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Continuous Slowing Down Approximation Range of Electrons in Human Tissues

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ABSTRACT

In this research, two analytical formulas were found to calculate the continuous slowing down approximation range (CSDA range) of electrons within the energy range from 10 MeV to 1000 MeV in the human tissues (blood, dense bone, bone cortex, brain, eye lens, lung, skin, testicles). The two new formulas were found using the data fitting method and depending on data obtained from the International Code (E-Star) values and the International Commission on Radiation Units and Measurements Report No. 37 of 1984 (ICRU Report 37). The first formula was found as a function of the energy of the incident electron only, and the largest deviation in the results obtained from this formula was about (6.21%). The second formula was found as a function of the total stopping power of the electrons only, and the largest deviation in the results obtained from this formula was about (6.95%). The two new formulas are considered simplified formulas and can be applied easily and without the need to perform complex mathematical operations and as a function of only one variable. The previous formulas are complex formulas that depend on a large number of constants and as a function of more than one variable and require many repeated and complex mathematical operations.

Keywords: Incident electron energy, total stopping power of electrons, human tissues, data fitting, international code e-star.

INTRODUCTION

Studying the interaction of nuclear radiation with the material is one of the important topics in medical physics because it has a major role in radiotherapy and knowing the measurements of ionizing radiation. This is done depending on the way it interacts and the amount of energy lost by the radiation inside the material with which it interacts. Also, the construction of nuclear detectors and radiation protective shields requires knowledge of how these radiations interact with different materials. (Mahmood, 2005; El-Ghossain, 2017)

Nuclear radiation is divided based on mass and charge into charged particles, which include heavily charged particles such as protons and alpha particles, Light-charged particles such as electrons and positrons, and uncharged particles such as neutrons, X-rays, and gamma rays. (Khan, 2010)

When heavily charged particles interact with the material, they interact mainly with the atomic electrons of that material, and because of the small size of the nucleus compared to the size of the atom, the possibility of the charged particles interacting with the atomic electrons is much greater than the possibility of them colliding with the nucleus. Therefore, the main reason for the loss of energy of the charged particles is coulomb scattering by atomic electrons, as a result, the atom is excited or ionized, and the path of these particles within the material is in the form of an almost straight line. (Loveland *et al.*, 2017)

As for light charged particles, such as electrons, they lose their energy by the same mechanism as heavy charged particles, with some fundamental differences resulting from the large difference in mass between light and heavy charged particles. When the falling electrons collide with atomic electrons, the falling electrons will be exposed to large deviations in their path, so their path will be winding inside the material. Also, the equality of mass between the atomic electrons and the incident electrons leads to the transfer of a large portion of the energy from the incident electrons to the atomic electrons, and since the mass of the electron is small compared to the mass of the heavy charged particle, its speed will be greater than that of the heavy charged particle when they have the same energy and thus it has a greater ability to penetrate the atom and interact with the nucleus. In this case, the electron will be affected by the coulomb field of the nucleus, which leads to a change in its direction and speed, and this leads to its acceleration and acquisition of kinetic energy, which it quickly gets rid of in the form of electromagnetic radiation known as stopping or braking rays. (Al-Assaf *et al.*, 2016; Fabjan and Schopper, 2020)

Many researchers have studied continuous slowing down approximation range of charged particles in several elements and compounds. The researchers Habeb and Aman Allah (2016) studied the total stopping power for positrons within the range of energies (0.02–50) MeV for two elements (carbon and silver) and continuous slowing down range (CSDA) for the same elements in the energy range (5-1000) MeV. The researcher El-Ghossain (2017) studied stopping power, and range of electrons interaction with different materials and human body parts in the energy range from 0.01 MeV to 1000 MeV. The researcher Gümüş (2019) studied the stopping power and range of electrons of kinetic energy from 20 eV to 10 MeV for some human body tissues. The researchers Ahmed, *et al.*, a(2020) studied the stopping power and range of protons in biological human soft and hard tissues (blood, brain, skeleton-cortical bone, and skin) of both children and adults in energies ranging from 1 MeV to 350 MeV.

This study aims to find new and simplified formulas to calculate the continuous slowing down approximation range of electrons in human tissues. These formulas should be accurate and depend on the least number of constants and as a function of the energy of the incident electron only or the total stopping power of electrons.

Interaction of electrons with material:

When the energy of the incident electrons is small, less than 1 MeV, these electrons lose their energy through inelastic collisions that lead to the excitation of the electrons of the atoms of the target material (as these electrons gain kinetic energy and move from their current orbit to a higher orbit) or ionization of these atoms (where the atomic electrons gain a large kinetic energy that enables them to leave the atom as the atom turns into a positive ion). Since the mass of the electron is small, its speed is large, and therefore the time for the falling electrons to stay near a particular atom is very small, and that leads to a decrease in the amount of qualitative ionization. (Qualitative ionization is the number of ionic electron pairs formed within one millimeter of impact in atmospheric air at a temperature of 15 degrees Celsius and a pressure of 760 mm Hg) (Podgorsak, 2016; Abd Almonem, 2023).

According to the laws of conservation of energy and momentum, when the incident electrons collide with the atomic electrons of the material, the energy transferred from the incident electrons to the atomic electrons of the material may reach half the energy of the incident electron in a single collision, meaning that the possibility of transferring a large amount of energy is great. Since the mass of the electron is small compared to the mass of the nuclei of the atoms of the material, when the falling electrons collide with the nucleus, they deviate from their original path at each collision, and thus the path within the material is in the form of a zigzag line. (Gümüş, 2019; Hussein, 2023).

As the energy of the incident electrons increases, they will penetrate the atom and reach the nucleus, and as a result of their passage near the nucleus, they will deviate from their path, this deviation will lead to their acceleration, and thus they will emit electromagnetic radiation whose intensity is proportional to the square of its acceleration, and these radiations are known as stopping or braking rays (Ahmed *et al.*, b2020).

Total stopping power of electrons:

The stopping power can be defined as the rate of energy lost from electrons falling into a material. The greater the distance within the material, the greater the amount of energy lost. It can also be defined as the amount of energy lost by the incident electrons in one millimeter of impact. Stopping power depends on the properties of the falling particle, represented by its kinetic energy (mass and speed), and the properties of the target material, represented by the atomic number, mass, and average ionization potential (Mohammed *et al.*, 2018; Osman and Gümüş, 2022).

The total stopping power is divided into two parts: Collision stopping power and radiative stopping power. This division is of great importance, especially when it comes to the amount of energy that a material receives as a result of radiation passing through it, because it is related to studying the effect of radiation on living cells and tissues and estimating radiation doses. (Habeb and Aman Allah, 2016; Gümüş, 2022)

Collision stopping power is defined as the rate of energy lost from incident electrons per distance unit as a result of Coulombic collisions with the atomic electrons of the target material. The radiation stopping power is defined as the rate of energy lost per distance unit from the path of electrons through the release of electromagnetic radiation as a result of nuclear suppression (Ahmed *et al.*, b2020).

The continuous slowing down approximation range:

The continuous slowing down approximation range of charged particles at a given energy can be defined as the average path length of these particles within the material. To shorten this long term, it can be referred to as (CSDA) range. The range for an incident particle is given as: (Gümüş and Bentabet, 2017; Pal *et al.*, 1985)

$$R = \int_0^E \left(\frac{dE}{dx}\right)^{-1} dE \quad \text{………………} \ (1)$$

The path of charged particles within a material ends when their kinetic energy ends. Since charged particles lose their energy randomly, their paths within the material are different, and a particle can travel a greater or smaller distance than another particle. Therefore, when calculating the CSDA range, we calculate the average range of the charged particles inside the material, but the actual range may be larger or smaller than the calculated range. (Priyanka *et al.*, 2012; Tabata *et al.*, 1996)

The basic formula used to calculate CSDA ranges:

Tabata *et al.* proposed a semi-empirical equation to calculate CSDA range, and many modifications and additions were made to this formula until it reached the following form: (Tabata *et al.*, 1996)

$$r_o = \frac{c_1}{B}\left[\frac{\ln(1+c_2\tau_o^{c_3})}{c_2} - \frac{c_4\tau_o^{c_5}}{1+c_6\tau_o}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The symbols from c_1 to c_6 are constants for an objective material, τ_o the energy of charged particle in units of the rest energy of electron and B is the stopping number that can be given as follows:

$$B = \ln\left(\frac{\tau_o}{I+c_7\tau_o}\right)^2 + \ln\left(1+\frac{\tau_o}{2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

I: is the mean excitation energy of the objective material expressed in units of the rest energy of the electron and c_7 is a constant for the objective material. The values of the constants from c_1 to c_7 can be obtained from the following equations:

$$\left.\begin{aligned} c_1 &= \frac{Ad_1}{Z^{d_2}} \\ c_2 &= d_3Z^{d_4} \\ c_3 &= d_5 - d_6Z \\ c_4 &= d_7 - d_8Z \\ c_5 &= d_9 - Zd_{10} \\ c_6 &= \frac{d_{11}}{Z^{d_{12}}} \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$
$$c_7 = d_{13}Z^{d_{14}}$$

Z: is the atomic number of the elements and *A*: atomic weight of the elements.
The constats from d_1 to d_{14} are given in (Table 1).

Table 1: Values of constants used in the Tabata formula.

n	d	n	d
1	3.6	8	0.0001303
2	0.98882	9	1.02441
3	0.001191	10	0.00012986
4	0.86620	11	1.030
5	1.02501	12	0.0111
6	0.00010803	13	0.0000011
7	0.99628	14	0.959

The previous formula is used to find CSDA range in elements. However, if it is used for compounds, the atomic number (Z) is replaced by the effective atomic number (Z_{eff}) and the atomic weight (A) by the effective atomic weight (A_{eff}). They can be obtained from the formulas below:

$$\left.\begin{aligned} Z_{eff} &= \frac{\sum_i f_i Z_i^2/A_i}{\sum_i f_i Z_i/A_i} \\ A_{eff} &= (Z/A)_{eff}^{-1} Z_{eff} \\ (Z/A)_{eff} &= \sum_i f_i Z_i/A_i \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The new formulas for calculating CSDA range of electrons:

The data fitting method was used to find two new formulas to calculate the CSDA range of electrons, using the curve expert basic program. This method is summed up by simulating the actual results and formulating a mathematical formula as a function of one or more variables and a certain number of constants, so that this formula achieves the least percentage of deviation from the actual results and with the least number of constants.

the actual results were obtained from reports of the national institute of standards and technology, physics laboratory, currently called the physical measurement laboratory, ionizing radiation department, NIST, and reports of the international commission on radiological units (ICRU). (Berger *et al.*, 2017)

The first formula to calculate CSDA range:

This formula was found as a function of the energy of the incident electron E in the energy range from 10 MeV to 1000 MeV and based on the values of only four constants. This formula is as follows:

$$R_{CSDA} = \frac{a+(c*(E^d))}{b+(E^d)} \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where E: is the energy of the incident electron in units of (MeV), and a, b, c, d are the four constants of this formula, as shown in (Table 2).

Table 2: Values of constants used in the first formula to find the CSDA range of electrons.

Human Tissues	a	b	c	D
Blood	-159.90387	158.33450	160.20409	0.81012
Dense Bone	-145.63994	120.82412	142.19590	0.78087
Bone Cortex	-134.19401	105.38370	131.55171	0.76686
Brain	-159.99554	160.91129	160.45560	0.81182
Eye Lens	-164.01843	162.62685	164.20680	0.81192
Lung	-160.64929	157.84798	160.38492	0.80908
Skin	-162.87562	163.70267	163.86031	0.81392
Testicles	-161.39282	158.03138	160.65864	0.80825

The second formula to calculate CSDA range:

This formula was found as a function of the total stopping power of the electrons dE/dx in the energy range from 10 MeV to 1000 MeV and based on the values of four constants. This formula is as follows:

$$R_{CSDA} = \frac{a+\left(c*\left(\frac{dE}{dx}\right)^d\right)}{b+\left(\left(\frac{dE}{dx}\right)^d\right)} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where dE/dx is the total stopping power of the electrons in units of (MeV cm^2 g^{-1}), and a, b, c, d are the four constants of this formula, as shown in (Table 3).

Table 3: Values of constants used in the second formula to find CSDA range of electrons.

Human Tissues	A	B	C	D
Blood	-344.05975	1.94630	280.30380	0.32870
Dense Bone	-379.03117	1.50823	336.89611	0.21215
Bone Cortex	-371.07451	1.38333	336.20474	0.18576
Brain	-340.19112	2.01416	274.39114	0.34070
Eye Lens	-333.83342	2.06223	266.87871	0.36099
Lung	-335.86045	1.97568	271.80162	0.33980
Skin	-336.96924	2.02513	270.12849	0.35527
Testicles	-352.49410	1.92739	289.09717	0.31728

RESULTS AND DISCUSSION

From observing (Table 4), calculated using the first formula, it is obvious that the greatest percentage of deviation in CSDA range was about 6% at the energy of 10 MeV, then it decreased to become approximately 1%, and less than that in the energy range from 40 to 1000 MeV. (Table 5), calculated from the second formula, it shows that the greatest deviation in CSDA range was approximately 7% at the energy of 10 MeV, then it decreased to approximately 1% in the energy range from 20 to 1000 MeV. Therefore, the percentage of deviation for the two aforementioned formulas is considered little and they can be considered effective for calculating CSDA range of the tissues studied in the energy range from 10 to 1000 MeV.

The first formula is considered simpler than the second formula because it is a function of the energy of the incident electron only, and therefore we can apply it directly without the need to perform additional calculations. As for the second formula, it is a function of the total stopping power of the incident electrons, and if we do not have the values of the total stopping power, we must calculate it first and then replace it in the second formula to calculate the CSDA range. However, it achieves a lower deviation rate than the first formula. Despite this, the two new formulas are considered simplified formulas with the smallest possible number of constants and can be applied easily and without the need to perform complex mathematical operations.

Table 4: The amount of deviation in the values calculated from the first formula from the values of the international code E-Star.

Energy (MeV)	Blood	Dense Bone	Bone Cortex	Brain	Eye Lens	Lung	Skin	Testicles
10	5.51%	6.17%	6.21%	5.46%	5.53%	5.56%	5.39%	5.63%
20	3.46%	3.58%	3.38%	3.44%	3.52%	3.50%	3.44%	3.55%
30	1.77%	1.62%	1.42%	1.79%	1.80%	1.80%	1.76%	1.79%
40	0.67%	0.46%	0.22%	0.65%	0.73%	0.68%	0.71%	0.68%
50	0.01%	0.27%	0.45%	0.05%	0.03%	0.07%	0.03%	0.06%
60	0.47%	0.69%	0.85%	0.50%	0.45%	0.48%	0.48%	0.51%
70	0.78%	0.96%	1.11%	0.76%	0.78%	0.77%	0.75%	0.78%
80	0.93%	1.13%	1.21%	0.93%	0.94%	0.96%	0.90%	0.96%
90	1.01%	1.19%	1.25%	1.03%	1.03%	1.05%	1.01%	1.06%
100	1.05%	1.20%	1.22%	1.07%	1.09%	1.09%	1.06%	1.09%
200	0.45%	0.43%	0.37%	0.47%	0.50%	0.49%	0.45%	0.51%
300	0.18%	0.24%	0.28%	0.17%	0.13%	0.14%	0.16%	0.12%
400	0.48%	0.53%	0.57%	0.47%	0.44%	0.45%	0.47%	0.44%
500	0.53%	0.58%	0.61%	0.53%	0.51%	0.50%	0.52%	0.51%
600	0.42%	0.47%	0.47%	0.40%	0.41%	0.40%	0.41%	0.42%
700	0.19%	0.25%	0.24%	0.18%	0.19%	0.18%	0.18%	0.21%
800	0.10%	0.04%	0.06%	0.11%	0.10%	0.11%	0.12%	0.07%
900	0.45%	0.38%	0.41%	0.45%	0.43%	0.45%	0.47%	0.40%
1000	0.86%	0.75%	0.78%	0.87%	0.78%	0.81%	0.81%	0.80%

Table 5: The amount of deviation in the values calculated from the second formula from the values of the international code E-Star.

Energy (MeV)	Blood	Dense Bone	Bone Cortex	Brain	Eye Lens	Lung	Skin	Testicles
10	6.95%	4.69%	4.59%	5.74%	6.21%	6.69%	6.56%	5.98%
20	0.43%	0.60%	0.35%	0.94%	0.79%	0.47%	0.69%	0.80%
30	0.89%	0.65%	0.48%	1.10%	0.97%	0.87%	0.92%	1.02%
40	0.61%	0.40%	0.27%	0.69%	0.61%	0.57%	0.65%	0.72%
50	0.35%	0.15%	0.12%	0.33%	0.23%	0.25%	0.27%	0.36%
60	0.11%	0.04%	0.05%	0.08%	0.04%	0.10%	0.08%	0.13%
70	0.05%	0.05%	0.05%	0.04%	0.15%	0.04%	0.08%	0.02%
80	0.14%	0.14%	0.10%	0.15%	0.20%	0.14%	0.13%	0.13%
90	0.18%	0.18%	0.11%	0.23%	0.25%	0.18%	0.22%	0.22%
100	0.23%	0.19%	0.10%	0.28%	0.29%	0.24%	0.24%	0.25%
200	0.12%	0.12%	0.03%	0.17%	0.13%	0.12%	0.10%	0.22%
300	0.05%	0.00%	0.03%	0.00%	0.05%	0.05%	0.07%	0.07%
400	0.13%	0.06%	0.10%	0.09%	0.12%	0.13%	0.14%	0.01%
500	0.12%	0.08%	0.10%	0.10%	0.12%	0.12%	0.15%	0.03%
600	0.09%	0.07%	0.09%	0.08%	0.10%	0.08%	0.09%	0.01%
700	0.03%	0.06%	0.08%	0.01%	0.01%	0.01%	0.00%	0.02%
800	0.02%	0.04%	0.05%	0.06%	0.09%	0.09%	0.09%	0.08%
900	0.12%	0.01%	0.01%	0.13%	0.19%	0.19%	0.19%	0.15%
1000	0.25%	0.03%	0.04%	0.27%	0.29%	0.29%	0.28%	0.27%

(Tables 6-8) show that the range of electrons inside the material increases with the increase in the energy of the incident electron. As the energy of the incident electron increases, its speed increases, and thus the time of its stay near the atoms decreases, the possibility of its collision with atoms decreases, and the amount of lost energy decreases. By increasing the path of the electron within the material. Its kinetic energy decreases and thus its speed decreases and it loses the largest amount of energy at the end of its path because its movement becomes slow and thus the electron has sufficient time to interact with the atoms it passes near and thus the lost energy increases. The energy the electrons lose per path unit at the beginning of their entry into the material is little, and the amount of qualitative ionization is constant, while at the end of its path its speed decreases, and thus the probability of collision increases and the amount of qualitative ionization increases. Then the qualitative ionization coefficient quickly decreases to zero when the energy of the incident electron becomes zero and its path ends inside the material.

Table 6: CSDA range of electrons in units (g/cm^2) in tissues (blood, dense bone, bone cortex, brain, eye lens, lung, skin and testicles) calculated from the first formula.

Energy (MeV)	Blood	Dense Bone	Bone Cortex	Brain	Eye Lens	Lung	Skin	Testicles
10	5.31	5.62	5.71	5.26	5.33	5.31	5.31	5.3
20	9.75	10.13	10.18	9.67	9.8	9.75	9.78	9.73
30	13.56	13.91	13.88	13.46	13.64	13.56	13.63	13.53
40	16.95	17.23	17.11	16.84	17.07	16.95	17.06	16.91
50	20.05	20.21	19.99	19.92	20.2	20.05	20.19	20
60	22.9	22.94	22.61	22.77	23.1	22.9	23.09	22.84
70	25.56	25.45	25.01	25.42	25.79	25.55	25.79	25.49
80	28.05	27.79	27.24	27.9	28.31	28.04	28.31	27.97
90	30.39	29.98	29.31	30.24	30.69	30.38	30.7	30.3
100	32.6	32.03	31.25	32.45	32.94	32.59	32.95	32.51
200	49.93	47.75	45.96	49.77	50.58	49.89	50.62	49.78
300	61.99	58.41	55.78	61.85	62.91	61.95	62.97	61.83
400	71.13	66.35	63.05	71.01	72.27	71.08	72.34	70.95
500	78.38	72.59	68.73	78.29	79.71	78.33	79.79	78.21
600	84.33	77.67	73.33	84.26	85.82	84.28	85.9	84.16
700	89.32	81.91	77.16	89.27	90.95	89.27	91.03	89.16
800	93.59	85.52	80.42	93.55	95.34	93.54	95.42	93.43
900	97.28	88.64	83.23	97.27	99.15	97.24	99.22	97.14
1000	100.52	91.37	85.68	100.52	102.49	100.48	102.56	100.39

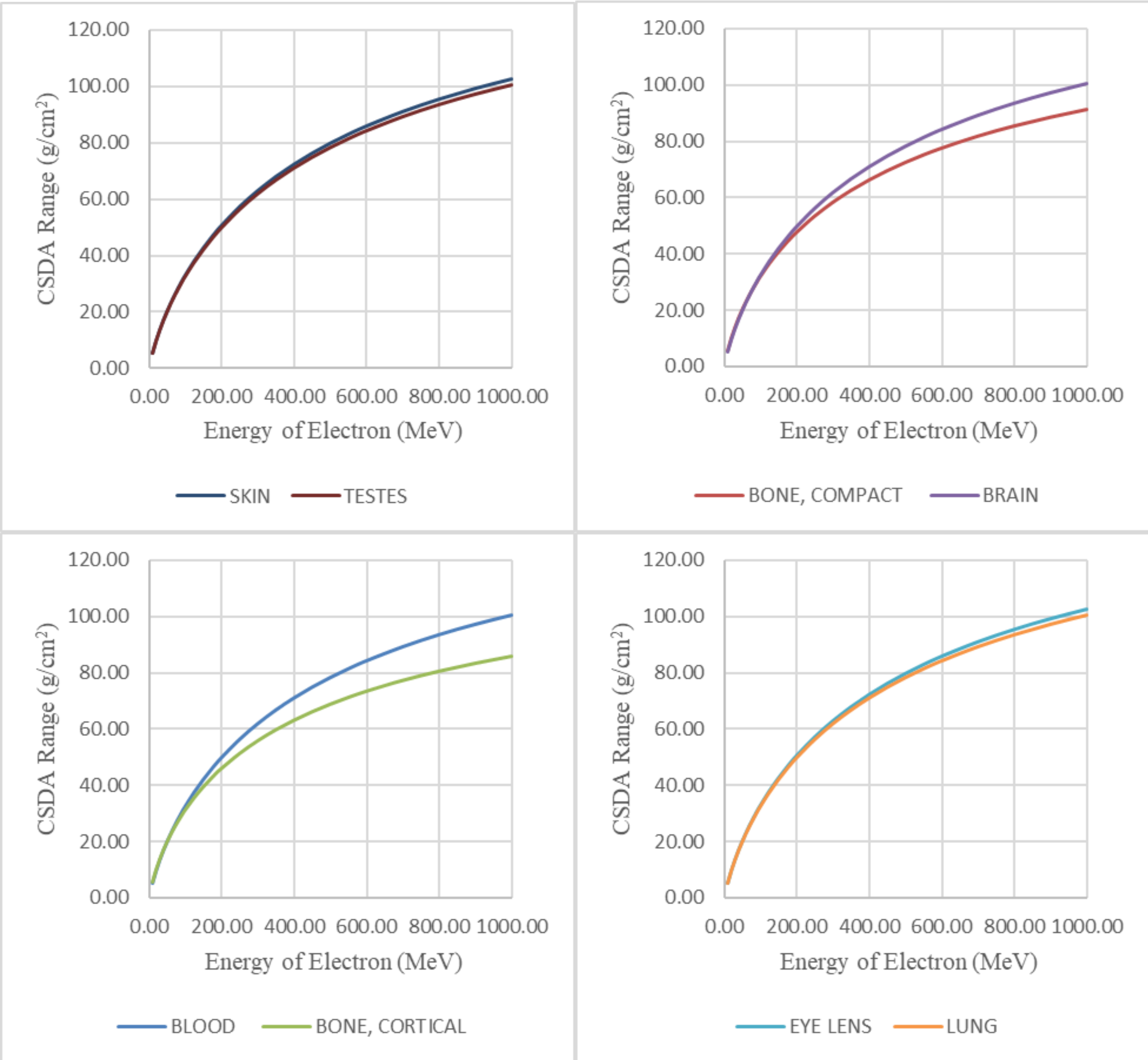

Fig. 1: CSDA range of electrons in units (g/cm^2) in tissues (blood, dense bone, bone cortex, brain, eye lens, lung, skin and testicles) calculated from the first formula.

Table 7: CSDA range of electrons in units (g/cm^2) in tissues (blood, dense bone, bone cortex and brain) calculated from the second formula.

R_{CSDA} Brain	Total Stopping	R_{CSDA} Bone	Total Stopping	R_{CSDA} Dense Bone	Total Stopping	R_{CSDA} Blood	Total Stopping
4.70	2.14	5.13	2.05	5.04	2.06	4.68	2.13
9.44	2.44	9.88	2.43	9.84	2.40	9.46	2.43
13.36	2.72	13.76	2.79	13.78	2.73	13.44	2.71
16.85	2.99	17.12	3.14	17.22	3.05	16.94	2.98
20.00	3.26	20.10	3.50	20.30	3.37	20.12	3.25
22.90	3.53	22.81	3.85	23.11	3.69	23.04	3.52
25.60	3.79	25.28	4.21	25.69	4.01	25.75	3.78
28.12	4.06	27.54	4.56	28.07	4.33	28.27	4.05
30.48	4.32	29.65	4.92	30.28	4.65	30.65	4.32
32.71	4.59	31.61	5.27	32.36	4.97	32.88	4.58
49.91	7.24	46.12	8.84	47.90	8.17	50.09	7.25
61.75	9.91	55.65	12.43	58.27	11.40	61.91	9.94
70.74	12.59	62.76	16.04	66.04	14.64	70.88	12.63
77.96	15.27	68.38	19.64	72.23	17.88	78.06	15.32
83.99	17.96	73.06	23.26	77.36	21.12	84.06	18.02
89.12	20.64	77.04	26.88	81.76	24.37	89.18	20.72
93.60	23.33	80.51	30.50	85.60	27.63	93.66	23.43
97.58	26.03	83.58	34.12	88.99	30.88	97.60	26.13
101.13	28.72	86.33	37.74	92.04	34.14	101.15	28.84

Table 8: CSDA range of electrons (g/cm^2) in tissues (eye lens, lung, skin and testicles) calculated from the second formula.

R_{CSDA} Testicles	Total Stopping Power	R_{CSDA} Skin	Total Stopping Power	R_{CSDA} Lung	Total Stopping Power	R_{CSDA} Eye Lens	Total Stopping Power
4.72	2.13	4.71	2.12	4.70	2.13	4.73	2.12
9.47	2.43	9.52	2.41	9.47	2.43	9.54	2.41
13.42	2.71	13.51	2.68	13.44	2.71	13.53	2.68
16.92	2.99	17.05	2.95	16.94	2.98	17.05	2.95
20.08	3.26	20.25	3.21	20.11	3.25	20.26	3.21
22.99	3.52	23.22	3.47	23.03	3.52	23.21	3.47
25.68	3.79	25.96	3.72	25.74	3.78	25.95	3.73
28.20	4.06	28.53	3.98	28.27	4.05	28.52	3.99
30.56	4.32	30.94	4.24	30.64	4.32	30.93	4.25
32.79	4.59	33.22	4.50	32.87	4.58	33.20	4.50
49.93	7.27	50.80	7.09	50.08	7.26	50.76	7.10
61.71	9.95	62.91	9.69	61.89	9.94	62.86	9.71
70.65	12.65	72.10	12.30	70.85	12.64	72.03	12.32
77.83	15.35	79.50	14.92	78.03	15.34	79.41	14.94
83.82	18.05	85.62	17.53	84.01	18.04	85.56	17.57
88.95	20.76	90.87	20.15	89.10	20.74	90.79	20.19
93.42	23.47	95.44	22.77	93.56	23.45	95.35	22.82
97.38	26.18	99.50	25.40	97.50	26.16	99.39	25.45
100.93	28.89	103.11	28.02	101.01	28.86	103.00	28.08

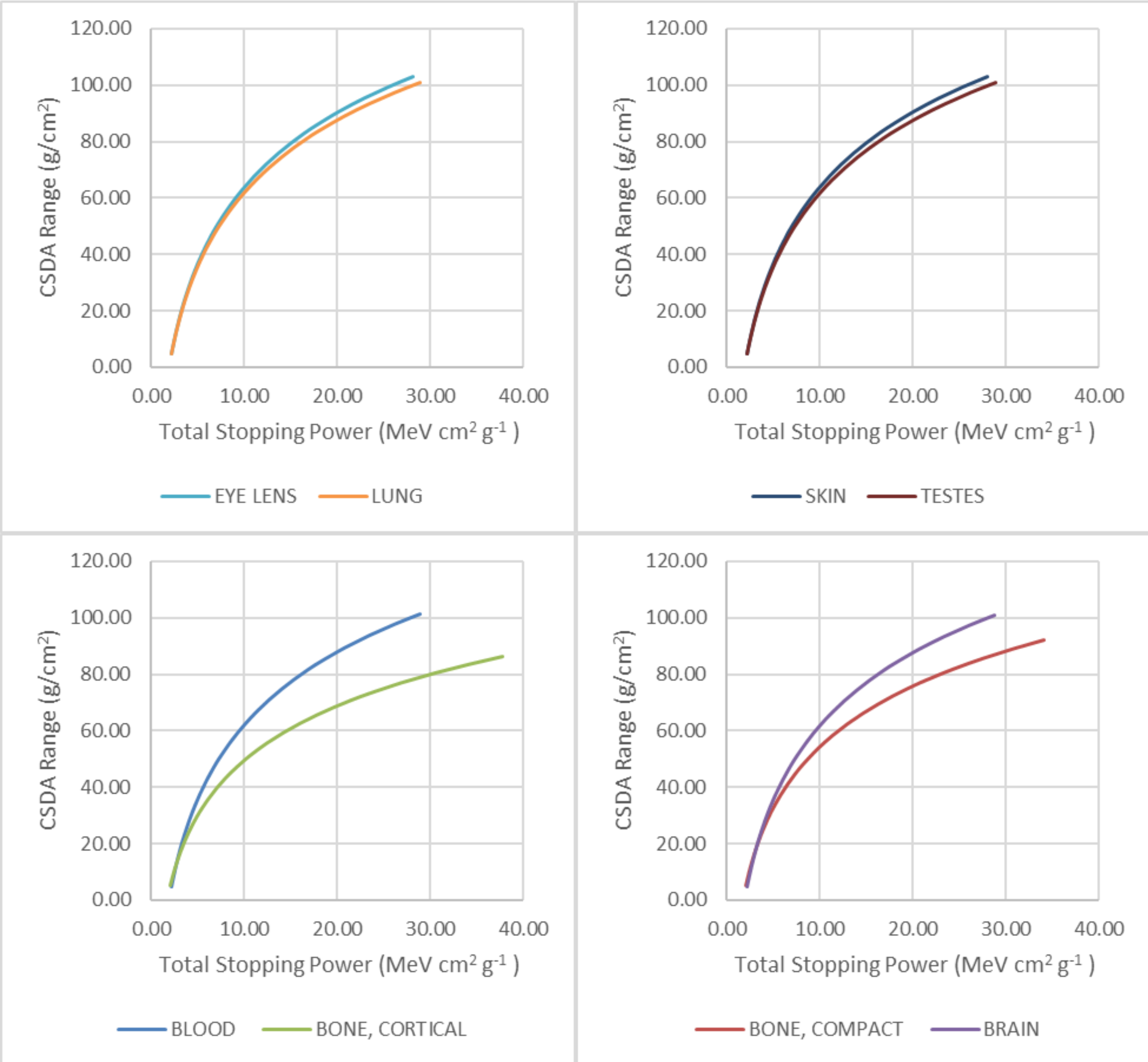

Fig. 2: CSDA range of electrons in units (g/cm^2) in tissues (blood, dense bone, bone cortex, brain, eye lens, lung, skin and testicles) calculated from the second formula.

The obtained results show that the incident electrons behave similarly in various tissues, regardless of the type of tissue. The behavior of the electrons falling on the target material is the same whether the target material is an element or a compound. Human tissues are expressed in the form of chemical compounds consisting of the combination of a group of elements in a certain weight ratio, as shown in (Table 9). When studying the lost energy and stopping power, the chemical bonding energy between the different elements that make up each compound is considered neglected and has no effect on the amount of lost energy and stopping power of the incident electrons. Therefore, the path of the electrons falling into the material is the same if the material is an element or a compound.

Table 9: Weight percentages of the elements involved in the composition of human body tissues (Detwiler *et al.*, 2021).

Element	Blood	Dense Bone	Bone Cortex	Brain	Eye Lens	Lung	Skin	Testicles
Hydrogen	10.187	6.398	4.723	11.067	9.927	10.128	10.059	10.417
Carbon	10.002	27.8	14.433	12.542	19.371	10.231	22.825	9.227
Nitrogen	2.964	2.7	4.199	1.328	5.327	2.865	4.642	1.994
Oxygen	75.941	41.002	44.61	73.772	65.375	75.707	61.9	77.388
Sodium	0.185	0	0	0.184	0	0.184	0.007	0.226
Magnesium	0.004	0.2	0.22	0.015	0	0.073	0.006	0.011
Silicon	0.003	0	0	0	0	0	0	0
Phosphorus	0.035	7	10.497	0.354	0	0.08	0.033	0.125
Sulfur	0.185	0.2	0.315	0.177	0	0.225	0.159	0.146
Chlorine	0.278	0	0	0.236	0	0.266	0.267	0.244
Potassium	0.163	0	0	0.31	0	0.194	0.085	0.208
Calcium	0.006	14.7	20.993	0.009	0	0.009	0.015	0.01
Iron	0.046	0	0	0.005	0	0.037	0.001	0.002
Zinc	0.001	0	0.01	0.001	0	0.001	0.001	0.002

CONCLUSIONS

Analyzing the obtained results, we conclude that in spite of the simplicity of the obtained formulas, they give highly accurate results with a very small percentage of deviation in the studied energy range. Also, the formulas used are experimental formulas based on data fitting, and therefore they only give results without interpreting these results. In addition, the two formulas can be applied to any element or compound after changing the values of the constants used.

REFERENCES

Abd Almonem, W.; Kadhim, R.O. (2023). Stopping power of alpha particles in some human body tissues using density functional theory. *J. Kufa. Phys.*, **15**(02), 98-107. DOI: 10.31257/2018/JKP/2023/v15.i02.12268

Ahmed, I.; Nowrin, H.; Dhar, H. a(2020). CSDA range and stopping power calculation using bethe-bloch formula for proton in common human cancer tissues. *African. Rev. Phys.*, **15**.

Ahmed, I.; Nowrin, H.; Dhar, H. b(2020). Stopping power and range calculations of protons in human tissues. *Baghdad. Sci. J. l.*, **17**(4), 1223-1223. DOI: 10.21123/bsj.2020. 17.4.1223

Al-Assaf, S.; Coqueret, X.; Zaman, H.M.D.K.; Sen, M.; Ulański, P. (2016). “The Radiation Chemistry of Polysaccharides.” Vienna, Austria, IAEA International Atomic Energy Agency.

Berger, M.J.; Coursey, J.S.; Zucker, M.A.; Chang, J. (2017). Stopping-power & range tables for electrons, protons, and helium ions. *NIST Stan. Refer. Data.* **124**, DOI: 10.18434/T4NC7P

Detwiler, R.S.; McConn, R.J.; Grimes, T.F.; Upton, S.A.; Engel, E.J. (2021). “Compendium Material Composition Data for Radiation Transport Modeling (No. PNNL-15870-Revision-2)”. Pacific Northwest National Lab. (PNNL), Richland, WA (United States).

El-Ghossain, M.O. (2017). Calculations of stopping power, and range of electrons interaction with different material and human body parts. *Inter. J. Sci. Tech. Res.*, **6**(1), 114-8.

Fabjan, C.W.; Schopper, H. (2020). “Detectors for Particles and Radiation”. Vol. 2, particle physics reference library, springer nature.

Gümüş, H. (2019). Stopping power and range calculations of electrons for some human body tissues. *ALKÜ Fen Bilimleri Dergisi*, 93-100.

Gümüş, H. (2022). Positron CSDA range and stopping power calculations in some human body tissues by using Lenz Jensen atomic screening function. *Radi. Phys. Chem.*, **196**, 110092. DOI: 10.1016/j.radphyschem.2022.110092

Gümüş, H.; Bentabet, A. (2017). CSDA range, stopping power and mean penetration depth energy relationships in some hydrocarbons and biologic materials for 10 eV to 100 MeV with the modified Rohrlich–Carlson model. *Appl. Phys. A*, **123**, 1-9. DOI: 10.1007/ s00339-017-0874-9

Habeb, S.J.; Aman Allah, S.M. (2016). Estimation of the total energy loss and continuous slowing down range (CSDA) of positrons in carbon and silver. *Tikrit J. Pure Sci.*, **21**(3), 135-143. DOI: 10.25130/tjps.v21i3.1006

Hussein, I.F.; Abdaljalil, R.O.; Mohammed, S.A.; Mkhaiber, A.F. (2023). Calculation of the electron stopping power of some components of human body tissues. *Kuwait J. Sci.*, **50**(4), 545-550. DOI: 10.1016/j.kjs.2023.03.009

Khan, F.M. (2010). “The Physics of Radiation Therapy”, 3rd ed., Lippincott, Williams and Wilkins.

Loveland, W.D.; Morrissey, D.J.; Seaborg, G.T. (2017). “Modern Nuclear Chemistry”. 2nd ed., John Wiley & Sons.

Mahmood, I.N. (2005). Stopping power of (1.895-7.4 MeV) 4He ions in composite foils and pure elements. *Raf. J. Sci.*, **16**(4), 81-88.

Mohammed, S.; Trabelsi, A.; Manai, K. (2018). Stopping power, CSDA range, absorbed dose and cross sections calculations of f18 simulated in water using Geant4 code. *Indian J. Sci. Tech.*, **11**(6), 1-10. DOI: 10.17485/ijst/2018/v11i6/87358

Osman, H.; Gümüş, H. (2022). Stopping power and CSDA range calculations of electrons and positrons over the 20 eV–1 GeV energy range in some water equivalent polymer gel dosimeters. *App. Radi. Iso.*, **179**, 110024. DOI: 10.1016/j.apra diso.2021.110024

Pal, P.B.; Gupta, S.K.; Varshney, V.P.; Gupta, D.K. (1985). Continuous slowing down approximation range of 50 keV to 1000 MeV positrons. *Japanese J. App. Phys.*, **24**(8R), 1070.

Podgorsak, E.B. (2016). “Radiation Physics for Medical Physicists.” 3rd ed., Springer. DOI: 10.1007/978-3-319-25382-4

Priyanka, A.; Rathi, S.K.; Verma, A.S. (2012). Continuous slowing down approximation (CS and DA) ranges of electrons and positrons for carbon, aluminium and copper. *Res. J. Recent Sci.*, **1**(6), 70-76.

Tabata, T.; Andreo, P.; Shinoda, K.; Ito, R. (1996). Range distributions and projected ranges of 0.1-to 100-MeV electrons in elemental absorbers. *Nuc. Instr. Methods Phys. Res. Sec. B: Beam Inter. Mat. Atoms*, **108**(1-2), 11-17.

تقريب مدى التباطؤ المستمر للإلكترونات في الانسجة البشرية

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الملخص

في هذا البحث تم إيجاد صيغتان تحليليتان لحساب تقريب مدى التباطؤ المستمر للإلكترونات ضمن مدى الطاقة من 10 ميغا الكترون فولط الى 1000 ميغا الكترون فولط في انسجة جسم الانسان (الدم، العظم الكثيف، قشرة العظم، الدماغ، عدسة العين، الرئة، الجلد، الخصيتين). تم إيجاد الصيغتين الجديدتين باستخدام طريقة موائمة البيانات وبالاعتماد على البيانات المتحصلة من قيم الكود العالمي (E-Star) وتقرير اللجنة الدولية لوحدات وقياسات الاشعاع رقم 37 لسنة 1984 (ICRU Report 37). تم إيجاد الصيغة الأولى كدالة لطاقة الالكترون الساقط فقط وكان أكبر مقدار للانحراف في النتائج المتحصلة من هذه الصيغة بحدود (6.21%) اما الصيغة الثانية فتم ايجادها كدالة لقدرة الإيقاف الكلية للإلكترونات فقط وكان أكبر مقدار للانحراف في النتائج المتحصلة من هذه الصيغة بحدود (6.95%). ان الصيغتين الجديدتين تعتبران صيغتين مبسطتين ويمكن تطبيقهما بسهولة وبدون الحاجة الى اجراء عمليات رياضية معقدة وكدالة لمتغير واحد فقط. اما الصيغ السابقة فهي صيغ معقدة تعتمد على عدد كبير من الثوابت وكدالة لأكثر من متغير وتحتاج الى العديد من العمليات الحسابية المتكررة والمعقدة.

الكلمات الدالة: طاقة الالكترون الساقط، قدرة الإيقاف الكلية للإلكترونات، النسيج البشري، موائمة البيانات، الكود العالمي E-Star.