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Total Stopping Power calculation of Electrons in (H2O and C22H10N2O5)

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Abstract: *In this research is to calculate the total stopping power (stot) of electrons which are two parts: Radiative stopping power (srad) and collisional stopping power (scoll) as well as stopping time for components: water (H2O) and kapton (C22H10N2O5) by using the relative Beth-Bloch equation in the range of electron energies (0.01-100) MeV.The present results are compared with values of Estar code.It is found that our results are in good agreement with values of Estar code and the correlation coefficient between them is (0.9).*

Keywords: Bethe-Bloch, stopping power, radiative, collision , kapton , mean excitation energy , Estar code

1. Introduction

The process of slowing the charged particles in the material is determined by two different processes: nuclear stopping resulting from the reaction of the charged particle incident with the nuclei of the target material atoms and the electronic stopping resulting from the reaction of the charged particle with the electrons of the target atom. The stopping power (-dE/dX) is defined as the lost energy rate of the path unit. The energy lost is the energy transferred from the charged particles to the atoms of the absorber medium passing through it, causing ionization or excitation to the atoms of that medium[1].The Study of stopping power of electron through matter is an effective tool for exploring the structure of matter .The importance of Stopping Power in variety of applications such as radiation physics, Chemistry ,Biology and Medicine especially for β^- and β^+ in matter have widely usage in medical applications [2]. The stopping power evaluations for β are studied in two different ways : the first is to consider the interactions of incoming of the electron and positron with target electrons , which is called collisional stopping power while the second is considered the fact that accelerated charged particles is radiated ,which is called radiative stopping power or Bremsstrahlung Loss [3].

2. Total Stopping Power of the Electrons

The electron loses their energy by ionization and excitation of the orbital electrons in the medium. Mass stopping Power (dE/ρdX) can be defined as the rate of energy loss per unit path length of an electron or positron by excitation or ionization which was known as "collisional energy loss." The mass collision stopping powers for electrons is given by [4]:

$$\left(\frac{\mathrm{dE}}{\rho\mathrm{dX}}\right)_{coll} = K\left[\mathrm{Ln}\left\{\frac{\tau^2(\tau+2)}{2\left(\frac{\mathrm{I}}{\mathrm{moc}^2}\right)}\right\} + \mathrm{F}^{\mp}(\tau) - \delta(\beta\gamma) - \frac{2\mathrm{C}}{\mathrm{Z}}\right] \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where,

$$\mathrm{C}=\pi\left(\frac{\mathrm{N}_A \mathrm{Z}}{\mathrm{A}}\right)\left(\frac{\mathrm{e}^2}{\mathrm{m_o\,c}^2}\right)^2$$

$$\mathrm{K} = \frac{2\mathrm{C}\,\mathrm{m}_o\mathrm{C}^2}{\beta^2} = \frac{0.1535\mathrm{Z}}{\mathrm{A}\beta^2} \quad (\mathrm{MeV}\ .\mathrm{cm}^2.\mathrm{g}^{-1})$$

, I and $\mathrm{m_o c^2}$ in eV

$$\tau = \frac{\mathrm{E}}{\mathrm{m_o c^2}}$$

E is the kinetic energy of the electrons in unites of $\mathrm{m_o c^2}$

$$\mathrm{F}^-(\tau) = (1-\beta^2) + \frac{1}{(\tau+1)^2}\left[\frac{\tau^2}{8} - (2\tau+1)\ln 2\right] \text{ for electron} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\mathrm{F}^+(\tau) = 2\ln 2 - \frac{\beta^2}{12}\left[23 + \frac{14}{(\tau+2)} + \frac{10}{(\tau+2)^2} + \frac{4}{(\tau+2)^3}\right] \text{ for positrons} \ldots\ldots (3)$$

Where,

$\frac{C}{Z}$ is shell correction accounting for non-participation of K-shell electrons at low energies and;

δ is for the polarization or density effect correction in condensed media[4-6]

$$\left.\begin{array}{ll} \delta = 0 & X < X_o \\ \delta = (4.606 \times X) + [a(X_i - X)^m)] & X_o < X < X_i \\ \delta = (4.606 \times X) + C & X > X_i \end{array}\right\} \ldots.(4)$$

where

$$X = \log(log(\frac{\beta}{\sqrt{1-\beta^2}})\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(5)$$

The parameters Xo , Xi , a , m and C Parameters for elements and many compounds and mixtures were published [5]see table(1).

Table (1). Density Effect Parameters for Compounds[6]

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Compound	I (eV)	Density (g/cm^3)	$-C$	X_o	X_i	M	a
Kapton	**79.6**	**1.4200**	**-3.3497**	**0.1509**	**2.5631**	**3.1921**	**0.15972**
Water	**75.0**	**1**	**-3.5017**	**0.2400**	**2.8004**	**3.4773**	**0.09116**

The radiative term, (dE/dx)Rad, accounts for the lost energy due to bremsstrahlung, Cerenkov radiation or nuclear interactions .SRad represent the inelastic collision with nucleus , which produces a quanta of electromagnetic radiation by particle which is important for electrons. Bethe and Heitler obtained an approximate relation between the collisional SColl and radiative SRad stopping powers by the relation: [3, 7].

$$Srad = Scoll \left(\frac{EZ}{800}\right) \quad \ldots\ldots (6)$$

$$Stot = Scoll + Srad \quad \ldots\ldots (7)$$

substituting the equation (6) in equation (7) we get [3]*:*

$$Stot = Scoll\left(1 + \frac{EZ}{800}\right) \quad \ldots\ldots (8)$$

3-Mean excitation energies I

Mean Ionization energy parameter I of an atom or molecule describes the average minimum amount of energy required to remove an electron from certain electron shell to infinity which measured in eV .A number of semi-empirical equations [8]:

$$\left.\begin{array}{ll} I \approx 19.0\ \mathrm{eV} & Z = 1 \\ I = 11.2 + 11.7Z\ \mathrm{eV} & 2 \le Z \le 13 \\ I = 52.8 + 8.171Z\ \mathrm{eV} & Z > 13 \end{array}\right\} \ldots\ldots (9)$$

The mean ionization energy parameter I is a function of the target atomic number Z.

For a compound [9]

$$I = \exp\left(\frac{\Sigma(N_i \times Z_i \times \ln I_i)}{n}\right) \ldots\ldots (10)$$

Where

N_i is Atoms cm^{-3} for the element with Z_i and I_i

n is Total number of electrons in the mixture

Stopping time

The stopping time is the time interval required to stop a charge particle in an absorber medium. This time can be expressed in terms of the stopping power by using the chain of differentiation[10] .

$$\frac{dE}{dt} = \left(\frac{dE}{\rho dX}\right)\left(\frac{\rho dX}{dt}\right) = \frac{1}{\rho}\left(\frac{dE}{dX}\right)(\rho v) = \rho v\left(\frac{dE}{\rho dX}\right) \ldots\ldots (11)$$

Where, v=dx/dt is the velocity of the particle. A rough estimate can be made of the time it takes a heavy charged particle to stop in matter, if one assumes that the slowing – down rate is constant. For a particle with kinetic energy E, this time is approximately [11].

$$t = \frac{E}{dE/dt} = \frac{E}{\rho v(\frac{dE}{\rho dX})} \ldots\ldots (12)$$

where, t in unit(sec)

3. Results and Discussion

The results of total stopping power are given in figures 1 and 2, respectively. These results are obtained by applying equations 1 , 2 , 4 ,5 and 7 using the MATLAB 2018 for water(H_2O) and kapton($C_{22}H_{10}N_2O_5$) in energy range (0.1 - 100) MeV. Figure 1 and 2 show a good agreement with Estar code when the energy is less than (3) MeV , while the difference in the stopping power increases when energy exceed (3)MeV and the correlation coefficient (0.9). When the electron entered a medium it will lose its kinetic energy and also change its direction continuously, therefore the electron will suffer many deviations at large angles along its path length after it approaches the nuclear field of the target atom. The collisional interaction between incident and orbital electrons are due to the interaction of the electrical fields of both electrons. As the incident electron approaches the orbital electrons no actual contact occurs between them, but its interaction is like the interaction of similar magnetic poles.The SRad value is proportional to the incident electron energy and this situation can be explained as the slow electrons (low energy electrons) spend most of their time interacting with orbital electrons and this indicates that these electrons have a high probability of interacting with atomic electrons, while the fast electrons have a low probability of interacting with atomic electrons and pass over the columbic field without being influenced by the electrons, thus this induces the electrons to open up more channels of radiative energy loss. By comparing the results of SColl and SRad, we

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found that the SColl dominates the SRad due to the low energy range therefore Stot value is largely influenced by SColl. In Figures (1 and 2), at energies greater than 1.5 MeV we observe a divergence between the present results and Estar results. This could be due to Bethe-Bloch relativistic formula used in the calculations of this work used the correction to density to minimize the errors.

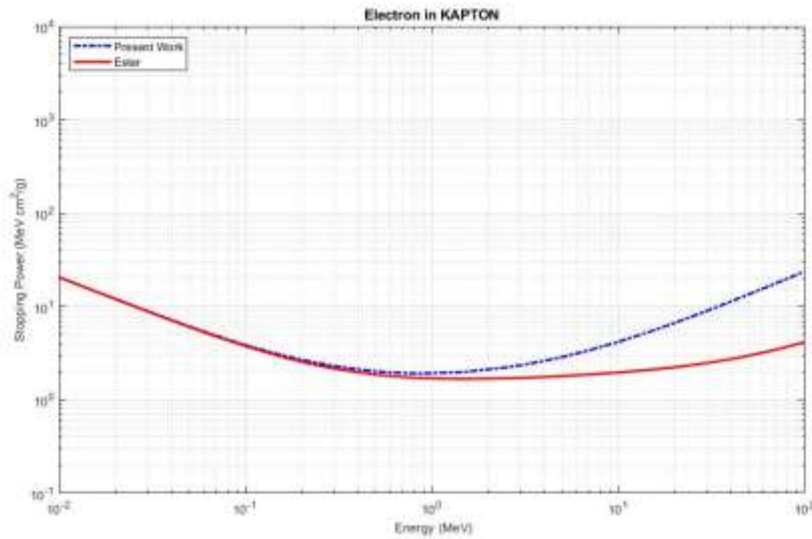

Fig. (1)Comparison of the present work and Estar results for total stopping power of electrons in the Compound Kapton

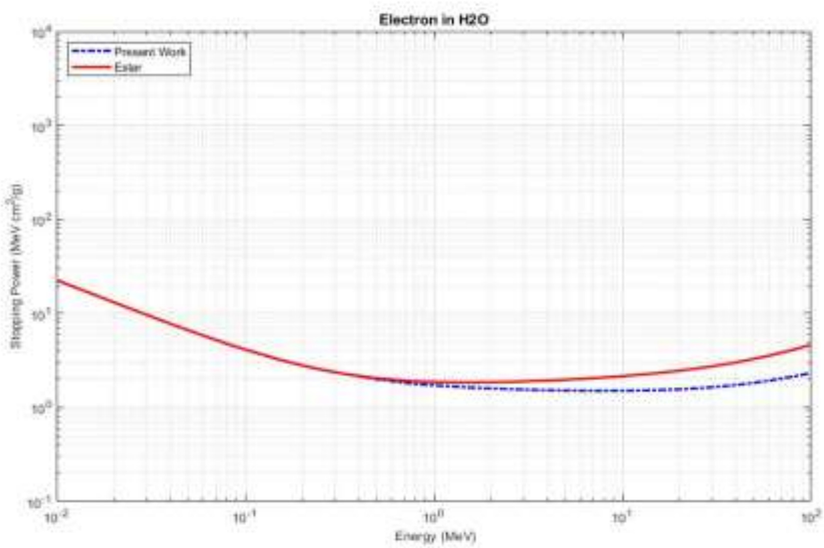

Fig. (2)Comparison of the present work and Estar results for total stopping power of electrons in the Compound water

In figure 3 show the stopping time is proportional to the energy of electrons using equations (10 and 11). It also appears that the time of the electrons in ($H_2O\ and C_{22}H_{10}N_2O_5$) has value highest in energies >10 and increase at idle time there is late power increases for electrons.

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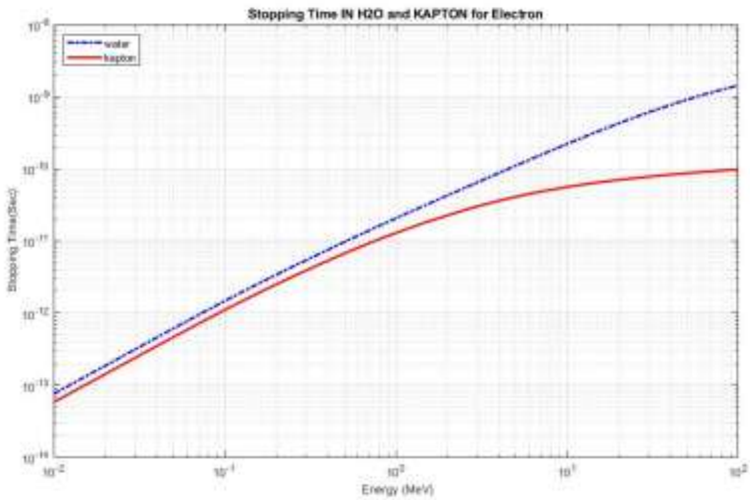

Fig .(3) Calculated stopping time of electrons in the Compounds (H_2O and $C_{22}H_{10}N_2O_5$)

4. Conclusions

Through the findings of this research work, we can conclude the following:

1. The calculations indicate that Stot decreases with increasing particle incident energy, and this energy depends upon the particle velocity which limits the type of interactions with the target.
2. depends upon the particle velocity which limits the type of interactions with the target.
3. The Stot value depends on incident particle energy but their dependence is weak on the atomic number of the target.
4. It was observed the difference was significant in the kapton complex when the energy was greater them (6) MeV. That is, the Bethe-Bloch equation need to be corrected.
5. It was observed that the stopping time for the water compound was greater than the kapton compound.

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