Study of Stopping Power of Electron in Human Tissues

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Abstract

Charged particles lose energy by nuclear interactions during their passing in material are very significant and useful especially in nuclear therapy. We used Bethe-Bloch equation programmed with Matlab and compared the results with E-star program. There are calculated total stopping power (collisional and radiative stopping power) for electron in tissues (Brain and Lung) by considering that each tissue consists of several elements; the total stopping power was measured for those elements within the energy range from 0.01-1000 MeV, taking into account the density correction used in the stopping power calculation. Results are presented and compared with the latest published data.

Key Words: Stopping Power, Human Tissue, E-star, Bethe-Bloch Equation, Electrons.

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Introduction

For more than 50 years, electron beam treatment has been an effective form of radiation therapy [1]. The stopping power of ions in matter has been theoretically explored from the early days of atomic physics, beginning with Bohr, Thomson, and Rutherford [2]. The average unit of energy loss sustained by charge particles per unit path length in the medium under investigation is defined as the medium's stopping power [3]. It is measured in MeV cm^{-1} and is denoted by the symbol - dE/dx .By dividing the stopping power by the density of the material, the mass stopping power, - dE/ρdx, is obtained and is measured in MeV cm^2 g^{-1} [4], electromagnetic force in collisions with atomic electrons cause an electron to lose energy, excitation and ionization occur [5]. Atomic orbital electrons collide in an inelastic collision. It is called this because it causes excitations and ionizations of middle atoms (Collisional Stopping Power). As for the inelastic nuclear collisional, as a results, “Bremsstrahlung” radiation is produced, and the stopping power is equal to (radiative stopping power) [6]. When the product of the inelastic collisions and excitation is proportionate to the stopping power, when you add up all of the atom's final states, you get [5, 7]:

$$-\frac{dE}{dx}=\frac{4\pi k_e^2 Z^2 e^4 n}{mc^2\,\beta^2}\left[\ln\frac{2mc^2\,\beta^2}{I(1-\beta^2)}-\beta^2\right] \quad (1)$$

β =V/c :speed of the particle relative to c, , I is denotes the material's excitation energy, n: the number of electrons per unit volume, z: is the atomic number of the target substance .Taking into account the loss of radiative stopping power, the total stopping power for target materials was calculated . After computing the collisional and radiative stopping power, the total stopping power is calculated by combining the two [6]:

$$\left(-\frac{dE}{dx}\right)_{tot}=\left(-\frac{dE}{dx}\right)_{col}+\left(-\frac{dE}{dx}\right)_{rad} \quad (2)$$

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Collisional Stopping Power

The electromagnetic force encountered in collisions with the atomic electron cause an electron to lose energy, similar to heavy charged particles traversing matter, resulting in excitation and ionizations. Collisional stopping power of electrons cannot be calculated using the heavy ion stopping power formula (1) for a variety of reasons. As heavy ion grant an atomic electron energy, it begins to move nearly in a direct line. The momentum transported to the atomic electron is approximately equal to a momentum acquired by the incident ion in the direction columnar to its route , this momentum shift can only a minor deviation for incident ions. In contrast, the deflection of incident electron with a teeny mass can be high, and unlike the heavy ions. The incident electron can lose a large part of its kinetic energy through a single collision with the atomic electron, which is a target of the same mass. This consideration, in fact, are related to incident electrons [4]. collisional stopping power formula can be written for electrons [8, 9] :

$$\left(-\frac{dE}{dx}\right)_{coll} = \frac{2\pi r_e^2 m_e c^2 Z\, N_\circ}{\beta^2 \mathrm{A}} \ln\frac{E^2}{I} + \ln\left(1+\frac{\tau}{2}\right) + F^-(\tau) - \frac{\delta}{2} \quad (3)$$

if

$$\tau = \frac{E}{m_e c^2} \quad (4)$$

$$F^-(\tau) = 1-\beta^2\left[1+\frac{\tau^2}{8}(2\tau+1)\ln 2\right] \quad (5)$$

$$\beta = \frac{V}{c} \quad (6)$$

r_e : radius of the electron
c : speed of light in a vacuum
m_e :static mass of the electron
v : speed of light in the material
$m_e c^2$: the electron's rest energy
$N_\circ$: Avogadro Number
A :the mass number for target material
Z : is the atomic number for target material
I :target material's average ionization potential
E : energy of the incident electron
$F^-(\tau)$: stopping power function of electrons
τ : electron' kinetic energy in terms of its static energy.
δ: density effect function.

The magnitude (δ) is a function of density effect, which causes a decrease in the stopping power due to the polarization that occurs in liquid and solid materials when the velocity of electrons is very high. Both scholars have risen (S.M Seltzer) and (M.J Berger) and the scholar (R.M. Sternheimer) In 1982 and 1983 by finding a formula for calculating(δ), the following formula was used [9, 10].

$$\left.\begin{aligned} \delta &= 0 \quad \bar{X} < \bar{X}_\circ \\ \delta &= (4.606\times\bar{X}) + \bar{C} + [\,\bar{a}\,(\bar{X}_1-\bar{X})^{\bar{m}}\,] \quad \bar{X}_\circ < \bar{X} < \bar{X}_1 \\ \delta &= (4.606\times\bar{X}) + \bar{C} \quad \bar{X} > \bar{X}_1 \end{aligned}\right\} (7)$$

$$\bar{X} = \log\left(\frac{\beta}{\sqrt{1-\beta^2}}\right) \quad (8)$$

Whereas, the values of the constants shown in Table (1) in equations (7) and (8) were used to calculate the density correction.

Table 1. The constants used in the equation for density correction [11]

Target material	C	x∘	x1	a	m
Brain	-3.4279	0.2206	2.8021	0.0825	3.5585
Lung	-3.4708	0.2261	2.8001	0.08588	3.5353

Radiative Stopping Power

In most atomic collisions, the acceleration of heavy charged particles is minimal, and there is almost no radiation unless extreme condition exist, moreover, bremsstrahlung (braking rays) happen when a particle of small mass is accelerated by the same electromagnetic forces inside an atom. When a particle gets sidetracked in the electric field of a nucleus, and to a lesser extent in the field of an atomic electron, braking rays occur. Radiations are frequently released to the forward direction, that is, in the direction of particle departure, at higher particle energies. Both Bethe and Hitler relied on their study of electron energy loss in elastic collisions on quantum mechanics [12]. When an electron travels close to a nucleus, the region which it acceleration is actually the nucleus's coulomb field. The partial inspection of the nuclear charge by atomic electrons becomes more significant when it is travels a farther distance, and the field loses its columbic character. The effect of atomic inspection by depend on how close the electron comes to the nucles, the inspection and sequent energy loss depend on the energy of an incident particles also. The bremsstrahlung efficiency varies in elements with different atomic number where the bremsstrahlung (braking rays) losses are much greatest in materials with high atomic number than in materials with low atomic number. The convergent formula for the proportion of an electron's radiative stopping power and collision stopping powers from total energy E_{tot} , expressed in

(MeV), in element with an atomic number (Z) is given below [13]:

$$\frac{(-dE/dx)_{rad}}{(-dE/dx)_{col}} \cong \frac{ZE}{800} \quad (9)$$

$$(-dE/dx)_{rad} = \frac{ZE}{800}\,(-dE/dx)_{col} \quad (10)$$

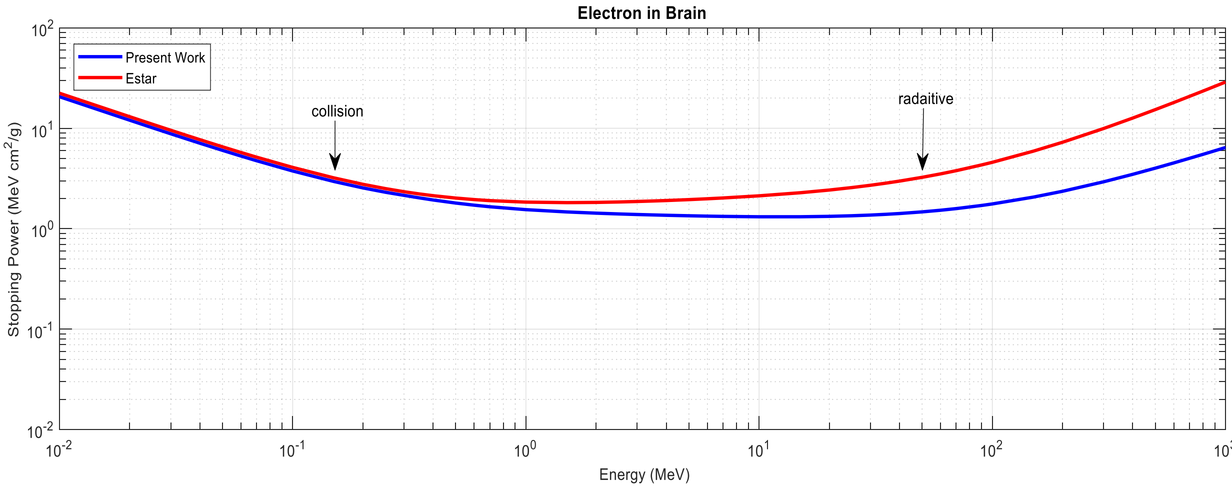

Figure 1. Comparison of the calculated total stopping power with the universal symbol E-STAR of Brain tissue

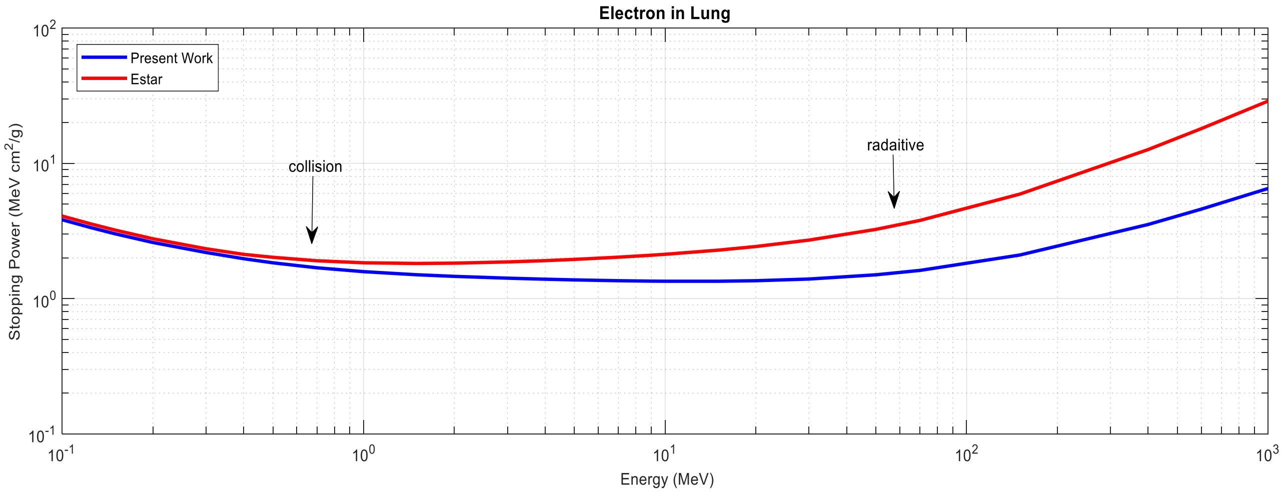

Figure 2. Comparison of the calculated total stopping power with the universal symbol E-STAR of Lung tissue

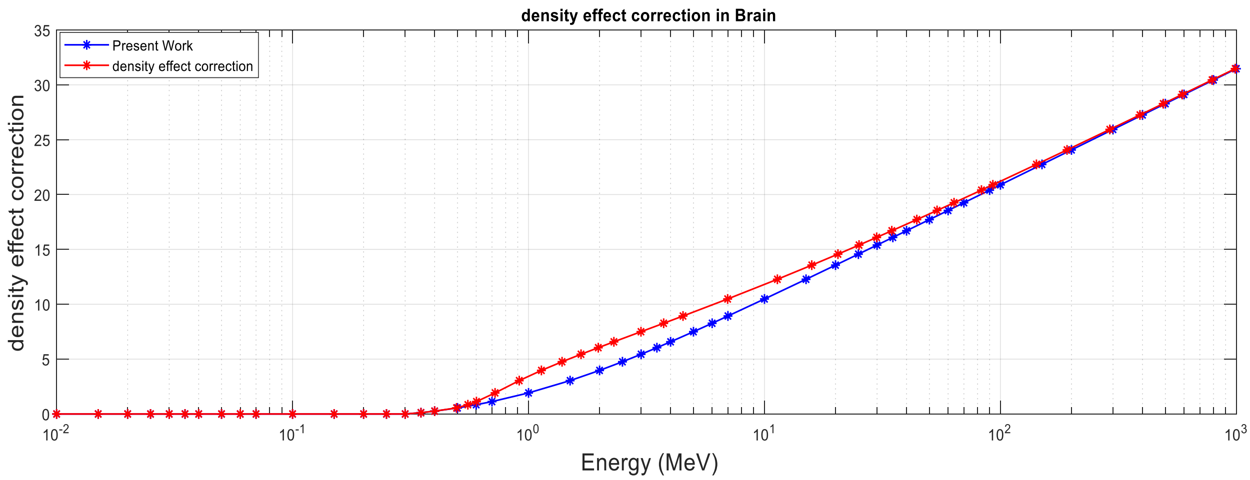

Figure 3. Comparison of density correction effect results for current action and E-STAR results in Brain tissue for electron project

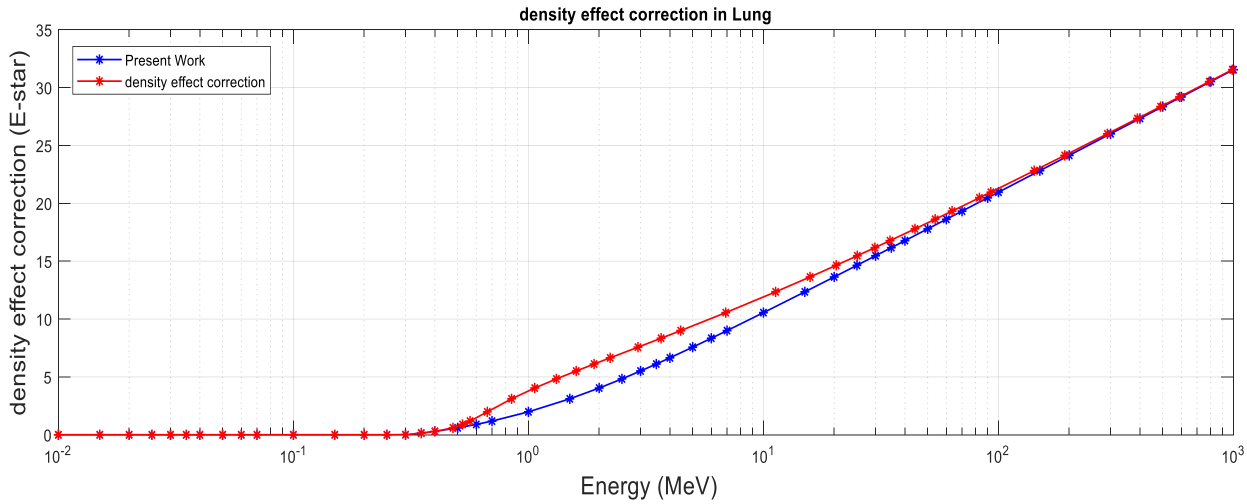

Figure 4. Comparison of density correction effect results for current action and E-STAR results in Lung tissue for electron project

Results and Discussion

The total stopping power is equal to the aggregate of the collision stopping power and the radial stopping power. The figures (1,2) show the comparison between the results of the stopping power calculated according to the Beth-Bloch equation with the results of the global program E-star .From the figures (1,2), we notice that the collision stopping power values of the S_{coll} electrons decrease to a lower value and we find that the S_{coll} curve becomes a straight line, and this is evidence that the Bethe - Bloch equation is insensitive to the change of energy values of the falling electron beyond (0.2 MeV). This behavior can be explain by the fact that the electrons of lower energy spend a longer period of time in their interactions with the electrons orbital of the target material. Thus, it has a higher probability of interacting with orbiting electrons and thus energy losses due to coulomeic collisions is dominant. The loss of the radiant energy of the electrons is caused by the interaction of the incident electrons with the nuclear field in the form of x-rays, or what is known as the suppression rays, due to the rapid chang in the speed of the fall of electron. When the electron passes close to the coulomeic field of the nucleus of the target atom, it will be subjected to a very large attractive force that results in a sharp deviation from its original path. The radiative stopping power in the present work deviates from the E-STAR results in the energy range E > 0.2 MeV. This difference is due to the fact that the radial stopping power of the S_{rad} was calculated in the E-STAR program according to the Berker-Stelzer equation while the Srad was calculated in the present work according to the equation (7). This requires adding modifications to equation (7) to ensure that there is no significant divergence in the computed values. Figures (3, 4) show the results of density correction as a function of energy, which was calculated through equation (7) and the results of the E-STAR program. The results were shown the values of the effect of density correction start to affect energies greater than 0.5MeV as the effect of density correction increases with the increase of the energy of the incident electrons on the studied targets. The comparison between the calculated results and the E-STAR results showed good agreement, especially between energies less than 0.6MeV and energies E > 30MeV.

Conclusions

1. We note that the values of collision stopping power are high at the low energies as a result of the interaction of the fallen electrons at these energies with the orbital electrons of the target atom and not reaching the target's nuclear field.
2. With the increase in the incident energy of the electrons, we notice an increase in the radiation stopping power, because the fallen electrons reach the nuclear field and what is known as nuclear braking or Bremshtrlhng production occurs.
3. We notice that the radial stopping power dominates at hight energies, while collisional stopping power dominates at low energies.
4. That the total stopping power is mostly a result for the collision stopping power, especially at lower energies where the the effect of the radiative stopping power is negligible.

5. Density correction has a great effect in the Bethe-Bloch equation to calculat the collisional stopping power at high energies, as a higher the material density and the higher the electron velocity, the greater the importance of this correction.

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