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Mass Stopping Power and Range of Alpha Particles in Biological Human Body (Water and Eye Lens Tissue)

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Abstract

We used the MATLAB Program to calculate the mass stopping power and range of alpha particles in biological human body tissues (such as water and the eye lens tissues) at energies between 0.2 and 200 MeV. The Bethe Block formula was used to calculate the mass stopping power, and the simple integration (continuous slowing down approximation) method was used to calculate the alpha particle ranges. Empirical formulae were developed to determine mass-stopping power and ranges of water and eye lens tissues. The results of graphing the mass-stopping power versus energy and range versus energy are presented, and compared the ASTAR (Alpha Stopping Power and Range) results with the present results for the mass-stopping powers and ranges of water. The results indicated remarkable agreement, particularly for energies that extend from 2 to 200 MeV, with a percentage deviation error of 4.81% - 6.39%. A graphical representation of the mass stopping power of water and eye lens tissue with their compositions is also provided. In addition, various radiation parameters essential in cancer treatment, such as absorbed dose, equivalent dose, effective dose, alpha particle depth, and linear energy transfer, are computed in this study.

Subject Areas

Applied Physics, Nuclear Physics, Nuclear Technology, Radiology

Keywords

Human Body Tissues, Alpha Particles, MATLAB, Mass Stopping Power, Range

1. Introduction

For the last century, scientists have been studying how charged particles interact with matter in order to understand their stopping power and energy dissipation. This research has a wide range of important applications, including ion implantation, fundamental particle physics, nuclear physics, radiation damage, and radiography [1] [2] [3] [4]. As heavy charged particles move through matter, they primarily lose energy through ionization and atomic excitation. This process has been extensively researched and is crucial to various scientific and technological advancements.

When heavy charged particles travel through matter, they tend to lose energy primarily through ionization and atomic excitation [4] [5] [6].

The stopping power is defined as the mean energy loss per unit path length $-\mathrm{d}E/\mathrm{d}x$. It depends on the charge and velocity of the projectile and, of course, the target material [7] [8] [9]. Early investigations of the energy loss of charged particles traversing matter arrive at a general stopping power formula. If an ion beam penetrates through matter, it loses energy due to collisions with electrons (electronic stopping) and target nuclei (nuclear stopping) [1]. The total stopping power is then just the sum of the stopping powers due to electronic and nuclear interactions [5] [6]. At low energies the total energy loss is usually described in terms of electronic stopping power [4] [5] [6]. The nuclear component of the stopping power can also be ignored [1].

In this work, we will examine the interactions between alpha particles and matter. The mass stopping power of alpha particles will be studied at a range of energies, from 0.2 to 200 MeV. We will also investigate how these interactions affect water and eye lens tissues. Additionally, we will calculate the alpha particle ranges in water and lens tissues at energies between 0.2 and 200 MeV.

2. Stopping Power

The electronic mass stopping power for alpha particles on water and eye lens tissues is calculated by the Bethe-Bloch formula. The full expression for the Bethe-Bloch formula can be written as:

$$-\frac{\mathrm{d}E}{\mathrm{d}x} = \frac{5.08\times 10^{-31} z^2 n}{\beta^2}\left[F(\beta) - \ln I\right] \tag{1}$$

where: β is v/c where v is the velocity and c is light speed, I is the mean excitation energy and $F(\beta)$ is given by [10]:

$$F(\beta) = \ln \ln \frac{1.02\times 10^{6}\beta^2}{1-\beta^2} - \beta^2 \tag{2}$$

The electron density n is calculated by:

$$n = N_{av}\left\langle \frac{z}{A} \right\rangle = 6.02\times 10^{23}\rho\left\langle \frac{z}{A} \right\rangle \tag{3}$$

2.1. Mass Stopping Power of Eye Lens

The mass stopping power of eye lens tissues is calculated after substituting the appropriate constant of electron density n and mean excitation energy I given in **Table 1** in Equation (1) by the following equation:

Table 1. Basic data for calculating mass stopping powers.

Material	<Z/A>	I (eV)	Density (ρ) (g/cm^3)	$n=\frac{\rho z N_a}{A}$ (electrons/m^3)
Eye Lens (ICRU-44)	0.54709	74.3	1.070E+00	3.52987×10^{29}
Water	0.55508	75.0	1.000E+00	3.34713×10^{29}

$$-\frac{\mathrm{d}E}{\mathrm{d}x\rho}=\frac{0.717269584}{\beta^2\times 1.070}\left[F(\beta)-4.308110952\right] \tag{4}$$

2.2. Mass Stopping Power of Water

The mass stopping power of water is calculated after substituting the appropriate constant of electron density n and mean excitation energy I given in **Table 1** in Equation (1) by the following equation:

$$-\frac{\mathrm{d}E}{\mathrm{d}x\rho}=\frac{0.680136816}{\beta^2\times 1.00}\left[F(\beta)-4.317488114\right] \tag{5}$$

3. Calculation of Alpha Particles Range

As it passes through the material, the alpha particle's range ionizes, reducing its energy slowly until it is almost zero. Because of the infinite range of Coulomb, the particle interacts with multiple electrons simultaneously and loses energy gradually but steadily as it moves. Following a predetermined distance, it then runs out of energy. The alpha particle range is the name given to this distance. The alpha particle's range is therefore defined as the average distance covered before it loses all of its initial kinetic energy [11].

The range of charged particle is computed by numerical integration of the stopping power [12]. The range of the alpha particles for the tissues under considerations is calculated using the following relation:

$$R=\int_{E_0}^{E_f}\frac{\mathrm{d}E}{MS(E)} \tag{6}$$

where, E_0 is the initial energy of incident charged particle in material, E_f is the final energy of incident charged particle in material and $MS(E)$ is the mass stopping power.

The higher alpha particles energy, the stronger their penetration through a given substance because the more Colombian interactions between the particles of alpha and absorption electrons will be required to dissipate energy before coming to rest [12]. All calculations were done using MATLAB program.

4. Alpha Depths, Absorbed Dose, Equivalent Dose, and Effective Dose

The Depth

The depth of a charged particles in the tissue or substance is given by the following relation:

$$T = \frac{R}{\rho} \tag{7}$$

where R is the range and is ρ the density of the tissue or substance.

Absorbed Dose

Two different materials, if subjected to the same gamma-ray exposure, will in general absorb different amounts of energy. Because many important phenomena, including changes in physical properties or induced chemical reactions, would be expected to scale as the energy absorbed per unit mass of the material, a unit that measures this quantity is of fundamental interest. The mean energy absorbed from any type of radiation per unit mass of the absorber is defined as the absorbed dose. The historical unit of absorbed dose has been the rad, defined as 100 ergs/gram. As with other historical radiation units, the rad has been replaced by its SI equivalent, the gray (Gy) defined as 1 joule/kilogram. The two units are therefore simply related by: 1 Gy = 100 rad the absorbed dose is a reasonable measure of the chemical or physical effects created by a given radiation exposure in an absorbing material. The absorbed dose is calculated by the following relation:

$$Ad = \frac{E}{1\ \text{grm}} \frac{1.6\times10^{-13}\ \text{J}}{1\ \text{MeV}} \frac{10^{7}\ \text{erg}}{1\ \text{J}} \frac{1\ \text{rad}}{\frac{100\ \text{erg}}{\text{gram}}} \tag{8}$$

Equivalent Dose

The equivalent dose is calculated by the following relation:

$$H_T = \sum_R W_R \times D \tag{9}$$

where W_R = Weighting factor = 20 for Alpha particle and D is Absorbed dose.

Effective Dose

The tissues differ in their sensitivity to the late effects of radiation, which represent the biological responses to the tissue, which are delayed for a long period of time, often several years. The effective dose is used to estimate the incidence of delayed effects in the future. If a part of the body such as the lungs receives a radiation dose, it represents a risk factor of lung cancer. If the same dose is given to another organ, it causes a different risk factor and is called the dose measured by the effective dose, is designated *E*.

$$E = \sum_T W_T H_T \tag{10}$$

where W_T is the weighting factor of tissue.

And for water and eye lens $W_T = 0.12$.

5. Percentage Deviation Error

The percentage deviation error for the present results of mass stopping power and that of ASTAR results of water are calculating by the following relation:

$$\text{Deviation Error} = \left(\frac{\text{Present Result} - \text{ASTAR Result}}{\text{ASTAR Result}} \right) \times 100\% \tag{11}$$

the Percentage deviation error was calculated in a Table 13 for the tissues that were compared to the Aster.

6. Results and Discussion

The Bethe Block theory and the MATLAB application were used in the current work to determine the mass stopping power using Equation (4) and Equation (5). The range of alpha particles in water and eye lens tissues is calculated using Equation (6). Table 2 shows the elemental composition of water and eye lens. The results of mass stopping powers and range of alpha particles in water, and eye lens respectively are given in Table 3 and Table 4. In Table 5 a comparison between the present results and that of ASTAR results of mass stopping powers of water are given while a comparison between the present results and that of ASTAR result of alpha particles range for water are given in Table 6. Table 7 is Values of mass stopping power of Water and its compositions and Table 8 for the Values of mass stopping power of Eye lens and its some of compositions.

To study the relation between the mass stopping power and the alpha particles energy the graphical method is used as shown in Figure 1 and Figure 2 for the tissues under consideration. The empirical formula for calculating mass stopping powers knowing alpha particles energy are obtained for all tissues under study as given in Table 9. Figure 3 depicts a comparison of the mass stopping power of an alpha particle in water for the current results and those of ASTAR. In Figure 4 and Figure 5 the relationship between the range and alpha particles for the tissues under study are shown while the empirical formula for calculating alpha particles range of all studied tissues is given in Table 10. In Table 11 and Table 12 the calculated depth of alpha particles, LET, absorbed dose, equivalent dose and effective dose of alpha particle for both water and eye lens are given. The percentage deviation errors of mass stopping power for water are given in Table 13.

Table 2. Elemental composition of water and eye lens.

Material	Composition
Eye Lens (ICRU-44)	1:0.096000 H 6:0.195000 C 7:0.057000 N 8:0.646000 O 11:0.001000 Na 15:0.001000 P 16:0.003000 S 17:0.001000 Cl
Water	1:0.111898 H 8:0.888102 O

Table 3. Values of mass stopping power (MeV·cm²/g) of water and eye lens.

Energy (MeV)	$\frac{dE}{dx\rho}\left(\frac{MeV \cdot cm^2}{g}\right)$ Water	$\frac{dE}{dx\rho}\left(\frac{MeV \cdot cm^2}{g}\right)$ Eye lens
0.2	2384.22475403096	2408.65305062471
0.4	3395.26985256277	3375.76682499890
0.6	3122.68961199742	3097.31868738319
0.8	2799.21374595122	2773.60364305991
1	2523.07437079105	2498.50202763589
2	1702.16894269649	1683.53933217218
3	1306.61486200367	1291.72133621023
4	1071.40076011691	1058.91422947724
5	913.861598045919	903.055516828838
6	800.185413092180	790.624160042245
7	713.871579595160	705.273148707949
8	645.859346277533	638.030206437612
9	590.736276465791	583.537500926490
10	545.058465969393	538.386718633458
20	316.595133121707	312.624876337861
30	228.250022083824	225.355761871248
40	180.334690817695	178.032310775232
50	149.945174521898	148.021536980534
60	128.821123405981	127.162424591830
70	113.221409208821	111.759310349188
80	101.194424044129	99.8844855919807
90	91.6180727928889	90.4296777128844
100	83.7994542394653	82.7105618050238
110	77.2866088775882	76.2807946937883
120	71.7716546686581	70.8363332270320
130	67.0373213031586	66.1626241157140
140	62.9257258579161	62.1037638892161
150	59.3192711893148	58.5436331508260
160	56.1284969629590	55.3938980512388
170	53.2840926935507	52.5861224863810
180	50.7314950861815	50.0664326671761
190	48.4271415891798	47.7918173890647
200	46.3358150948924	45.7275059064572

Table 4. Values of range (in g/cm²) of water and eye lens.

Energy (MeV)	Range (g/cm²) Water	Range (g/cm²) Eye lens
0.2	1.71308E−05	1.71824E−05
0.4	5.5658E−05	5.59033E−05
0.6	0.000110888	0.000111467
0.8	0.000180834	0.000181882
1	0.000264257	0.000265908
2	0.000858572	0.000865136
3	0.001710535	0.00172501
4	0.00278951	0.002814734
5	0.004076382	0.00411508
6	0.005557546	0.00561235
7	0.007222584	0.007296056
8	0.009063144	0.009157786
9	0.011072309	0.011190566
10	0.013244206	0.013388481
20	0.043030551	0.043559648
30	0.085729848	0.086854372
40	0.139806674	0.141722047
50	0.204303086	0.207194516
60	0.278537097	0.282582158
70	0.361986677	0.367356877
80	0.454233224	0.461095058
90	0.554929976	0.56344569
100	0.663782684	0.674110839
110	0.780536979	0.792832893
120	0.904969697	0.919385798
130	1.036882674	1.053568786
140	1.176098184	1.195201767
150	1.322455475	1.344121825
160	1.475808098	1.500180515
170	1.636021795	1.663241735
180	1.80297281	1.833180013
190	1.976546519	2.009879121
200	2.156636302	2.193230933

Table 5. Comparison of mass stopping power (MeV·cm²/g) of this work and that of ASTAR results for water.

$\frac{\mathrm{d}E}{\mathrm{d}x\rho}\left(\frac{\mathrm{MeV}\cdot\mathrm{cm}^2}{\mathrm{g}}\right)$	
This work (water)	A star
2384.22475403096	1.582E+03
3395.26985256277	2.062E+03
3122.68961199742	2.240E+03
2799.21374595122	2.256E+03
2523.07437079105	2.190E+03
1702.16894269649	1.624E+03
1306.61486200367	1.255E+03
1071.40076011691	1.034E+03
913.861598045919	8.848E+02
800.185413092180	7.771E+02
713.871579595160	6.949E+02
645.859346277533	6.301E+02
590.736276465791	5.776E+02
545.058465969393	5.340E+02
316.595133121707	3.144E+02
228.250022083824	2.284E+02
180.334690817695	1.815E+02
149.945174521898	1.516E+02
128.821123405981	1.308E+02
113.221409208821	1.155E+02
101.194424044129	1.036E+02
91.6180727928889	9.416E+01
83.7994542394653	8.645E+01
77.2866088775882	-
71.7716546686581	7.215E+01
67.0373213031586	-
62.9257258579161	-
59.3192711893148	6.229E+01
56.1284969629590	-
53.2840926935507	5.505E+01
50.7314950861815	-
48.4271415891798	-
46.3358150948924	4.950E+01

Table 6. Comparison of range (in g/cm²) of water of this work and ASTAR results.

Range (cm²/g)	
This work (water)	ASTAR
1.71308E−05	2.151E−04
5.5658E−05	3.230E−04
0.000110888	4.150E−04
0.000180834	5.034E−04
0.000264257	5.931E−04
0.000858572	1.123E−03
0.001710535	1.829E−03
0.00278951	2.711E−03
0.004076382	3.759E−03
0.005557546	4.967E−03
0.007222584	6.330E−03
0.009063144	7.842E−03
0.011072309	9.500E−03
0.013244206	1.130E−02
0.043030551	3.668E−02
0.085729848	7.452E−02
0.139806674	1.240E−01
0.204303086	1.845E−01
0.278537097	2.557E−01
0.361986677	3.372E−01
0.454233224	4.287E−01
0.554929976	5.300E−01
0.663782684	6.409E−01
0.780536979	
0.904969697	9.588E−01
1.036882674	
1.176098184	
1.322455475	1.333E+00
1.475808098	
1.636021795	1.760E+00
1.80297281	
1.976546519	
2.156636302	2.240E+00

Table 7. Values of mass stopping power (in MeV·cm²/g) of water and its compositions.

Energy (MeV)	Mass stopping power (MeV·cm²/g)		
	Water	H	O
0.2	2384.22475403096	6.019E+03	1.272E+03
0.4	3395.26985256277	7.915E+03	1.639E+03
0.6	3122.68961199742	8.222E+03	1.792E+03
0.8	2799.21374595122	7.808E+03	1.820E+03
1	2523.07437079105	7.157E+03	1.777E+03
2	1702.16894269649	4.588E+03	1.329E+03
3	1306.61486200367	3.351E+03	1.038E+03
4	1071.40076011691	2.675E+03	8.602E+02
5	913.861598045919	2.242E+03	7.395E+02
6	800.185413092180	1.939E+03	6.519E+02
7	713.871579595160	1.713E+03	5.845E+02
8	645.859346277533	1.538E+03	5.313E+02
9	590.736276465791	1.398E+03	4.880E+02
10	545.058465969393	1.283E+03	4.520E+02
20	316.595133121707	7.238E+02	2.688E+02
30	228.250022083824	5.156E+02	1.963E+02
40	180.334690817695	4.047E+02	1.564E+02
50	149.945174521898	3.353E+02	1.309E+02
60	128.821123405981	2.875E+02	1.131E+02
70	113.221409208821	2.524E+02	9.997E+01
80	101.194424044129	2.256E+02	8.979E+01
90	91.6180727928889	2.043E+02	8.166E+01
100	83.7994542394653	1.870E+02	7.502E+01
110	77.2866088775882	-	-
120	71.7716546686581	1.552E+02	6.270E+01
130	67.0373213031586	-	-
140	62.9257258579161	-	-
150	59.3192711893148	1.334E+02	5.418E+01
160	56.1284969629590	-	-
170	53.2840926935507	1.174E+02	4.792E+01
180	50.7314950861815	-	-
190	48.4271415891798	-	-
200	46.3358150948924	1.053E+02	4.311E+01

Table 8. Values of mass stopping power (in MeV·cm²/g) of Eye lens and its some of compositions.

Energy (MeV)	Mass stopping power (MeV·cm²/g)				
	Eye lens	H	C	O	N
0.2	2408.65305062471	6.019E+03	1.595E+03	1.272E+03	1.486E+03
0.4	3375.76682499890	7.915E+03	1.862E+03	1.639E+03	1.940E+03
0.6	3097.31868738319	8.222E+03	1.906E+03	1.792E+03	2.086E+03
0.8	2773.60364305991	7.808E+03	1.866E+03	1.820E+03	2.069E+03
1	2498.50202763589	7.157E+03	1.795E+03	1.777E+03	1.978E+03
2	1683.53933217218	4.588E+03	1.372E+03	1.329E+03	1.406E+03
3	1291.72133621023	3.351E+03	1.085E+03	1.038E+03	1.088E+03
4	1058.91422947724	2.675E+03	8.982E+02	8.602E+02	8.985E+02
5	903.055516828838	2.242E+03	7.720E+02	7.395E+02	7.711E+02
6	790.624160042245	1.939E+03	6.804E+02	6.519E+02	6.785E+02
7	705.273148707949	1.713E+03	6.102E+02	5.845E+02	6.080E+02
8	638.030206437612	1.538E+03	5.544E+02	5.313E+02	5.523E+02
9	583.537500926490	1.398E+03	5.090E+02	4.880E+02	5.069E+02
10	538.386718633458	1.283E+03	4.712E+02	4.520E+02	4.691E+02
20	312.624876337861	7.238E+02	2.788E+02	2.688E+02	2.777E+02
30	225.355761871248	5.156E+02	2.028E+02	1.963E+02	2.021E+02
40	178.032310775232	4.047E+02	1.612E+02	1.564E+02	1.608E+02
50	148.021536980534	3.353E+02	1.348E+02	1.309E+02	1.344E+02
60	127.162424591830	2.875E+02	1.163E+02	1.131E+02	1.161E+02
70	111.759310349188	2.524E+02	1.027E+02	9.997E+01	1.025E+02
80	99.8844855919807	2.256E+02	9.214E+01	8.979E+01	9.197E+01
90	90.4296777128844	2.043E+02	8.375E+01	8.166E+01	8.360E+01
100	82.7105618050238	1.870E+02	7.690E+01	7.502E+01	7.677E+01
110	76.2807946937883	-	-	-	-
120	70.8363332270320	1.552E+02	6.420E+01	6.270E+01	6.410E+01
130	66.1626241157140	-	-	-	-
140	62.1037638892161	-	-	-	-
150	58.5436331508260	1.334E+02	5.543E+01	5.418E+01	5.536E+01
160	55.3938980512388	-	-	-	-
170	52.5861224863810	1.174E+02	4.899E+01	4.792E+01	4.894E+01
180	50.0664326671761	-	-	-	-
190	47.7918173890647	-	-	-	-
200	45.7275059064572	1.053E+02	4.406E+01	4.311E+01	4.401E+01

Table 9. The empirical formulae for calculating mass stopping powers.

Equation	$y = y_0 + A_1 * (1 - \exp(-x/t_1)) + A_2 * (1 - \exp(-x/t_2))$
Water	$A_1 = -525.17835 \pm 281.24707$ $t_1 = 30.29513 \pm 27.2601$ $A_2 = -2749.90762 \pm 270.11886$ $t_2 = 2.72637 \pm 0.627$ $y_0 = 3330.68748 \pm 146.50026$ $R^2 = 0.96955$
Eye lens	$A_1 = -531.86671 \pm 269.70529$ $t_1 = 29.57687 \pm 25.25264$ $A_2 = -2739.78871 \pm 258.80006$ $t_2 = 2.66924 \pm 0.59292$ $y_0 = 3327.15093 \pm 142.5736$ $R^2 = 0.97145$

Table 10. The empirical formulae for calculating range.

Equation	$y = a \times x^b$
Water	$a = 2.64257\text{E}{-4} \pm 1.99087\text{E}{-18}$ $b = 1.7 \pm 1.47723\text{E}{-15}$ $R^2 = 1$
Eye lens	$a = 2.65908\text{E}{-4} \pm 1.49334\text{E}{-18}$ $b = 1.702 \pm 1.10114\text{E}{-15}$ $R^2 = 1$

Table 11. Alpha depth in the tissue, LET, absorbed dose, equivalent dose and effective dose of Alpha particle in water.

Energy (MeV)	Alpha depth in the Water(cm)	LET (MeV/cm)	Absorbed dose (rad)	Equivalent dose (rem)	Effective dose (rem)
0.2	1.71308E−05	2384.22475403096	3.2E−09	0.000000064	7.68E−09
0.4	5.5658E−05	3395.26985256277	6.4E−09	0.000000128	1.54E−08
0.6	0.000110888	3122.68961199742	9.6E−09	0.000000192	2.3E−08
0.8	0.000180834	2799.21374595122	1.28E−08	0.000000256	3.07E−08
1	0.000264257	2523.07437079105	1.6E−08	0.00000032	3.84E−08
2	0.000858572	1702.16894269649	3.2E−08	0.00000064	7.68E−08
3	0.001710535	1306.61486200367	4.8E−08	0.00000096	1.15E−07
4	0.00278951	1071.40076011691	6.4E−08	0.00000128	1.54E−07
5	0.004076382	913.861598045919	8E−08	0.0000016	1.92E−07
6	0.005557546	800.185413092180	9.6E−08	0.00000192	2.3E−07
7	0.007222584	713.871579595160	1.12E−07	0.00000224	2.69E−07
8	0.009063144	645.859346277533	1.28E−07	0.00000256	3.07E−07

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9	0.011072309	590.736276465791	1.44E−07	0.00000288	3.46E−07
10	0.013244206	545.058465969393	1.6E−07	0.0000032	3.84E−07
20	0.043030551	316.595133121707	3.2E−07	0.0000064	7.68E−07
30	0.085729848	228.250022083824	4.8E−07	0.0000096	1.15E−06
40	0.139806674	180.334690817695	6.4E−07	0.0000128	1.54E−06
50	0.204303086	149.945174521898	8E−07	0.000016	1.92E−06
60	0.278537097	128.821123405981	9.6E−07	0.0000192	2.3E−06
70	0.361986677	113.221409208821	1.12E−06	0.0000224	2.69E−06
80	0.454233224	101.194424044129	1.28E−06	0.0000256	3.07E−06
90	0.554929976	91.6180727928889	1.44E−06	0.0000288	3.46E−06
100	0.663782684	83.7994542394653	1.6E−06	0.000032	3.84E−06
110	0.780536979	77.2866088775882	1.76E−06	0.0000352	4.22E−06
120	0.904969697	71.7716546686581	1.92E−06	0.0000384	4.61E−06
130	1.036882674	67.0373213031586	2.08E−06	0.0000416	4.99E−06
140	1.176098184	62.9257258579161	2.24E−06	0.0000448	5.38E−06
150	1.322455475	59.3192711893148	2.4E−06	0.000048	5.76E−06
160	1.475808098	56.1284969629590	2.56E−06	0.0000512	6.14E−06
170	1.636021795	53.2840926935507	2.72E−06	0.0000544	6.53E−06
180	1.80297281	50.7314950861815	2.88E−06	0.0000576	6.91E−06
190	1.976546519	48.4271415891798	3.04E−06	0.0000608	7.3E−06
200	2.156636302	46.3358150948924	3.2E−06	0.000064	7.68E−06

Table 12. Alpha depth in the tissue, LET, absorbed dose, equivalent dose and effective dose of Alpha particle in eye lens.

Energy (MeV)	Alpha depth in the Eye lens(cm)	LET (MeV/cm)	Absorbed dose (rad)	Equivalent dose (rem)	Effective dose (rem)
0.2	1.61E−05	2577.25876416844	3.2E−09	0.000000064	7.68E−09
0.4	5.22E−05	3612.07050274882	6.4E−09	0.000000128	1.54E−08
0.6	1.04E−04	3314.13099550001	9.6E−09	0.000000192	2.3E−08
0.8	1.70E−04	2967.75589807411	1.28E−08	0.000000256	3.07E−08
1	2.49E−04	2673.39716957040	1.6E−08	0.00000032	3.84E−08
2	8.09E−04	1801.38708542424	3.2E−08	0.00000064	7.68E−08
3	1.61E−03	1382.14182974495	4.8E−08	0.00000096	1.15E−07
4	2.63E−03	1133.03822554065	6.4E−08	0.00000128	1.54E−07
5	3.85E−03	966.269403006857	8E−08	0.0000016	1.92E−07

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6	5.25E−03	845.967851245202	9.6E−08	0.00000192	2.3E−07
7	6.82E−03	754.642269117505	1.12E−07	0.00000224	2.69E−07
8	8.56E−03	682.692320888245	1.28E−07	0.00000256	3.07E−07
9	1.05E−02	624.385125991344	1.44E−07	0.00000288	3.46E−07
10	1.25E−02	576.073788937800	1.6E−07	0.0000032	3.84E−07
20	4.07E−02	334.508617681511	3.2E−07	0.0000064	7.68E−07
30	8.12E−02	241.130665202236	4.8E−07	0.0000096	1.15E−06
40	1.32E−01	190.494572529498	6.4E−07	0.0000128	1.54E−06
50	1.94E−01	158.383044569171	8E−07	0.000016	1.92E−06
60	2.64E−01	136.063794313258	9.6E−07	0.0000192	2.3E−06
70	3.43E−01	119.582462073631	1.12E−06	0.0000224	2.69E−06
80	4.31E−01	106.876399583419	1.28E−06	0.0000256	3.07E−06
90	5.27E−01	96.7597551527863	1.44E−06	0.0000288	3.46E−06
100	6.30E−01	88.5003011313755	1.6E−06	0.000032	3.84E−06
110	7.41E−01	81.6204503223535	1.76E−06	0.0000352	4.22E−06
120	8.59E−01	75.7948765529242	1.92E−06	0.0000384	4.61E−06
130	9.85E−01	70.7940078038140	2.08E−06	0.0000416	4.99E−06
140	1.12E+00	66.4510273614613	2.24E−06	0.0000448	5.38E−06
150	1.26E+00	62.6416874713838	2.4E−06	0.000048	5.76E−06
160	1.40E+00	59.2714709148255	2.56E−06	0.0000512	6.14E−06
170	1.55E+00	56.2671510604277	2.72E−06	0.0000544	6.53E−06
180	1.71E+00	53.5710829538784	2.88E−06	0.0000576	6.91E−06
190	1.88E+00	51.1372446062992	3.04E−06	0.0000608	7.3E−06
200	2.05E+00	48.9284313199092	3.2E−06	0.000064	7.68E−06

Table 13. Percentage of deviation error of stopping power for water.

Energy (MeV)	Deviation (water)
0.2	5.07E+01
0.4	6.47E+01
0.6	3.94E+01
0.8	2.41E+01
1	1.52E+01
2	4.81E+00
3	4.11E+00
4	3.62E+00
5	3.28E+00
6	2.97E+00

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7	2.73E+00
8	2.50E+00
9	2.27E+00
10	2.07E+00
20	6.98E−01
30	−6.57E−02
40	−6.42E−01
50	−1.09E+00
60	−1.51E+00
70	−1.97E+00
80	−2.32E+00
90	−2.70E+00
100	−3.07E+00
110	-
120	−5.24E−01
130	-
140	-
150	−4.77E+00
160	-
170	−3.21E+00
180	-
190	-
200	−6.39E+00

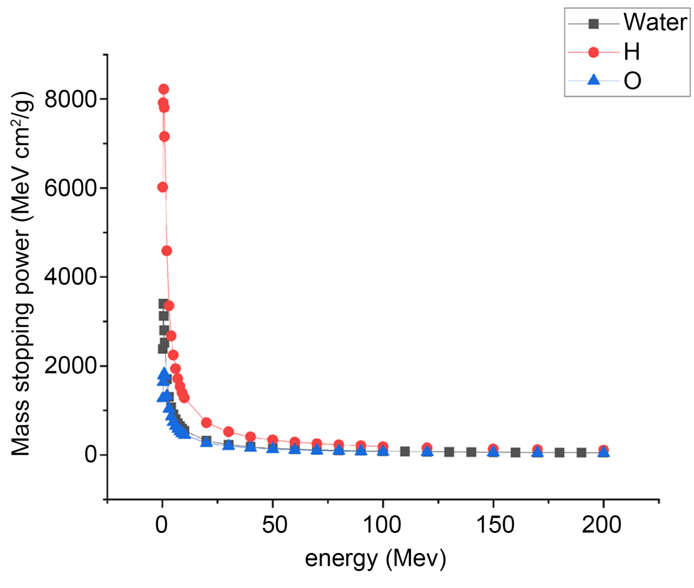

Figure 1. Mass stopping power of water and its composition.

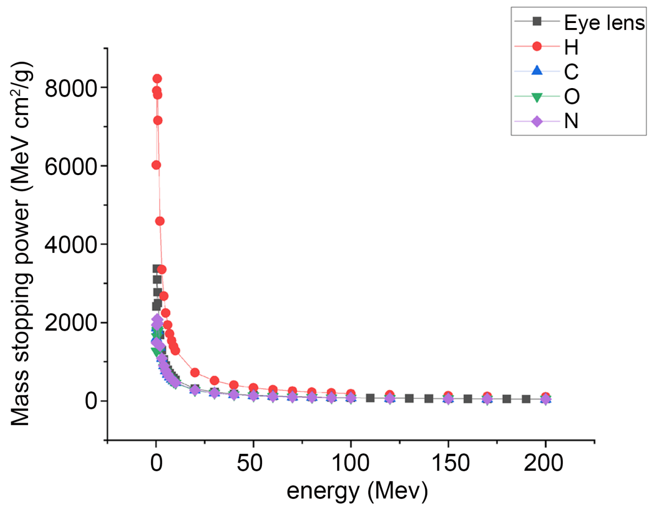

Figure 2. Mass stopping power of eye lens tissues and its some of composition.

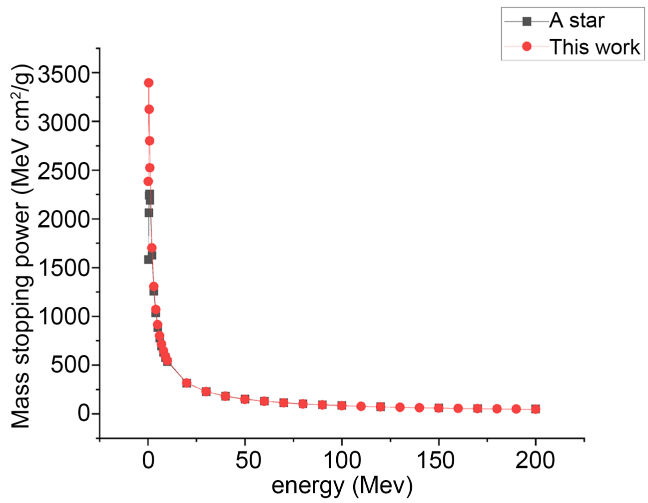

Figure 3. Mass stopping power of water measured in this work and that of ASTAR results versus energy of Alpha particles.

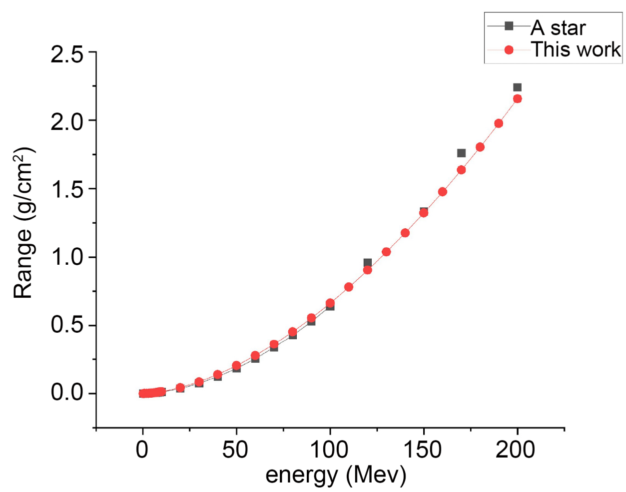

Figure 4. Range of water versus energy of Alpha particles.

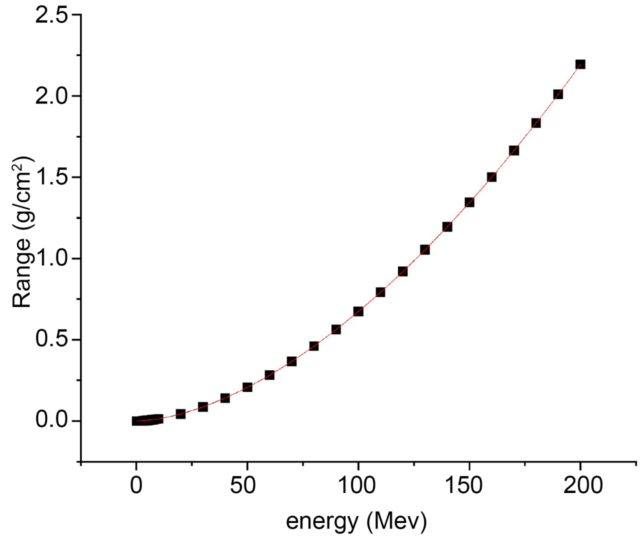

Figure 5. Range of eye lens versus energy of Alpha particles.

7. Conclusions

Our research aims to evaluate how much energy alpha particles deposit in water and eye lens tissues. We used energy levels between 0.2 and 200 MeV and calculated the mass stopping power for each beam with the Bethe-Bloch formula. Based on our findings, we can draw the following conclusions:

1) The mass stopping power is proportional to Z (the charge of the incident particles), Z/A (the ratio of atomic and mass' number of the tissue) and I (the ionization energy of the tissues).

2) The mass stopping power increases rapidly at low energies reaches a maximum and decreases gradually with increasing energy.

3) The mass stopping power allows us to calculate the range of the heavy particles in the absorber material.

4) The current fitting curves for mass stopping power and alpha particle range in water are excellent and accord with ASTAR data in the alpha energy rage of 2 to 200 MeV, with a deviation error of 4.81% - 6.39%.

5) Semi-empirical formulas for mass stopping power and range of alpha particles in water and eye lens tissues were developed for alpha particle energies ranging from 0.2 to 200 MeV.

6) The mass stopping power of alpha particles in water and eye lens tissues is equal to their average composition values.

Conflicts of Interest

The authors declare no conflicts of interest.

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