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# Scattering of Electrons/Positrons by H-atoms and $H_2$ Molecules under Weakly Coupled Plasmas

Research Article

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**Abstract.** In this paper we have examined the screening effects of weak Debye plasma on elastic scattering of electrons ($e^-$) or positrons ($e^+$) by atomic as well molecular hydrogen at intermediate and high incident energies $E_i \geq 50$ eV. The present theoretical work aims at investigating how plasma influences the angular and total scattering, in the background of free or no-plasma situation. The basic calculations are carried out in the '*eikonal-Born-series*' (EBS) approach suitable for atomic hydrogen, along with the '*Independent Atom-in-Molecule*' (IAiM) model for the $H_2$ molecular target. Debye screening length $\Lambda_D$ is adopted as the parameter to assess the effect of the plasma environment on the scattering. Reduction in the *forward differential cross sections* (FDCS) and the total (complete) cross sections (TCS) is studied at typical values $\Lambda_D = 5, 7.5$ and 10 Bohr radii $a_0$. Our results show that, compared to the TCS, the FDCS are more sensitive to the plasma effects, for both H and $H_2$ targets. Further for both these targets, differences between electron and positron scattering are also observed in our theoretical results.

**Keywords.** Electron or positron scattering; Atomic and molecular hydrogen targets; Eikonal-Born-series; Scattering cross sections; Screening by plasma; Debye screening length

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## 1. Introduction

Atomic and molecular hydrogen are the most abundant species in various astrophysical and laboratory plasmas. H atoms and $H_2$ molecules as free or isolated targets have been the well-known targets for electron scattering studies since long. H atom having an exact wave function and the electron charge-density, offers a standard target for testing theoretical models and calculations for electron scattering processes. In this paper, we consider the collisional interaction of the external electrons (i.e. electrons other than those already in plasma) impinging on the embedded atomic or molecular hydrogen. We have also examined separately here the collisions of incident positrons for these two target species. Our focus is on elastic scattering, which may at first sight seem to be not so important. Elastic scattering dominates practically at any energy, and it seeks to diffuse the incident beam into the embedding medium without any transfer of energy from the projectile electron/positron to the target.

In the free case or no-plasma situation, theoretical as well as experimental studies on these collisions are well known in literature since long. About four decades back, Byron and Joachain [1] developed a high energy method called '*eikonal-Born-series*' or EBS theory to derive $e^-$-H elastic scattering cross sections accurately. The direct elastic scattering amplitude ($f^d_{EBS}$) considered through $O(k^{-1})$, with $k$ as the incident electron wave-vector magnitude, is given in the EBS theory as follows.

$$f^d_{EBS} = f_{B1} + \mathrm{Re}\, f_{B2} + f_{G3} + i\,\mathrm{Im}\, f_{B2} \tag{1.1}$$

Where subscripts $B1$ and $B2$ stand for the first and the second Born approximations, while $G3$ indicates the third Glauber approximation term. Details of the EBS theory and the inclusion of electron exchange through the high energy Ochkur amplitude $g_{och}$ are discussed in [2]. All the scattering amplitudes in equation (1.1) depend on the scattering angle $\theta$ through the elastic wave-vector transfer, $\Delta = |\vec{k}_i - \vec{k}_f| = 2k\sin\frac{\theta}{2}$, with ($\vec{k}_i$) and ($\vec{k}_f$) as the initial and the final wave-vectors of the external electron. If the incident electrons are fast enough, the cross sections of $e^-$-H scattering are described reasonably well in this approximation [1, 2].

Electron scattering from $H_2$ molecules has also been extensively studied theoretically, as discussed in [3–5]. Our present interest is in the range of high incident energies $E_i > 50$ eV. Therefore, for $e^-$-$H_2$ scattering we invoke a high energy formalism, called '*Independent Atom-in-Molecule*', (IAiM) approximation [3, 5]. The electron-charge density of H (1s) atom is given in au by $\rho(r) = 1/\pi \exp(-\lambda r)$, with $\lambda = 2Z$ and the atomic number $Z = 1$. In the IAiM approximation, the first step is to assign to $Z$, the variational value $Z^* = 1.193$ for the H-atom bound in the $H_2$ molecule, to account for the covalent bonding in the molecule. The $e^-$-$H_2$ cross sections are calculated in this two-centre approximation, by taking $\lambda = 2Z^*$. Further details in this regard are discussed in [3–5].

Also considered in the present theoretical work are positrons which, as projectiles of collisions with free atomic or molecular hydrogen, have also been studied previously in various approximations [6]. For positron scattering with atomic hydrogen, the EBS theory can be employed by noting that the first and the third terms of equation (1.1) are both opposite in sign to that of electrons, while the exchange effect is absent. For positron-$H_2$ scattering, the high energy IAiM model has been employed in the present work, by incorporating appropriate changes in view of the basic difference between the electron and the positron.

Now, in the above theoretical highlights the target atoms or molecules are supposed to be free or isolated as usual, say in a beam-beam experiment. Our special interest in this paper is in the target atoms or molecules embedded in weak Debye plasmas. The Debye plasma has property of screening the coulomb potential by a factor $\exp(-r/\Lambda_D)$, where $\Lambda_D$ is the characteristic Debye screening length, which is a function of the electron concentration $n_e$ and electron-temperature $T_e$ of the plasma medium. Presently the Debye length $\Lambda_D$ is conveniently expressed in the unit of the usual Bohr radius '$a_0$'. The infinite range coulomb potential $(+q/r)$ of a point charge $+q$ embedded in plasma, becomes the short range screened coulomb potential

$$V_{sc}(r;\Lambda_D) = +(q/r)\exp(-r/\Lambda_D) \tag{1.2}$$

with $r$ as a radial distance. For the present purpose let us work with plasma parameter viz., the inverse length $\lambda_D = 1/\Lambda_D$ expressed in $a_0^{-1}$. Atomic-molecular scattering of electrons or positrons in plasma environments has been investigated by several authors e.g. [7–9].

With this introductory background, the aim of the present paper is the following. We examine the effect of weak plasma identified through $\lambda_D = 1/\Lambda_D$, on the differential and the total cross sections of $e^-$-H, $e^+$-H, $e^-$-$H_2$, and $e^+$-$H_2$ elastic scattering, at intermediate and high incident energies. Atomic units $(au)$ are used presently unless stated otherwise. Sample results on electrons as well as positrons are obtained here and quantitative conclusions are reported on the effect of different Debye plasmas on the $e^-$ and $e^+$ cross sections of atomic as well as molecular hydrogen.

## 2. Theoretical Methodology

Let us outline our basic theoretical methodology by considering first the elastic scattering of fast electrons by free or isolated hydrogen atoms. In this case, the *differential cross section* (DCS) including exchange, is given exactly by the following expression [2].

$$\frac{d\sigma}{d\Omega}(\theta,k) = \frac{3}{4}\left|f^d_{EBS} - g_{och}\right|^2 + \frac{1}{4}\left|f^d_{EBS} + g_{och}\right|^2 \tag{2.1}$$

The high energy elastic DCS are peaked in the forward direction i.e. at scattering angle $\theta = 0$ $(\Delta = 0)$. The *forward DCS* (FDCS) is dominated by target polarization effects, and is represented by the real part of the second Born amplitude $Ref^2_B$, vide equation (1.1). Detailed expressions for the different terms of equation (1.1) are given in [1]. For example the first Born scattering amplitude derived through the H-atom static potential $V_{st}(r)$, is given by,

$$f_{B1} = 2\frac{(\Delta^2 + 2\lambda^2)}{(\Delta^2 + \lambda^2)^2} \tag{2.2}$$

Where $\lambda = 2Z = 2$ corresponding to H(1s)-atoms. Details of the DCS calculations in the EBS theory are omitted here, but the high-energy results obtained are in a good accord with experimental data, as shown in [1–3].

The integrated or total (complete) cross section, referred to as the Bethe-Born cross section $\sigma^{BB}_{tot}$ in earlier literature [1,2], is denoted presently by the symbol $Q_T(E_i)$, and this quantity is related to the imaginary part of the forward scattering amplitude $O(k^{-1})$ through the optical theorem, viz.,

$$Q_T(E_i) = \frac{4\pi}{k}\,\mathrm{Im}\,f_{B2}(\theta = 0) \tag{2.3}$$

Now, if the target atoms are surrounded by a weak plasma medium, the basic coulombian interactions of the e$^-$-H system are influenced through the Debye screening factor $\exp(-r/\Lambda_D)$. To derive for the said influence on the static potential $V_{st}$ (in au) of the H atom, suppose that the radial coordinate of the projectile electron is given tentatively $r_0$, while that of the bound electron in the atom is denoted by $r_1$, and let us define inter-electron separation coordinate as $r_{01} = |\boldsymbol{r}_0 - \boldsymbol{r}_1|$. Thus, the static potential in the plasma medium will be given by [1],

$$V'_{st} = \frac{1}{\pi}\int e^{-\lambda \cdot r_1}\left[\frac{\exp\left(-\frac{r_{01}}{\Lambda_D}\right)}{r_{01}} - \frac{\exp\left(-\frac{r_0}{\Lambda_D}\right)}{r_0}\right] dr_1; \qquad \lambda = 2 \tag{2.4}$$

Taking the plasma screening factor to be approximately the same i.e. $\exp(-r_0/\Lambda_D)$ in both the coulombian terms in (2.4), and reverting to symbol $r$ for the projectile electron coordinate, we obtain finally,

$$V'_{st} = -\left(1 + \frac{1}{r}\right)e^{-\lambda' \cdot r}. \tag{2.5}$$

It is assumed that, the external plasma is so weak that it does not alter the basic target properties like the charge-distribution, ionization energy etc. In that case, employing equation (2.5), the first Born amplitude $f_{B1}$ for $H$ atoms in plasma is given again by equation (2.2), but with $\lambda = 2$ replaced by $\lambda'$ where the new parameter is

$$\lambda' = \lambda + \lambda_D \tag{2.6}$$

Thus the replacement of $\lambda = 2$ by $\lambda'$ defined in equation (2.6) accounts for the presence of plasma medium characterized by the inverse-length parameter $\lambda_D$. Now, it is known that the plasma tends to curtail long range interactions like polarization potential. This potential dominates the electron-atom/molecule DCS in the forward direction. Therefore, in order to see the maximum effect of the surrounding plasma on the DCS, we calculate presently the forward elastic e$^-$-H scattering at energies from 50 eV onwards. Expressions for various scattering amplitudes [1, 2, 10] needed to calculate the atomic FDCS, incorporating $\theta = 0$, $\Delta = 0$, are as given hereunder.

$$f_{B1} = \frac{4}{\lambda'^2} \tag{2.7a}$$

$$\mathrm{Re}\,f_{B2} = \frac{4\pi}{k\lambda'^2} \tag{2.7b}$$

$$\mathrm{Im}\,f_{B2} = \frac{8}{k\lambda'^2}\left[\ln\left(\frac{\lambda' k}{\omega}\right) - \frac{1}{\lambda'^2}\right] \tag{2.7c}$$

$$f_{G3} = 0 \tag{2.7d}$$

$$g_{och} = -\frac{32}{k^2\lambda'^4} \tag{2.7e}$$

The third Glauber amplitude $f_{G3}$ is zero in the forward direction, as was shown by Dewangan [11]. The parameter $\lambda'$ is chosen through equation (2.6), for a particular plasma. Further $\omega = 0.465$ au is the average excitation energy of the H atom. The TCS are obtained through equation (2.3). Let us turn now to $e^-$-$H_2$ elastic scattering in the high energy IAiM model. This model yields the following expression [4,5] for the orientation-averaged elastic DCS $\bar{I}(\theta,k,Z^*)$, including the exchange effect.

$$\bar{I}(\theta,k,Z^*) = 2\left|f^d_{EBS} - \frac{1}{2}g_{och}\right|^2\left[1+\frac{\sin\Delta R}{\Delta R}\right] \tag{2.8}$$

In equation (2.8) both the scattering amplitudes are considered initially without any plasma. In (2.8) the required scattering amplitudes for H-atom (inside the modulus sign) are essentially the same as in [1,2,10] but we have $\lambda = 2Z^*$, and $Z^* = 1.193$, representing the atom bound in the $H_2$ molecule. Of course this corresponds to $e^-$-$H_2$ system without any plasma. The factor in the square bracket in equation (2.8), with $R = 1.4\,a_0$ as the bond-length in $H_2$ molecule, arises from the interference of electron-waves scattered by two H-atoms in this molecule. Note that this factor simply becomes 2 in the forward direction.

Our next task is to incorporate the effect of plasma environment in the $e^-$-$H_2$ scattering. For this purpose, we replace $\lambda = 2Z^*$ by $\lambda' = 2Z^* + \lambda_D$, along the line of arguments presented above, i.e. equation (2.6). Thus, the $e^-$-$H_2$ cross sections are calculated essentially in the EBS method, by introducing the Debye screening via $\lambda_D$.

Finally the positron scattering with $H_2$ molecules in plasma is treated here along the lines of $e^-$-$H_2$ calculations, but by including the appropriate changes corresponding to positrons, in equations (2.7a)-(2.7e) and (2.8).

Specific values are chosen for the plasma parameter $\lambda_D$, and we return to this point in Section 3.

## 3. Results, Discussions and Conclusions

In this paper the elastic scattering of fast electrons as well as positrons is studied for atomic and molecular hydrogen targets. The differential and the total (complete) cross sections are calculated, (a) without any plasma medium, and (b) with embedding plasmas characterized by $\Lambda_D$. The usual DCS and TCS for free atoms/molecules well reproduce the experimental and other data at high energies, and are not shown here. The EBS being a high energy method does not yield accurate results at a lower energy like 50 eV. However, even at such energies it is still meaningful to calculate and make relative comparisons of our results without and with plasma.

Our aim in this paper is to examine quantitatively how the FDCS $\frac{d\sigma}{d\Omega}$ $(\theta = 0)$ and the TCS $Q_T$ are affected when the targets are in the midst of plasma.

## 4. Choice of parameter $\lambda_D$

In order to choose the parameter $\lambda_D$ representing the plasma strength, we note that the average radius of H (1s)-atom is $\langle r\rangle = 1.5\,a_0$. Hence to ensure that the plasma is weak enough, we choose model values of the Debye length $\Lambda_D$ to be typically larger than $3\langle r \rangle$. Thus our calculations are carried out first at three selected Debye lengths $\Lambda_D = 5.0$, 7.5 and 10 all in $a_0$, and $\lambda_D$ is set accordingly in equation (2.6). If the Debye length is chosen to be smaller, it would mean progressively stronger plasma, which may even alter the basic properties of the target, and the Debye screening model itself would not be reliable. On the other hand, for large values of $\Lambda_D$ the cross sections are hardly influenced by the plasma. The present choice of $\Lambda_D$ values is identical for electrons as well as positrons, and also for both these targets.

Let us now discuss the results obtained presently for atomic and molecular hydrogen.

## 5. Scattering of $e^-$ or $e^+$ with H atoms in plasma

The present FDCS and TCS for electron-H scattering without and with plasma confinement are exhibited in Table 1, at selected electron energies from 50 eV to 10 keV. The usual cross sections of $e^-$-H (free) scattering are compared with the theoretical values of [1–3] at the first two energies. The agreement is quite good, and the small difference in the cross sections is due to the choice of the atomic average excitation energy $\omega$.

Now, the effect of external weak plasma is to reduce the electron-target interaction strength, resulting into a decrease of the cross sections compared to free (or no-plasma) case. Out of the three typical values of $\Lambda_D$ chosen presently, the smallest value i.e. 5.0 $a_0$ has the strongest influence on the $e^-$-H elastic FDCS of at all energies considered here, and at that $\Lambda_D$, the FDCS as well as the TCS of H-atoms are reduced by maximum percentage compared to no-plasma situation. It was shown in [7] that DCS of electron scattering by a polar molecule like $H_2O$ in plasma are considerably reduced in the forward direction, since the long range dipole potential is effectively curtailed by the Debye screening. The reduction trend is also observed in the elastic positron-Hydrogen calculations carried out by Ghoshal et al. [8].

We have shown in Table 1 our theoretical values of $e^-$-H cross sections at a typically moderate Debye length $\Lambda_D = 7.5\ a_0$, at selected energies. For the FDCS, the difference between the free and plasma cases is around 21%. The effect is maximum in the forward direction, and it decreases progressively at higher angles of scattering. For the TCS the decrease is around 10% (Table 1). Further, Figure 1 is the graphical plot for the FDCS of $e^-$-H scattering over a very wide range of energy, without and with plasma (at four different $\Lambda_D$). With H-atoms again, the TCS ($Q_T$) are also reduced in the presence of plasma, as shown at four different $\Lambda_D$ values in Figure 2.

The overall summary of plasma effects on elastic $e^-$-H scattering is given through Figure 3. We find that for $\Lambda_D \geq 30\ a_0$ the FDCS decreases by less than 5%. The TCS decreases by less than 5% for $\Lambda_D \geq 25\ a_0$, as expected.

Let us now turn to positron-H collisions, in which case it is desirable to first highlight the basic difference between $e^-$ and $e^+$ results for H atoms in the absence of plasma. The present $e^-$ and $e^+$ FDCS (Figure 4) for free H atoms although overestimating at lower energies, indicate the right trend. For positrons the exchange effect is absent and the polarization effect is opposite to that for electrons and hence the positron FDCS are on the lower side, more so at lower energies. Since the DCS in Figure 4 correspond to forward scattering the difference between $e^-$ and $e^+$ results persists even at high energies.

**Table 1.** FDCS (au) and TCS ($a_0^2$) of electron-H atom elastic scattering at selected energies. Here, asterisk (*) indicates compared data from [1–3]

| Energy $E_i$ (eV) | FDCS without Plasma | | FDCS with Plasma ($\Lambda_D = 7.5\ a_0$) | TCS without Plasma | | TCS with Plasma ($\Lambda_D = 7.5\ a_0$) |
|---|---|---|---|---|---|---|
| 50 | 13.96 | (14.20)* | 11.46 | 12.69 | (12.20)* | 11.58 |
| 100 | 8.55 | (8.25)* | 6.92 | 7.53 | (7.49)* | 6.83 |
| 150 | 6.62 | | 5.32 | 5.48 | | 4.96 |
| 200 | 5.58 | | 4.47 | 4.35 | (4.39)* | 3.94 |
| 300 | 4.46 | | 3.55 | 3.13 | (3.17)* | 2.82 |
| 400 | 3.85 | | 3.06 | 2.47 | (2.50)* | 2.23 |
| 500 | 3.45 | | 2.73 | 2.06 | | 1.85 |
| 600 | 3.17 | | 2.51 | 1.77 | | 1.59 |
| 700 | 2.96 | | 2.34 | 1.55 | | 1.39 |
| 800 | 2.80 | | 2.21 | 1.39 | | 1.25 |
| 900 | 2.66 | | 2.10 | 1.25 | | 1.13 |
| 1000 | 2.55 | | 2.01 | 1.15 | | 1.03 |
| 1500 | 2.19 | | 1.72 | 0.81 | | 0.73 |
| 2000 | 1.99 | | 1.56 | 0.63 | | 0.57 |
| 5000 | 1.56 | | 1.21 | 0.28 | | 0.25 |
| 6000 | 1.50 | | 1.17 | 0.24 | | 0.22 |
| 7000 | 1.45 | | 1.13 | 0.21 | | 0.19 |
| 8000 | 1.41 | | 1.10 | 0.19 | | 0.17 |
| 9000 | 1.39 | | 1.08 | 0.17 | | 0.15 |
| 10000 | 1.36 | | 1.06 | 0.15 | | 0.14 |

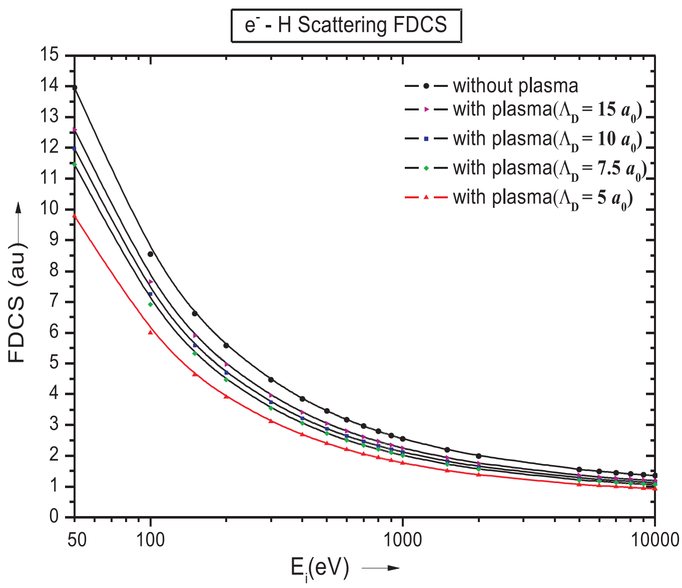


**Figure 1.** FDCS ($au$) of e$^-$-H elastic scattering, plotted vs. incident electron energy, at different Debye screening lengths, the top most curve showing free or no-plasma case.

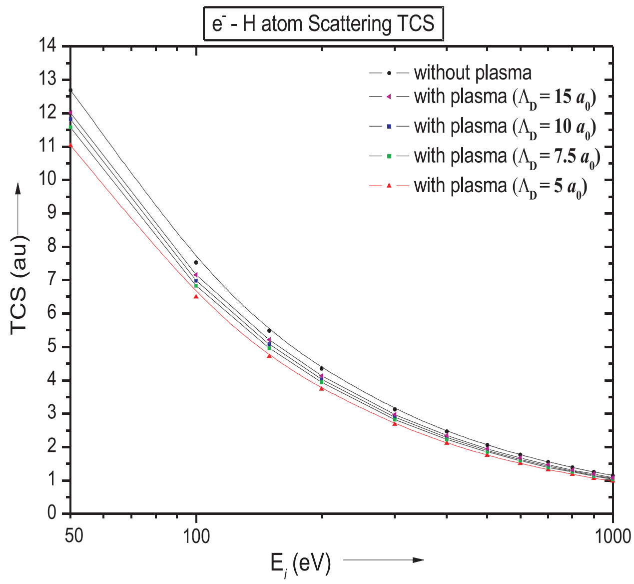


**Figure 2.** TCS $Q_T$ $(a_0^2)$ of e$^-$-H elastic scattering plotted vs. incident electron energy, at different Debye screening lengths, the top most curve showing free or no-plasma case.

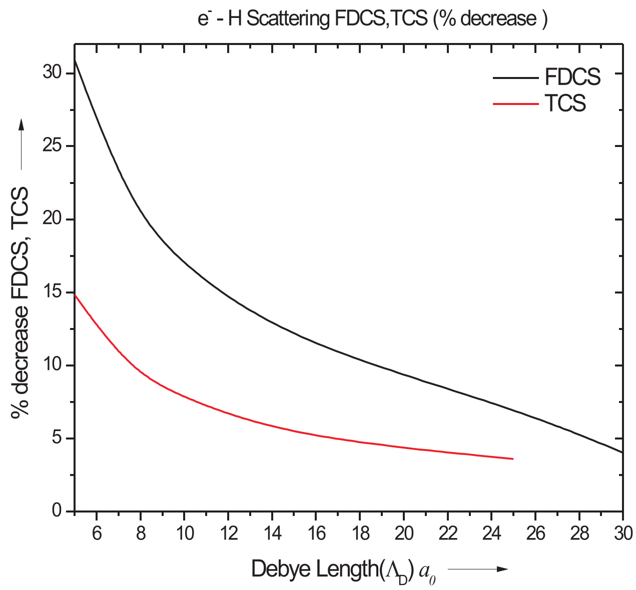


**Figure 3.** Percentage difference relative to no–plasma case for e$^-$-H scattering a wide range of $\Lambda_D$; upper curve FDCS, lower curve TCS.

Next, considering positron scattering in plasma, we have shown in Figure 5, the e$^+$-H FDCS at a typically moderate Debye length $\Lambda_D$ = 7.5 $a_0$, over a range of intermediate and high energies. In the usual no-plasma situation, our calculated values of FDCS and TCS agree with those of [1–3]. For FDCS, the difference between the free and plasma cases is about 18%. Let us note here that, in the EBS theory there is no difference between the TCS of electrons and positrons. Therefore in the present calculations the positron $Q_T$ are the same as in Figure 2, and the discussion on electron $Q_T$ applies here too.

The effect of external plasma on positron scattering dwindles at large enough $\Lambda_D$, similar to electron scattering case as in Figure 3.

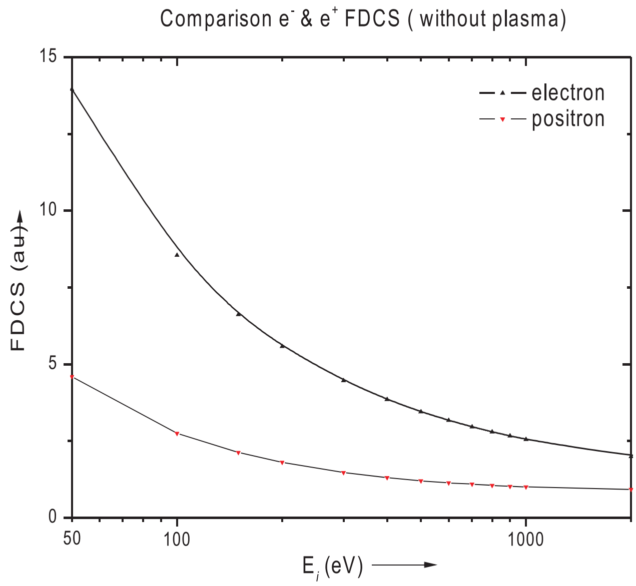


**Figure 4.** Comparison of the present $e^-$ and $e^+$ FDCS (au) for H-atoms in the absence of plasma.

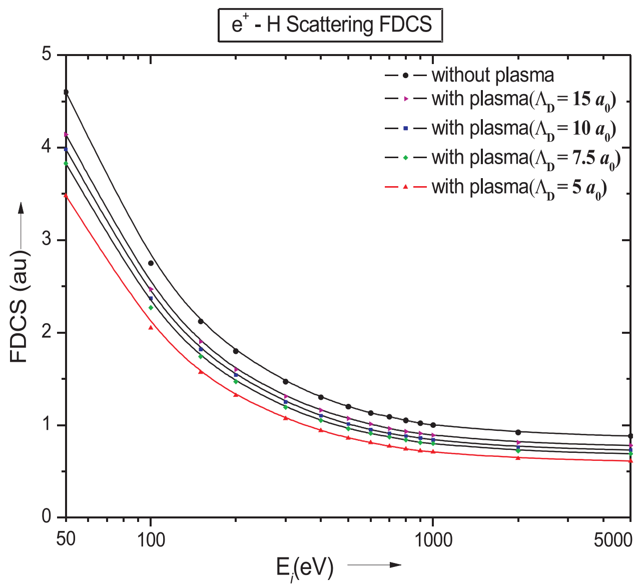


**Figure 5.** FDCS ($au$) of positron-H elastic scattering plotted vs. incident electron energy, at different Debye screening lengths, the top most curve showing free or no-plasma case.

## 6. Scattering of $e^-$ or $e^+$ with $H_2$ molecules in plasma

Now let us we consider our $e^-$-$H_2$ scattering cross sections calculated in the EBS theory along with IAiM approximation. The approximate IAiM method holds better when the de Broglie wave length ($\lambda_{dB}$) of incident electrons (or, for that matter, positrons) is smaller than the bond-length $R = 1.4\ a_0$ of $H_2$. In other words the method is reliable above $E_i = 270$ eV, which corresponds to $\lambda_{dB}$ equal to $R$. At lower energies, this approximation together with the EBS theory gives overestimated results, but still a relative comparison of cross sections without and with plasma can be made.

We have shown in Table 2 the electron FDCS and TCS of molecular hydrogen from $E_i = 50$ eV onwards. In this case the decrease in electron-FDCS and TCS, brought about by plasma with $\Lambda_D = 7.5\ a_0$ is almost similar to that in the respective H atom cases. For FDCS, the difference between the free and plasma cases is around 19%, while for the TCS it is around 8% (Table 2).

**Table 2.** The present FDCS ($au$) and TCS ($a_0^2$) of electron-$H_2$ molecule scattering at selected energies. The percentage decrease in plasma ($\Lambda_D = 7.5\ a_0$) is shown relative to no-plasma case

| Energy | FDCS without Plasma | FDCS with Plasma $\Lambda_D = 7.5\ a_0$ | TCS without Plasma | TCS with Plasma $\Lambda_D = 7.5\ a_0$ |
|---|---|---|---|---|
| 50 | 25.47 | 20.84 | 20.37 | 18.89 |
| 100 | 16.57 | 13.56 | 11.85 | 10.93 |
| 200 | 11.13 | 9.1 | 6.75 | 6.21 |
| 300 | 8.97 | 7.32 | 4.83 | 4.43 |
| 400 | 7.76 | 6.32 | 3.79 | 3.48 |
| 500 | 6.97 | 5.67 | 3.14 | 2.88 |
| 600 | 6.40 | 5.21 | 2.69 | 2.47 |
| 700 | 5.98 | 4.86 | 2.36 | 2.16 |
| 800 | 5.64 | 4.58 | 2.1 | 1.93 |
| 1000 | 5.14 | 4.17 | 1.74 | 1.59 |
| 2000 | 4.00 | 3.24 | 0.95 | 0.87 |
| 5000 | 3.10 | 2.5 | 0.42 | 0.39 |
| 7000 | 2.89 | 2.33 | 0.31 | 0.29 |
| 10000 | 2.71 | 2.18 | 0.23 | 0.20 |

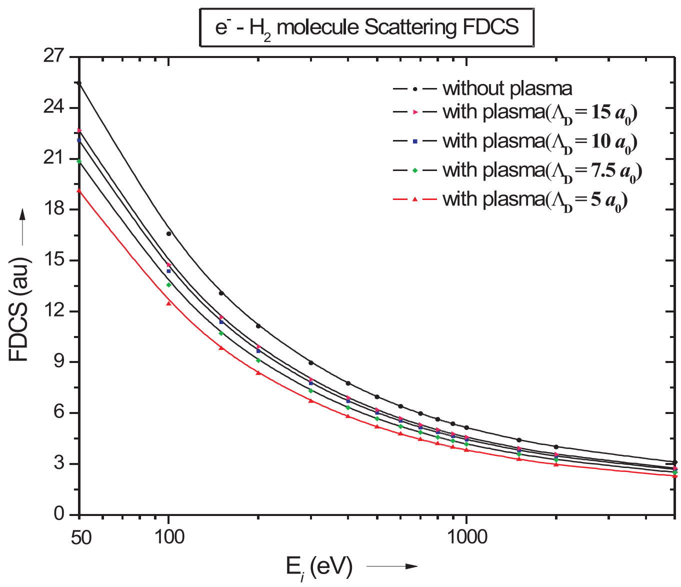


**Figure 6.** FDCS ($au$) of $e^-$-$H_2$ elastic scattering plotted vs. incident electron energy, at different Debye screening lengths, the top most curve showing free or no-plasma case

Increasing $\Lambda_D$ results into lesser and lesser decrease in these cross sections, as against no-plasma case, and that is expected. Our Figure 6 is the graphical plot for the FDCS of $e^-$-$H_2$ scattering over a very wide range of energy, without and with plasma (at four different $\Lambda_D$). Finally in the Figure 7, we have exhibited the TCS of molecular hydrogen for a comparative graphical study of the plasma effects at four different $\Lambda_D$.

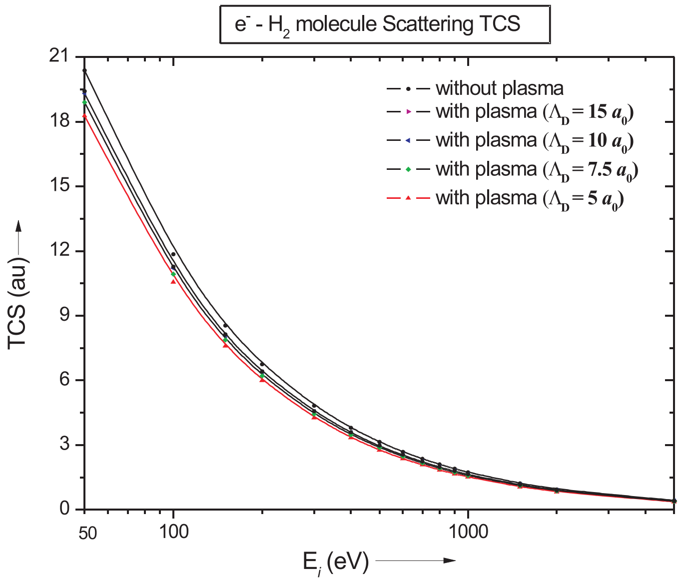


**Figure 7.** TCS $Q_T(a_0^2)$ of $e^-$-$H_2$ elastic scattering plotted vs. incident electron energy, at different Debye screening lengths, the top most curve showing free or no-plasma case

The overall summary of plasma effects on elastic $e^-$-$H_2$ scattering is given Figure 8. We find that for $\Lambda_D \geq 26\ a_0$, the FDCS decreases by less than 5% and the TCS decreases by less than 5% for $\Lambda_D \geq 20\ a_0$.

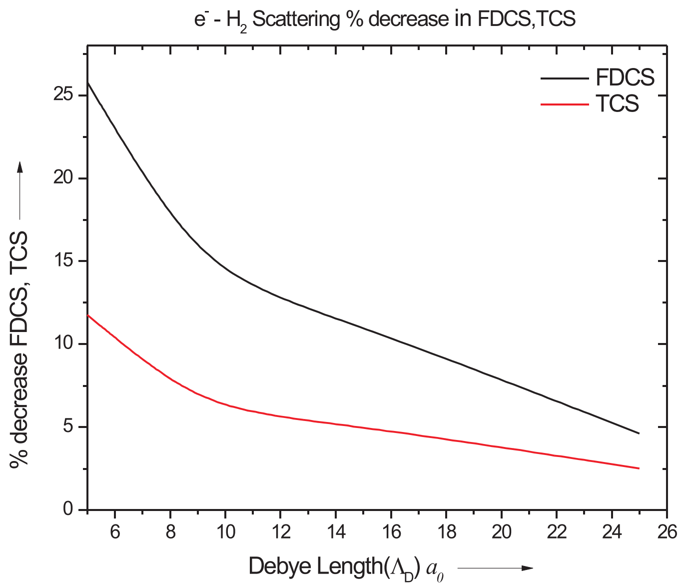


**Figure 8.** Percent difference relative to no-plasma case for $e^-$-$H_2$ scattering over a wide range of $\Lambda_D$; upper curve FDCS, lower curve TCS

Finally we report our studies on positron scattering with $H_2$ molecules. As in the previous case of atomic hydrogen, the present $e^-$ and $e^+$ FDCS for molecular Hydrogen without plasma also basically differ, and that is shown in Figure 9. The positron values are lower, more so at lower incident energies as expected.

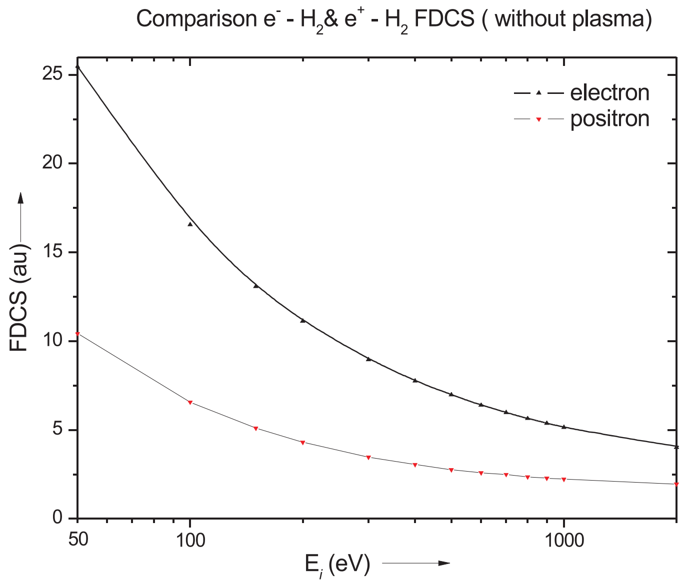


**Figure 9.** Comparison of the present $e^-$-$H_2$ and $e^+$-$H_2$ FDCS ($au$) without plasma

Figure 10 exhibits the FDCS of $e^+$-$H_2$ elastic scattering plotted vs. incident energy, at different Debye screening lengths, the top most curve showing the basic no-plasma case. The TCS behaviour in plasma is same as in the electron $-H_2$ case.

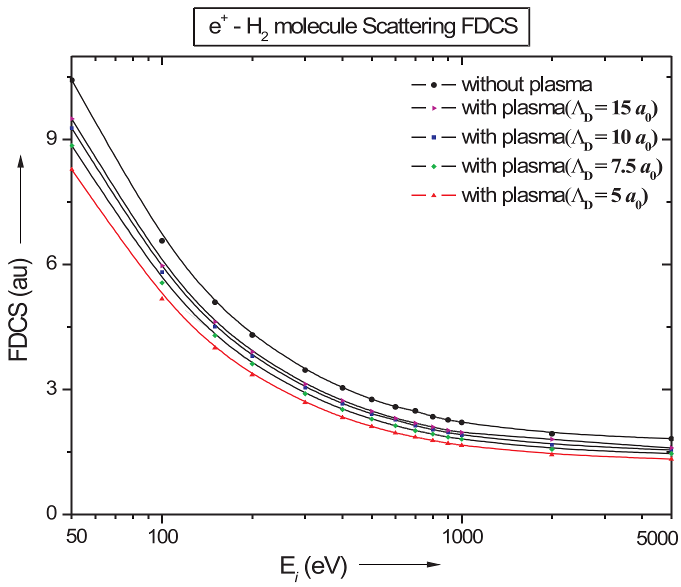


**Figure 10.** FDCS of $e^+$-$H_2$ elastic scattering plotted vs. incident energy, at different Debye screening lengths, the top most curve showing free or no-plasma case

## 7. Conclusion

In conclusion of the present study, we find that the influence of external plasma medium is rather more on the FDCS of elastic electron scattering from H and $H_2$, while the TCS ($Q_T$) are affected to a lesser degree, as discussed. As far as the angular distribution of scattered electrons (or, for that matter, positrons) is concerned the highest effect occurs in the forward direction, and that is almost independent of energy. The reduction effects decrease as the Debye length increases. The Debye length corresponding to weakly coupled plasma chosen here is arbitrary but it is taken to be sufficiently larger than the average atomic radius 1.5 $a_0$ of the H atom. Positron scattering with free molecules has been explored well in literature [12], while studies on $e^+$ collisions with molecules like $H_2$ in plasma are scare or none. Hence the present work holds significance.

Our calculations in this paper lead to an interesting question; can we ascertain an upper limit, in terms of $\Lambda_D$, beyond which the weak Debye plasma becomes practically ineffective in influencing the electron (or positron) interactions and thereby the cross sections? Our present findings indicate that, even the FDCS, which are more sensitive to plasma screening, are reduced by less than 5% in a plasma with $\Lambda_D$ more than 25 $a_0$ or so. This conclusion is significant in terms of the electron or positron scattering taking place in plasmas of real physical situations.

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### Competing Interests

The authors declare that they have no competing interests.

### Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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