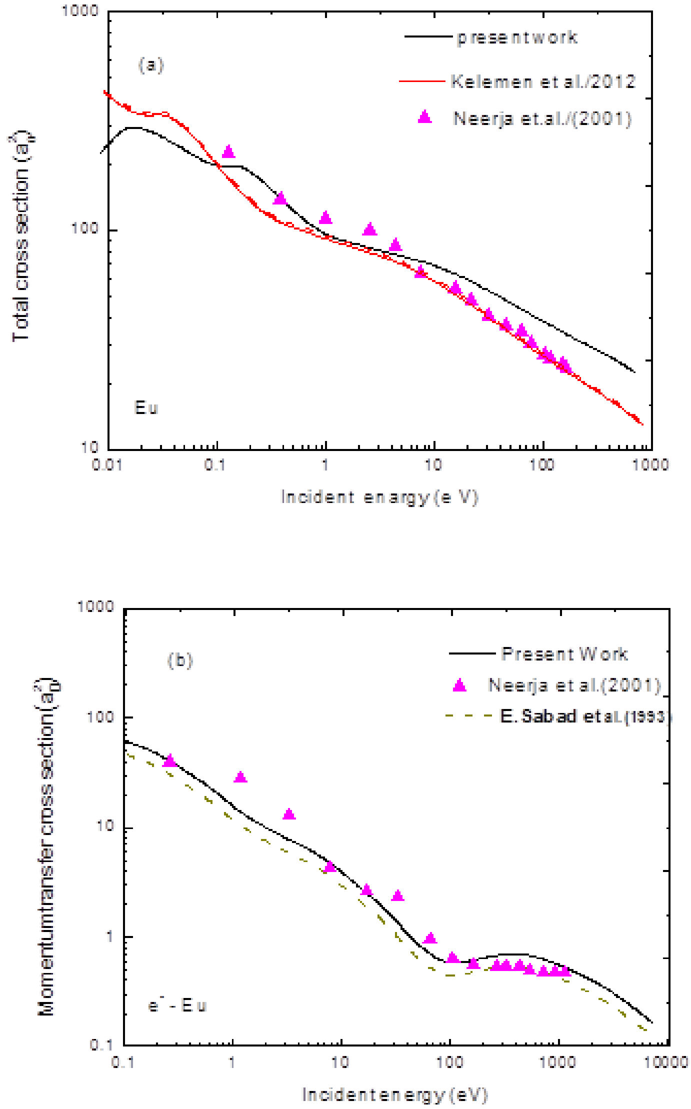

Figure (6): The Scattering of electrons (a02) from Eu –atoms

(a) TcS's (b) MTCS's

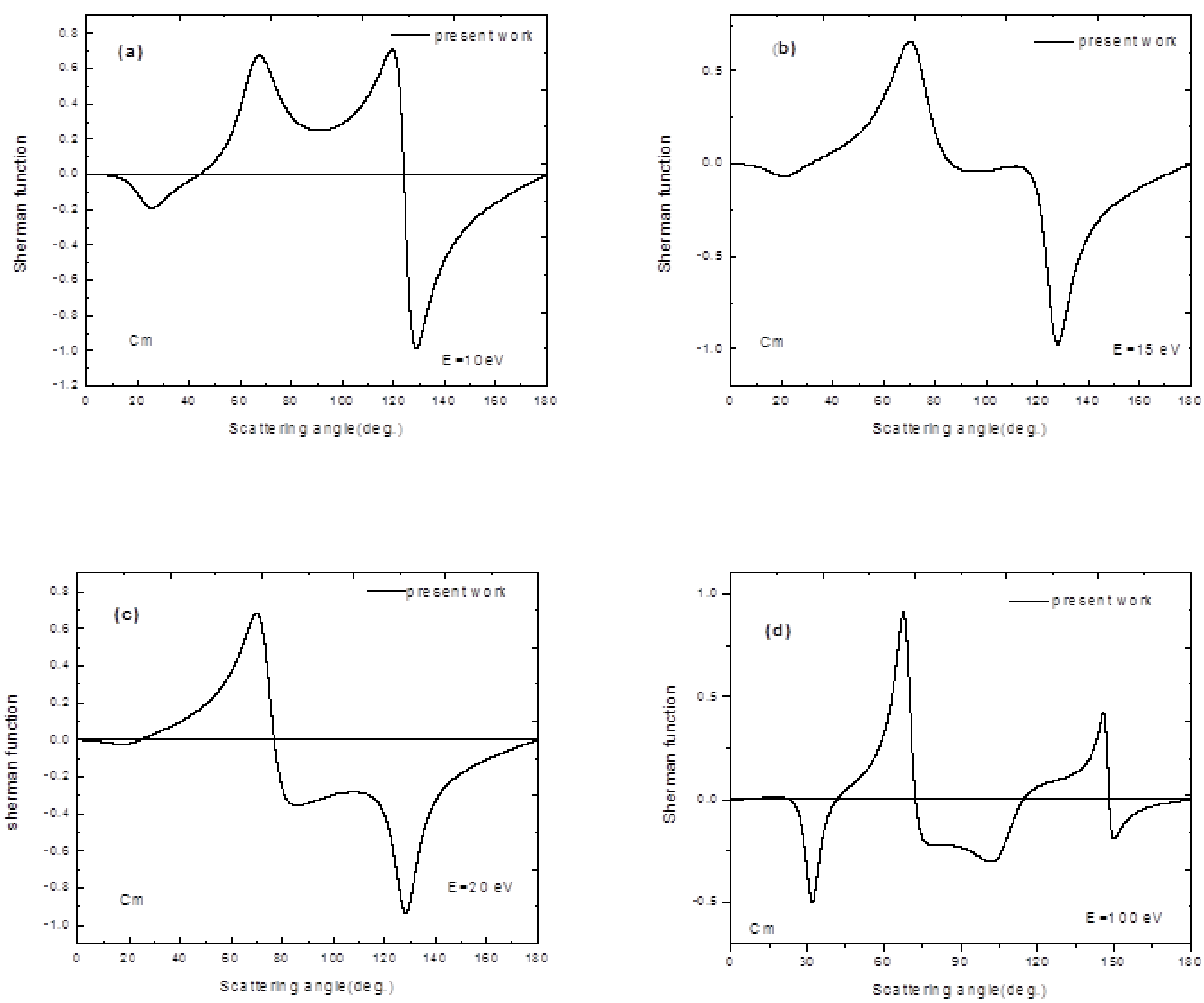

Figure (7): Sherman function S (Θ) for the Scattering of electrons by Cm – atoms for an incident energy (a) 10 eV , (b) 15 eV , (c) 20 eV and (d) 100 eV.

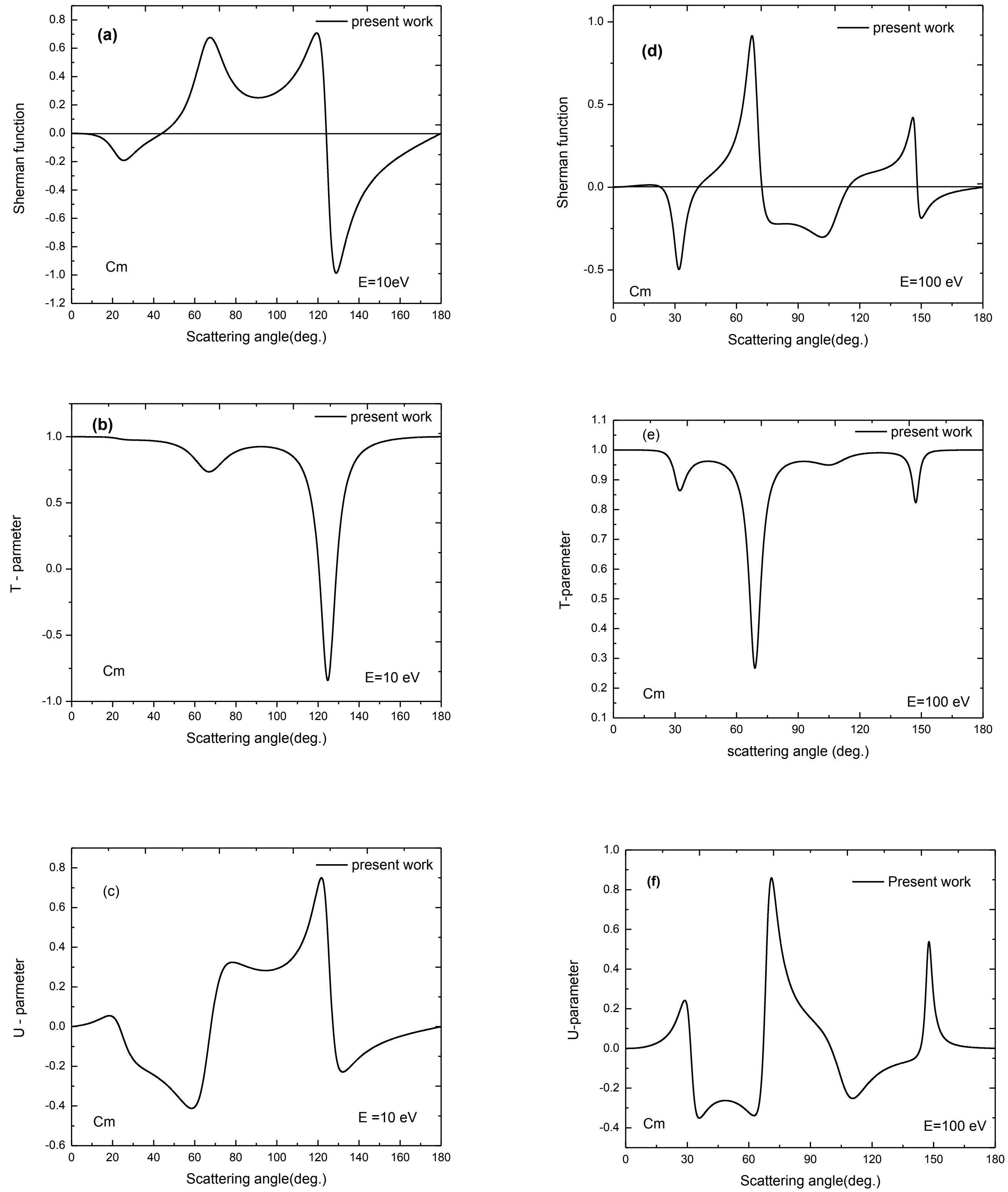

Figure (8): Spin Polarization parameters S(ϴ) ,T(ϴ), and U(ϴ) at (10) eV and (100) eV for Scattering of electrons from Cm- atoms.

The Ytterbium atom (Yb) is also chosen from the Lanthnid series, to study the Sherman function at different energies (10, 15, 50, 100) eV as shown in Figure (9) and compared with Salvat et al. [29], and Yuan et al. [35]. In addition, we were able to calculate the spin polarization parameters to the same atom, as shown in Figure (10) at energies (10, 200) eV and we were able to compare our results with the results obtained by Neerja et al. [12], there was some compatibility due to the optical potential used in our calculations.

Moreover, we calculated the Sherman function S(θ) of the Europium(Eu) atom as shown in figure (11) at different energies (10, 15, 20, 200) eV. Also, we studied the spin polarization parameters for electrons from Eu at incident energies (10, 200) eV as explained in Figure (12). Since there are no experimental measurements and theoretical calculations were available for comparison, our calculations are considered as a reference for other investigators because they are considered for the first time .

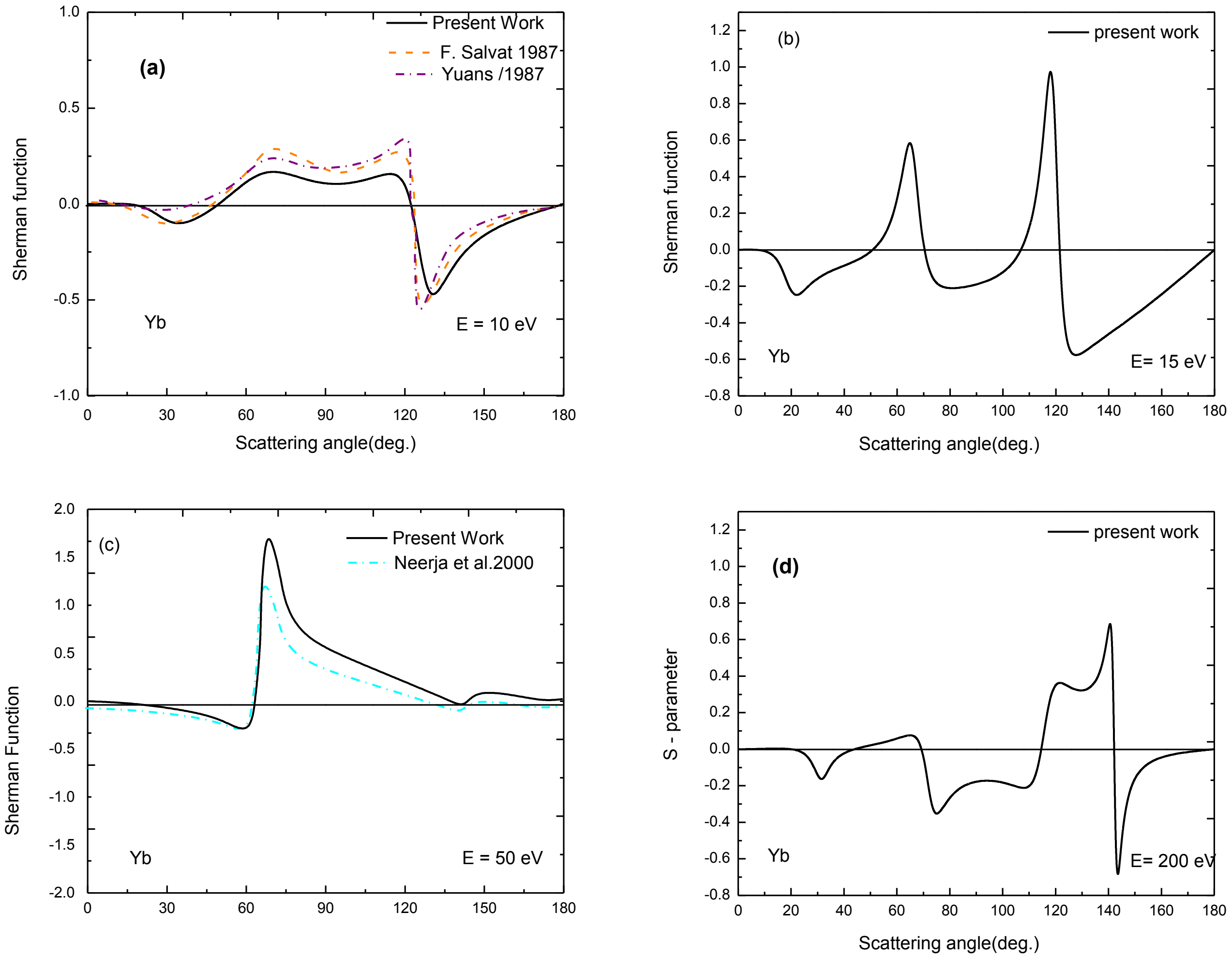

Figure (9): Sherman function S (ϴ) for the Scattering of electrons by Yb – atoms for an incident energy (a) 10 eV , (b) 15 eV , (c) 50 eV and (d) 200 eV.

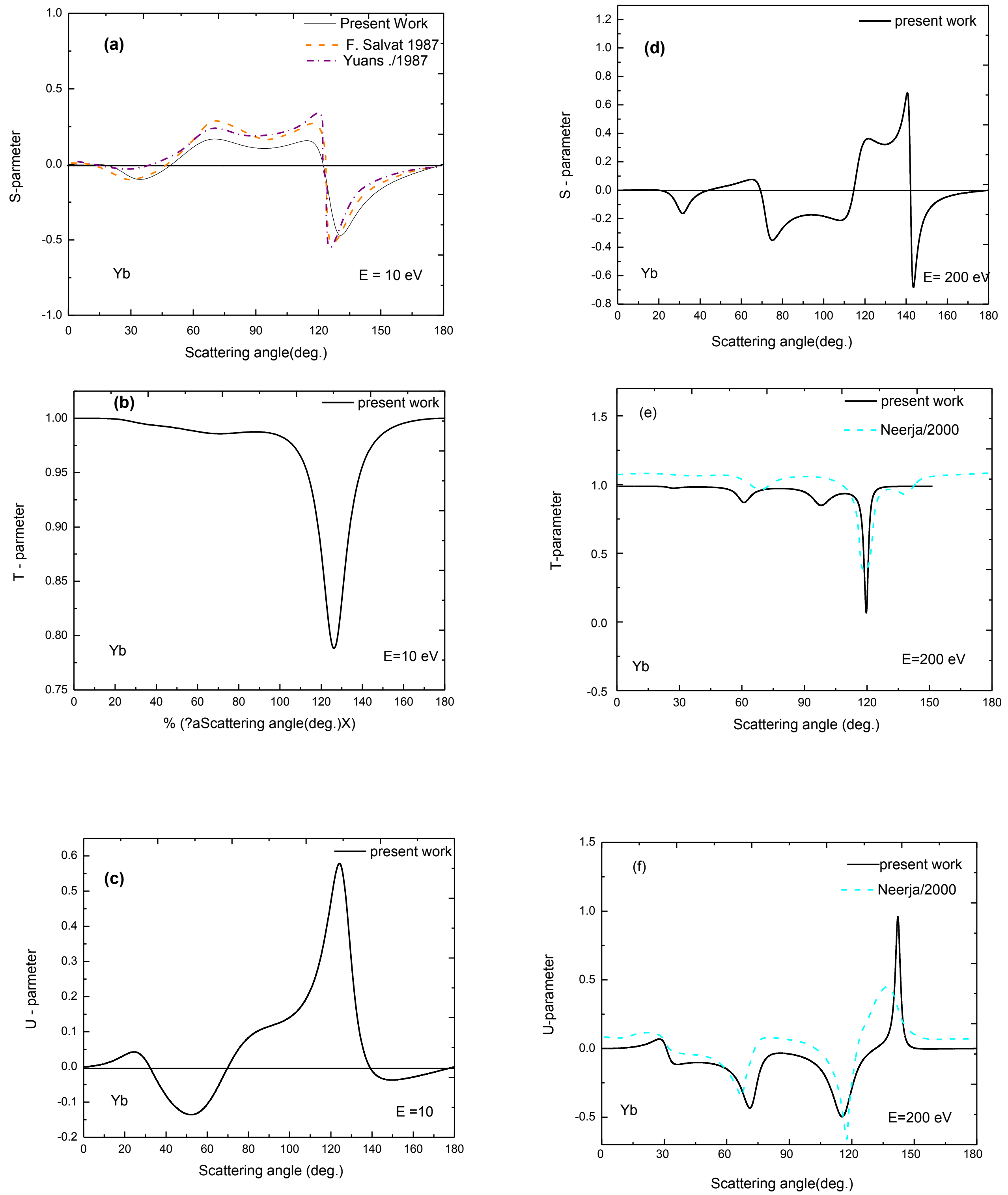

Figure (10): Spin Polarization parameters S(Θ) ,T(Θ), and U(Θ) (a, b, c)at (10) eV and (d, e, f) at(200) eV for Scattering of electrons from Yb- atoms.

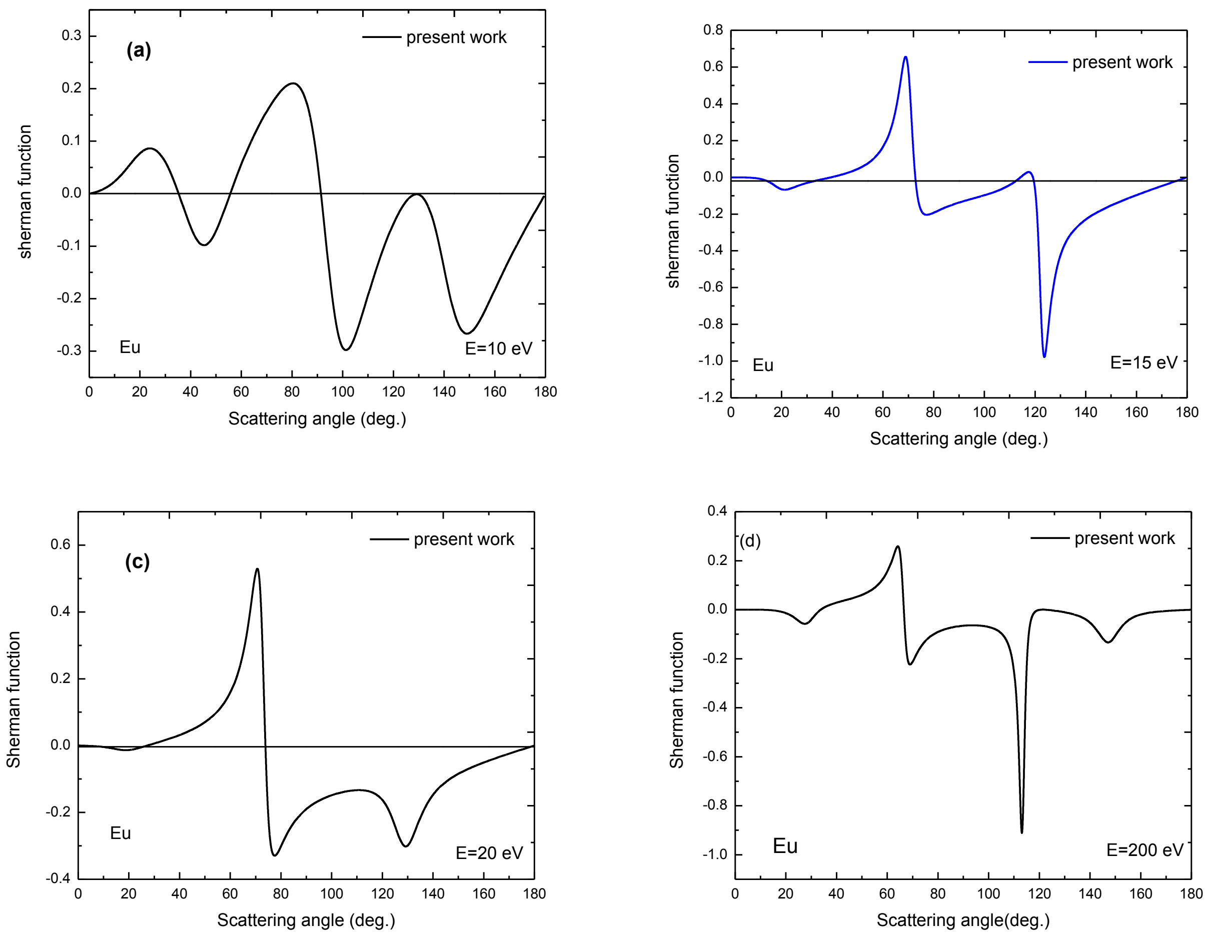

Figure (11): Sherman function S (ϴ) for the Scattering of electrons by Eu – atoms for an incident energy (a) 10 eV , (b) 15 eV , (c) 20 eV and (d) 200 eV.

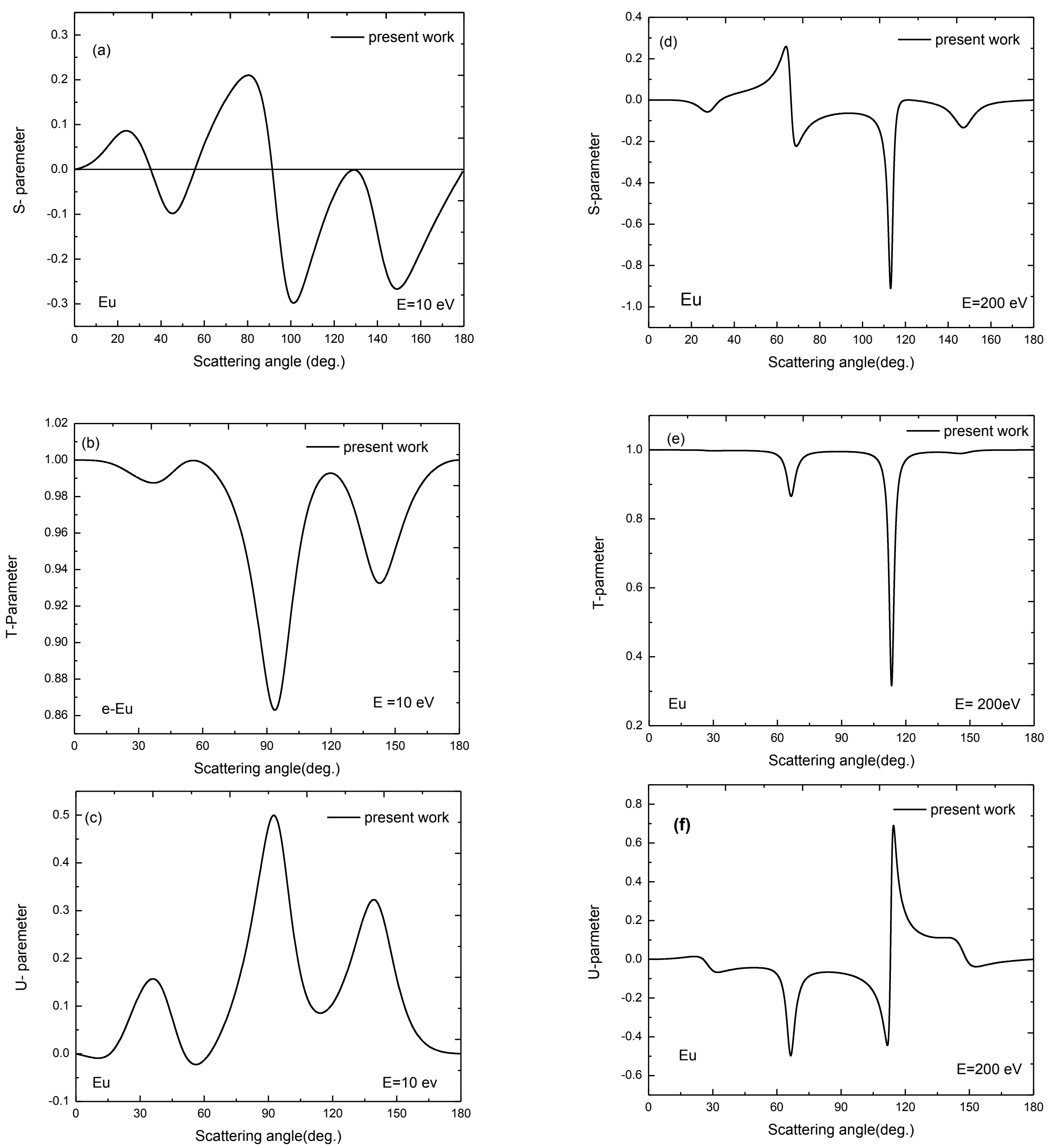

Figure (12): Spin Polarization parameters S(ϴ),T(ϴ), and U(ϴ) at (10) eV and (200) eV for Scattering of electrons from Eu- atoms.

4. Conclusion

The scattering electrons from Cm, Eu and Yb atoms have been treated by solving the Dirac equation numerically for the model potential. representing. The projectile-target interaction, which consists of static $V_{st}(r)$, exchange $V_{ex}(r)$, and the correlation-polarization potential $V_{copl}(r)$ terms. Through the process of scattering of electrons we were able to deduce the following points:

1- Our current study is an extension of studies that conducted in this field.

2- Some atoms were extracted in the periodic table, which were not previously discussed in practice or theoretically.

3- Build and install a new optical potential by integrating different potentials with correlation potential of Perdew -Zunger.

4- We calculated the spin polarization parameters of electrons.

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