Journal homepage www.jzs.univsul.edu.iq
Journal of Zankoy Sulaimani
Part-A- (Pure and Applied Sciences)

Theoretical Study of Alpha Particles Energy loss in essential elements of Human Bones

Saman K. Ezzulddin[1]

1 College of Science-Salahaddin University, Erbil Iraq
Email: saman.ezzlddin@su.edu.krd

Article info

Original: 24 June 2016
Revised: 1 September 2016
Accepted: 16 October 2016
Published online: 20 March 2017

Key Words: *Alpha Particles, Stopping Power, Range, Energy loss, SRIM*

Abstract

Energy loss of light ions, such as alpha particles, has measured in human Bones with a different energy, are very important and very useful especially in nuclear therapy and radiation protection. Using SRIM Computer Programs to calculate the stopping power in bones by considering the tissue mostly composed of 7 elements, the alpha stopping powers and Range were calculated for those elements with the energy interval (0.1–4.5) MeV. In addition, the Results of stopping power for alpha in Bones tissues are presented and compared with the latest published data

1. INTRODUCTION

Charged particles are generated in accelerators, nuclear decays, or in the cosmic ray field. All such particles interact with matter through the Lorentz force, primarily the Coulomb force. In addition, the strongly interacting particles, such as protons and alpha particles, interact with nuclei through the short-range nuclear force [1].

When fast ion passes through matter, it loses energy principally by scattering electrons in the matter it passes through and more importantly at low energies by scattering from the nuclei of the atoms. The energy loss by α- particle per unit distance is an important term in radiation physics [2]. Charged particles are often used for radiation therapy because they have a well-defined penetration in tissues, the depth is dependent on the nature of the irradiated material and the incident energy of particles. Charged particles (protons, deuterons, alpha particles) have a significant effect in radiation therapy since they have the ability to deliver their energies to the target [3].

2. Methodology:

2.1 Theory:

Over the years, the study of the interaction of alpha particles with matter has evolved into large research field due to new powerful experimental methods and facilities around the world. The interaction of alpha ions with matter is a unique method to investigate the processes in complex atomic systems, which play a leading role in the development of modern physics [4].

In calculating the alpha particles ranges and stopping in solid targets, there are numerous techniques and calculation methods [5, 6]. Among these techniques, one method was improved by Biersack for slowing down ions in the matter based on the analysis of directional angular spread of ion motion as a function of energy [7].

2.1.1 Energy Loss Mechanisms:

In any radiation, energy is transferred from the radiation particle to the electrons of the interacting or absorbing medium. If the energy of radiation is rapidly transferred to the matter within a short distance of the interacting matter, the number of electric excitations and ionizations of the interacting atoms are very high and hence more damage is done to the interacting matter. At any given time the particle is interacting with many electrons, so the net electric charge is to decrease its velocity continuously until the particle is stopped [1]. A moving α particle penetrates matter; the major interaction is the collision between α particle and the orbiting electron. Very rarely α- particle collides with the nucleus of an atom due to the extremely small volume occupied by a nucleus in space.

The energy transferred to the orbiting electron in a collision by an α- particle is only a small fraction of the α- particle energy due to the very small mass of an electron compared to that of an α- particle. This can be shown for the maximum energy transfer which occurs when α- particle has a head on collision with an electron [11].

These processes are responsible for the slowing down of alpha particles in matter. Charged particles interact with electrons and nuclei via coulomb interaction. Due to coulomb interaction, α- particles may excite an electron to higher energy state. Ionization and excitation break a chemical bond and generate reactive species that cause further chemical reactions.

2.1.2 The Bethe-Bloch

Formula Bohr's stopping model was unique for many years. However, Bohr understood the limits of its application. The model didn’t take into account the discrete energy of target electrons. Some years later, Bohr pointed out that the binding effects are very important during the slowing-down process. Distant collisions are treated as free-electron scattering by the projectile ion. However, interactions at small distances were considered as electromagnetic excitations of harmonic oscillators and could not be described by means of classical mechanics. Hans Bethe treated the energy loss process by means of the quantum mechanics using the first Bohr approximation [7]. He used the momentum transfer rather than impact parameter to characterize collisions [12]. Bethe-Bloch expression for the stopping power of an alpha particle derived from using relativistic quantum mechanics is given by

$$-\frac{dE}{dx} = \frac{4\pi}{m_e c^2}\cdot\frac{nz^2}{\beta^2}\cdot\left(\frac{e^2}{4\pi\varepsilon_o}\right)^2\cdot\left[\ln\left(\frac{2m_e c^2\beta^2}{I.(1-\beta^2)}\right)-\beta^2\right] \tag{1}$$

Where B=v/c, *v* is velocity of the particle, *E* is energy of the particle, *x* is distance travelled by the particle, *c* the speed of light, *ze* the particle charge, *e* is charge of the electron, *me* is rest mass of the electron, *n* is electron density of the target and *I* is excitation potential of the target.

2.1.3 Range

In passing through matter, charged particles ionize and thus lose energy in a number of steps until their energy is (almost) zero. The range is the average distance traveled before a particle has lost all of its original kinetic energy [15].The range *R* is continuously slowing down and the approximation is given by:

$$R = \int_0^R dx = \int_{E_0}^0 \frac{-dE}{\frac{-dE}{dx}} = \int_{E_1}^{E_0} \frac{dE}{S} \tag{2}$$

Where *dx*= the path length. *S*= the stopping power. E_o= the initial kinetic energy of the charged particles E_1= some lower limit of energy.

2.2 SRIM

SRIM is a software package concerning the Stopping and Range of Ions in Matter. Since its introduction in 1985, major upgrades are made about every six years. Currently, more than 700 scientific citations are made to SRIM every year. For SRIM-2010, the following major improvements have been made: (1) about 2,800 new experimental stopping powers were added to the database, increasing it to over 28,000 stopping values. (2) Improved corrections were made for the stopping of ions in compounds. (3) New heavy ion stopping calculations have led to significant improvements on SRIM stopping accuracy. (4) A self-contained SRIM module has been included to allow SRIM stopping and range values to be controlled and read by other software applications. (5) Individual interatomic potentials have been included for all ion/atom collisions, and these potentials are now included in the SRIM package [8, 9].

3. Results:

Table1 (The range of α Particle in different element with different energy)

E_α/MeV	Range of α Particle/μm						
	P	Mg	Ca	C	H	N	O
0.1	**0.7994**	**0.8123**	**1.3400**	**0.4901**	**6.1600**	**1.4100**	**1.1400**
0.11	0.8508	0.8712	0.1.4400	0.5247	6.5300	1.5100	1.2200
0.12	0.8998	0.9284	0.1.5300	0.5581	6.8700	1.6000	1.2900
0.13	0.9476	0.9840	0.1.6100	0.5905	7.2000	1.6900	1.3700
0.14	0.9940	1.0400	0.1.6900	0.6221	7.5100	1.7800	1.4400
0.15	1.0400	1.0900	0.1.7700	0.6528	7.8200	1.8600	1.5000
0.16	1.0800	1.1400	0.1.8500	0.6828	8.1100	1.9400	1.5700
0.17	1.1300	1.1900	0.1.9300	0.7122	8.3900	2.0200	1.6300
0.18	1.1700	1.2400	2.0000	0.7410	8.6600	2.0900	1.7000
0.2	1.2500	1.3400	2.1400	0.7971	9.1800	2.2400	1.8200
0.22	1.3500	1.4600	2.3100	0.8648	9.8000	2.4200	1.9600
0.25	1.4500	1.5800	2.4700	0.9303	10.3800	2.5800	2.1000
0.275	1.5500	1.6900	2.6300	0.9941	10.9300	2.7500	2.2300
0.3	1.6500	1.8000	2.7800	1.0600	11.4600	2.9000	2.3600
0.325	1.7400	1.9000	2.9300	1.1200	11.9800	3.0500	2.4900
0.35	1.8400	2.0100	3.0700	1.1800	12.4800	3.2000	2.6100
0.375	1.9300	2.1200	3.2200	1.2400	12.9700	3.3400	2.7300
0.4	2.0200	2.2200	3.3500	1.3000	13.4400	3.4800	2.8400
0.45	2.2100	2.4300	3.6300	1.4100	14.3800	3.7600	3.0700
0.5	2.4000	2.6300	3.9000	1.5300	15.3000	4.0200	3.2900
0.55	2.5900	2.8300	4.1600	1.6400	16.2100	4.2800	3.5100
0.6	2.7800	3.0300	4.4200	1.7600	17.1200	4.5400	3.7200
0.65	2.9800	3.2300	4.6800	1.8700	18.0300	4.8000	3.9300
0.7	3.1700	3.4300	4.9400	1.9900	18.9600	5.0500	4.1400
0.8	3.5700	3.8400	5.4700	2.2200	20.8500	5.5600	4.5500
0.9	3.9900	4.2500	5.9900	2.4600	22.8300	6.0800	4.9700
1	4.4100	4.6700	6.5300	2.7000	24.8900	6.6000	5.4000
1.1	4.8600	5.0900	7.0700	2.9500	27.0500	7.1400	5.8300
1.2	5.3100	5.5300	7.6300	3.2000	29.3100	7.6900	6.2700
1.3	5.7800	5.9700	8.2000	34600	31.6800	8.2600	6.7200
1.4	6.2600	6.4200	8.7800	3.7200	34.1600	8.8500	7.1800
1.5	6.7600	6.8900	9.3700	4.0000	36.7500	9.4600	7.6500
1.6	7.2600	7.3600	9.9800	4.2800	39.4400	10.0800	8.1400
1.7	7.7900	7.8500	10.6000	4.5700	42.2500	10.7200	8.6400
1.8	8.3300	8.3500	11.2400	4.8600	45.1600	11.3900	9.1500
2	9.4400	9.3800	12.5500	5.4800	51.3000	12.7700	10.2100
2.25	10.9100	10.7400	14.2800	6.2900	59.5500	14.6000	11.6200
2.5	12.4600	12.1700	16.1000	7.1400	68.4600	16.5500	13.1100
2.75	14.0900	13.6700	18.0100	8.0500	78.0100	18.6200	14.6800
3	15.8000	15.2600	20.0100	9.0100	88.1900	20.8000	16.3400
3.25	17.5900	16.9200	22.1100	10.0100	99.0100	23.0900	18.0900
3.5	19.4500	18.6500	24.2900	11.0700	110.4600	25.4900	19.9200
3.75	21.3900	20.4700	26.5700	12.1700	122.5400	28.0100	21.8300
4	23.4000	22.3600	28.9300	13.3200	135.2400	30.6400	23.8200
4.5	**27.6400**	**26.3600**	**33.9200**	**15.7700**	**162.4900**	**36.2300**	**28.0500**

Table 2 (The electron S_e (MeV/(mg/cm^2)) and Nuclear stopping S_n (MeV/(mg/cm^2)) of α Particle in difference element with difference energy)

	Phosphor		Magnesium		Calcium		Carbon		Hydrogen		Nitrogen	
E/ MeV	S_e	S_n	S_e	S_n	S_e	S_n	S_e	S_n	S_e	S_n	S_e	S_n
0.1	0.983	0.01027	0.904	0.01136	0.606	0.0100	1.221	0.0137	3.677	0.0627	0.954	0.0133
0.11	1.028	0.00960	0.939	0.01060	0.641	0.0093	1.267	0.01273	3.889	0.0581	0.999	0.0123
0.12	1.069	0.00901	0.971	0.00994	0.674	0.0088	1.312	0.01119	4.093	0.0541	1.042	0.0115
0.13	1.107	0.00850	1.001	0.00937	0.705	0.0083	1.353	0.01118	4.29	0.0508	1.082	0.0109
0.14	1.141	0.00805	1.028	0.00886	0.735	0.0079	1.393	0.01055	4.478	0.0478	1.121	0.0103
0.15	1.172	0.00765	1.054	0.00841	0.763	0.0075	1.430	0.00999	4.66	0.0452	1.159	0.0097
0.16	1.201	0.00729	1.079	0.00801	0.789	0.0071	1.465	0.00949	4.835	0.0429	1.194	0.0092
0.17	1.226	0.00697	1.101	0.00765	0.814	0.0068	1.498	0.00905	5.003	0.0408	1.228	0.0088
0.18	1.250	0.00668	1.123	0.00733	0.838	0.0066	1.529	0.00865	5.165	0.0389	1.261	0.0084
0.2	1.291	0.00617	1.162	0.00676	0.882	0.0061	1.585	0.00795	5.471	0.0357	1.323	0.0077
0.22	1.332	0.00564	1.204	0.00617	0.932	0.0056	1.646	0.00723	5.82	0.0324	1.393	0.0070
0.25	1.365	0.00520	1.240	0.00568	0.975	0.0051	1.697	0.00665	6.133	0.0297	1.458	0.0065
0.275	1.390	0.00483	1.272	0.00528	1.013	0.0048	1.742	0.00615	6.412	0.0274	1.516	0.0060
0.3	1.409	0.00452	1.298	0.00493	1.047	0.0045	1.779	0.00573	6.659	0.0255	1.569	0.0056
0.325	1.422	0.00424	1.322	0.00462	1.076	0.0042	1.811	0.00537	6.874	0.0239	1.617	0.0052
0.35	1.432	0.00400	1.341	0.00436	1.102	0.0040	1.837	0.00505	7.06	0.0224	1.661	0.0049
0.375	1.438	0.00379	1.358	0.00413	1.124	0.0038	1.859	0.00477	7.218	0.0212	1.700	0.0047
0.4	1.442	0.00360	1.372	0.00392	1.144	0.0036	1.878	0.00453	7.349	0.0200	1.735	0.0044
0.45	**1.442**	0.00328	1.394	0.00357	1.175	0.0033	1.904	0.00411	7.538	0.0181	1.793	0.0040
0.5	1.435	0.00302	1.408	0.00327	1.197	0.0030	1.920	0.00376	7.644	0.0166	1.838	0.0037
0.55	1.424	0.00279	1.417	0.00303	1.212	0.0028	1.927	0.00348	**7.679**	0.0153	1.871	0.0034
0.6	1.410	0.00261	1.420	0.00282	1.222	0.0026	**1.928**	0.00323	7.659	0.0142	1.893	0.0032
0.65	1.393	0.00244	**1.420**	0.00265	1.227	0.0024	1.923	0.00302	7.594	0.0133	1.905	0.0030
0.7	1.375	0.00230	1.417	0.00249	**1.229**	0.0023	1.914	0.00284	7.497	0.0125	**1.909**	0.0028
0.8	1.336	0.00206	1.404	0.00223	1.223	0.0021	1.887	0.00254	7.238	0.0111	1.899	0.0025
0.9	1.297	0.00187	1.384	0.00202	1.209	0.0019	1.852	0.00230	6.936	0.0100	1.870	0.0023
1	1.258	0.00172	1.360	0.00185	1.191	0.0017	1.812	0.00210	6.622	0.0092	1.829	0.0021
1.1	1.220	0.00159	1.334	0.00171	1.170	0.0016	1.770	0.00194	6.317	0.0084	1.782	0.0019
1.2	1.184	0.00148	1.306	0.00159	1.146	0.0015	1.727	0.00180	6.028	0.0078	1.731	0.0018
1.3	1.150	0.00138	1.277	0.00149	1.122	0.0014	1.684	0.00168	5.76	0.0073	1.680	0.0017
1.4	1.117	0.00130	1.249	0.00140	1.098	0.0013	1.641	0.00158	5.513	0.0068	1.629	0.0016
1.5	1.087	0.00123	1.220	0.00132	1.074	0.0012	1.559	0.00148	5.287	0.0064	1.580	0.0015
1.6	1.058	0.00116	1.192	0.00125	1.050	0.0012	1.558	0.00140	5.079	0.0061	1.534	0.0014
1.7	1.030	0.00110	1.165	0.00119	1.026	0.0011	1.519	0.00133	4.889	0.0058	1.489	0.0013
1.8	1.005	0.00105	1.139	0.00113	1.004	0.0011	1.481	0.00127	4.713	0.0055	1.447	0.0013
2	0.957	0.00096	1.088	0.00104	0.961	0.0010	1.409	0.00116	4.4	0.0050	1.370	0.0011
2.25	0.905	0.00087	1.030	0.00094	0.911	0.0008	1.328	0.00105	4.067	0.0045	1.286	0.0010
2.5	0.859	0.00080	0.977	0.00086	0.866	0.0008	1.255	0.00095	3.784	0.0041	1.211	0.0009
2.75	0.818	0.00073	0.929	0.00079	0.826	0.0007	1.189	0.00088	3.539	0.0038	1.146	0.0009
3	0.782	0.00068	0.885	0.00073	0.789	0.0007	1.130	0.00080	3.325	0.0035	1.088	0.0008
3.25	0.749	0.00064	0.845	0.00068	0.756	0.0006	1.076	0.00076	3.137	0.0033	1.035	0.0008
3.5	0.720	0.00060	0.809	0.00064	0.725	0.0006	1.027	0.00071	2.969	0.0031	0.988	0.0007
3.75	0.693	0.00056	0.776	0.00060	0.697	0.0006	0.983	0.00067	2.819	0.0029	0.946	0.0007
4	0.668	0.00053	0.745	0.00057	0.672	0.0005	0.942	0.00063	2.684	0.0027	0.907	0.0006
4.5	0.625	0.00048	0.691	0.00052	0.626	0.0005	0.870	0.00057	2.451	0.0025	0.838	0.0006

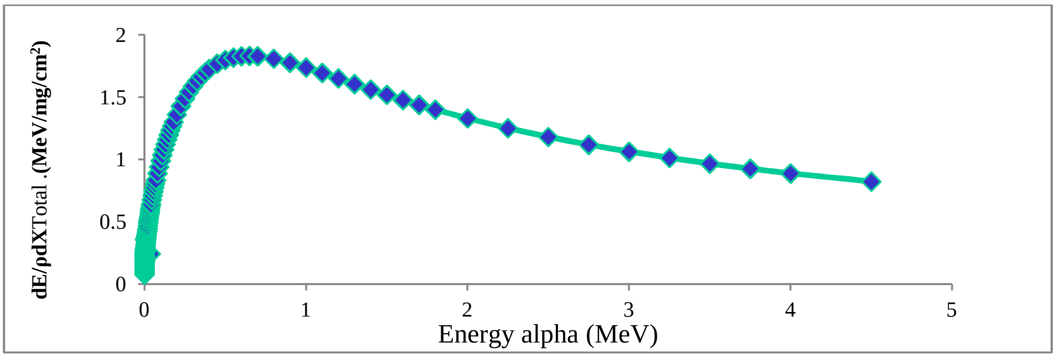

Figure.1 The Total stopping power for Alpha Particles in Human Bones with different of energy

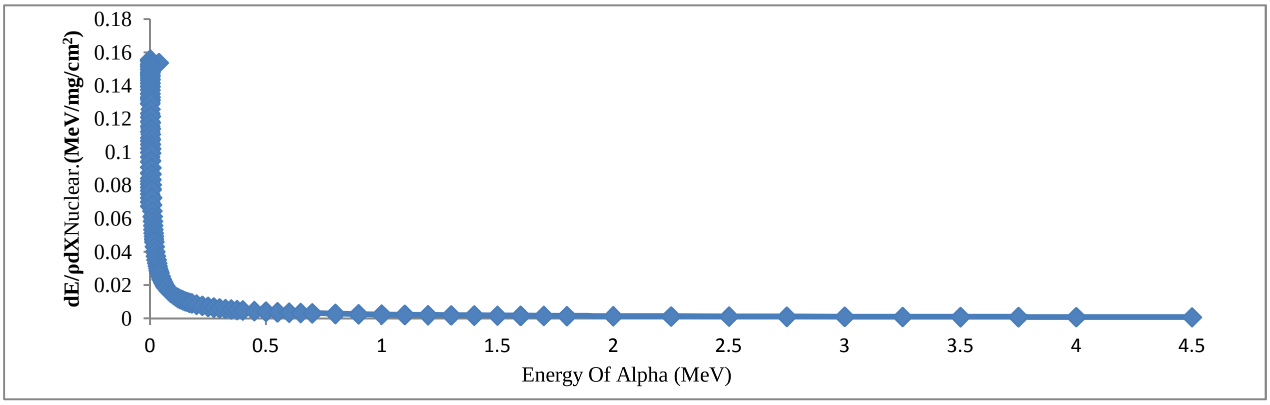

Figure.2 The nuclear stopping power for Alpha Particles in Human Bones with different of energy.

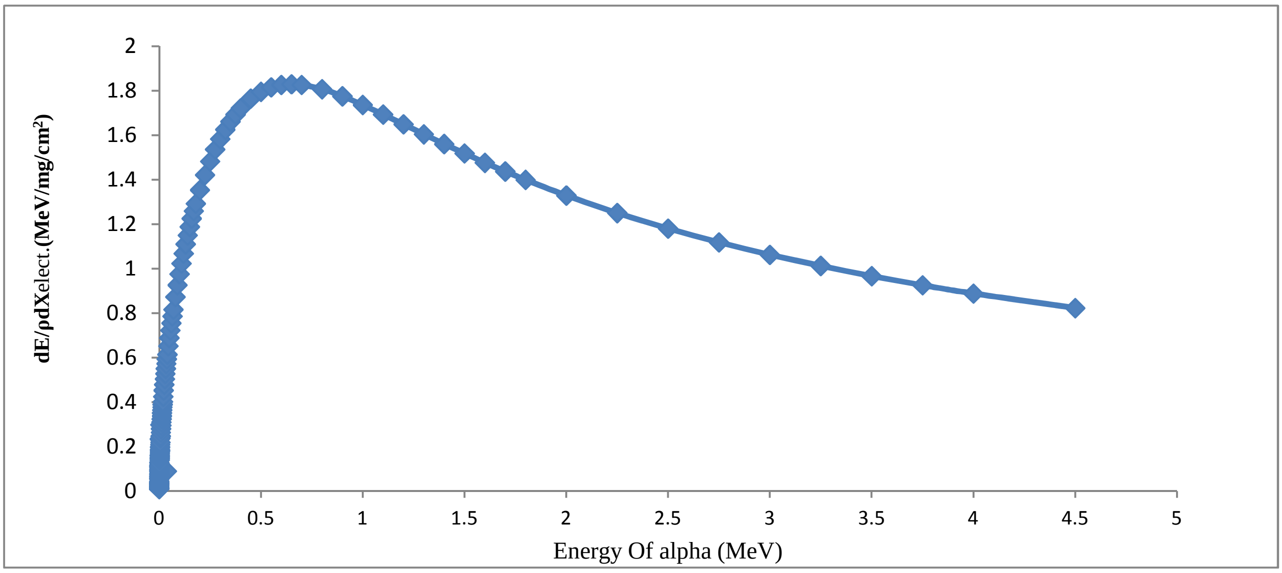

Figure.3 Represented the electronic stopping power for Alpha Particles in Human Bones with different of energy.

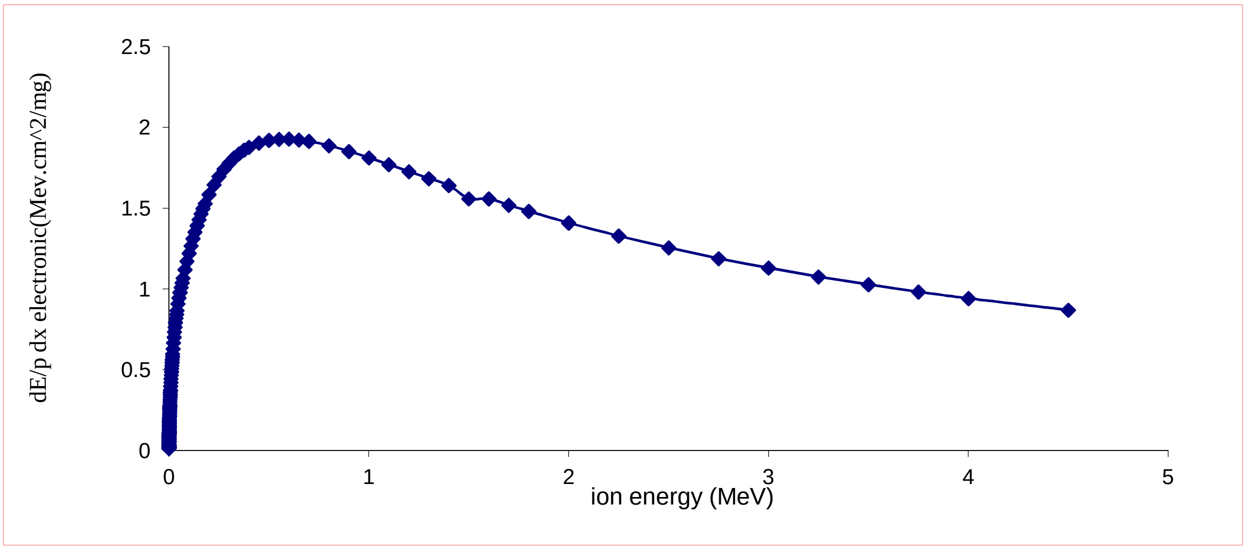

Figure.4 The Electron Stopping power of Alpha Particles in Carbon with different of energy.

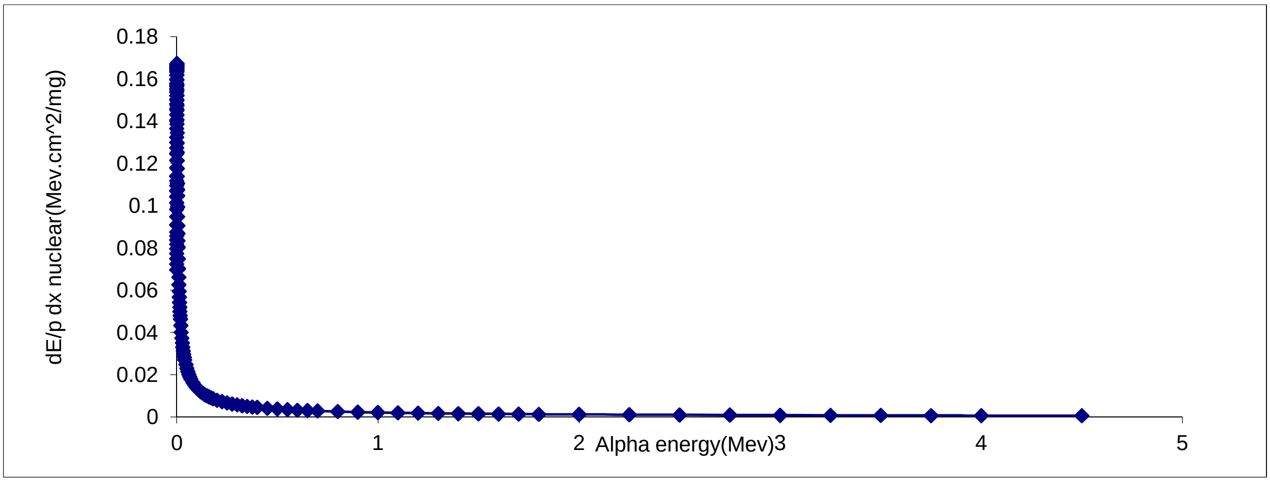

Figure.5 The nuclear Stopping power of Alpha Particles in Carbon with different of energy.

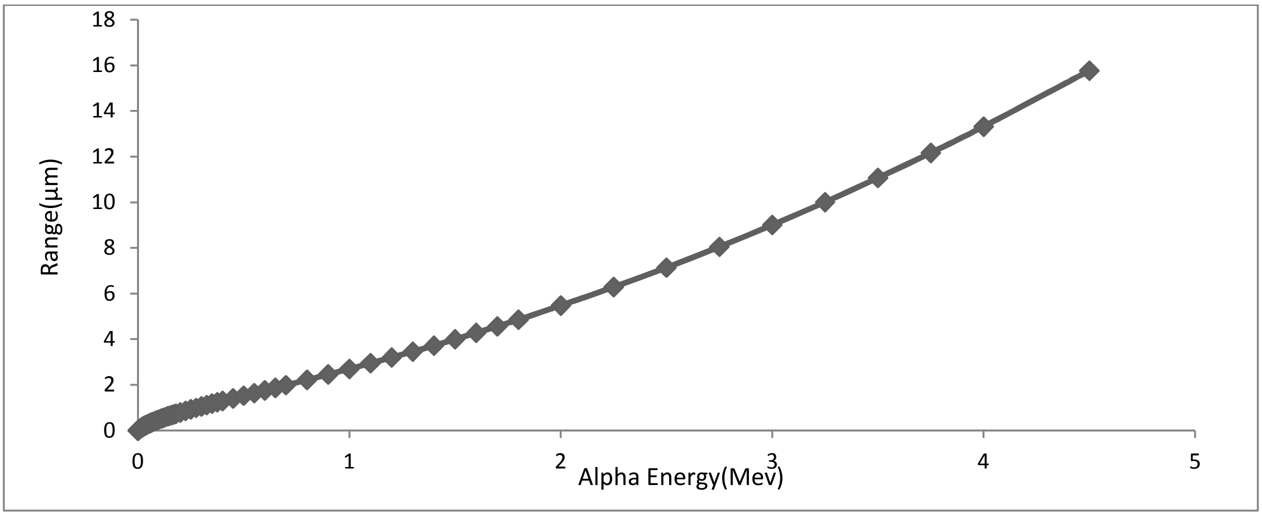

Figure.6 The range of Alpha Particles in Carbon with different of energy.

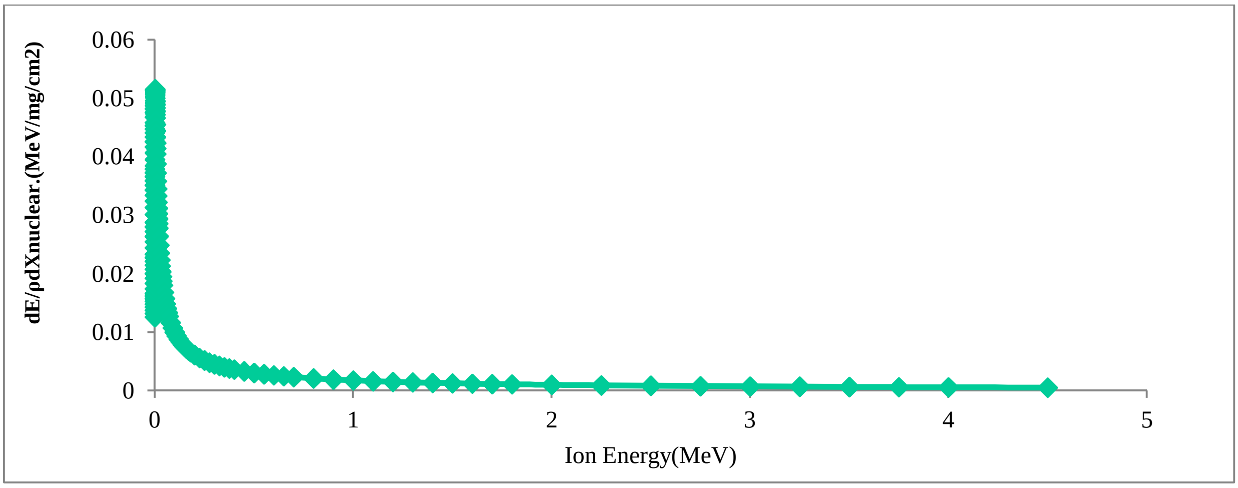

Figure.7 The nuclear Stopping power of Alpha Particles in Calcium with different of energy.

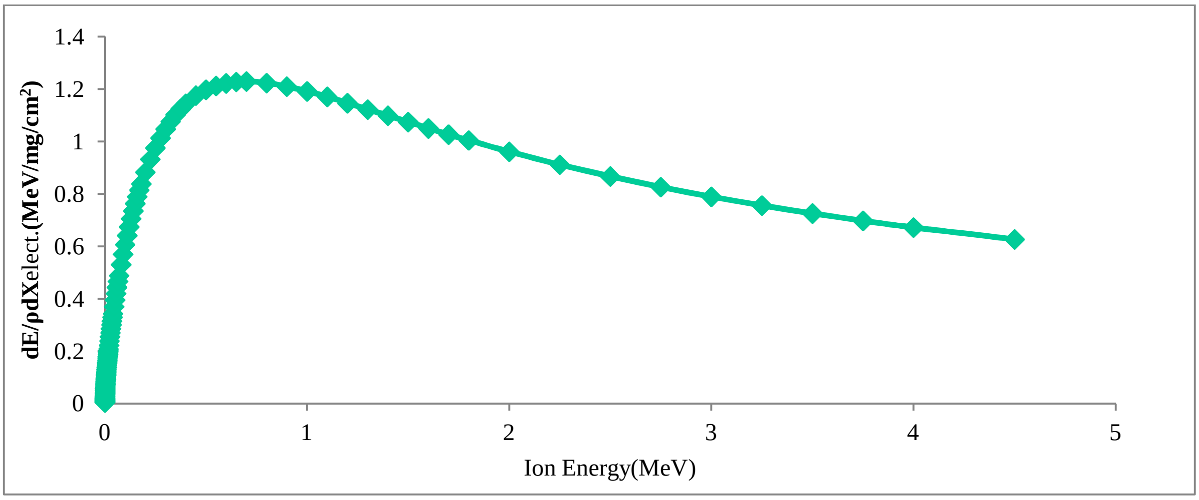

Figure.8 The Electron Stopping power of Alpha Particles in Calcium with differences of energy

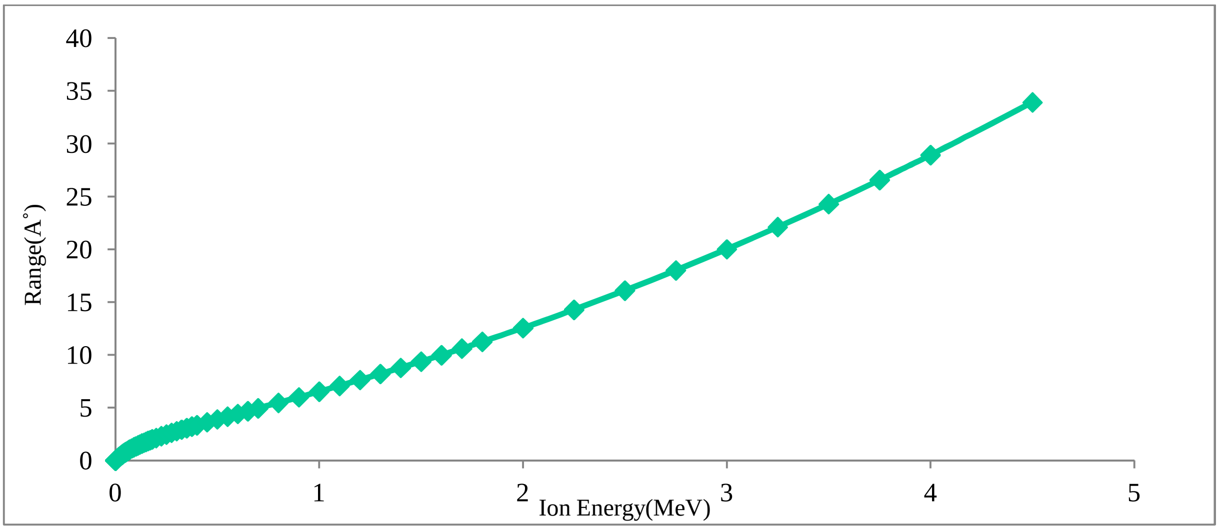

Figure. 9 The range of Alpha Particles in Calcium with different of energy

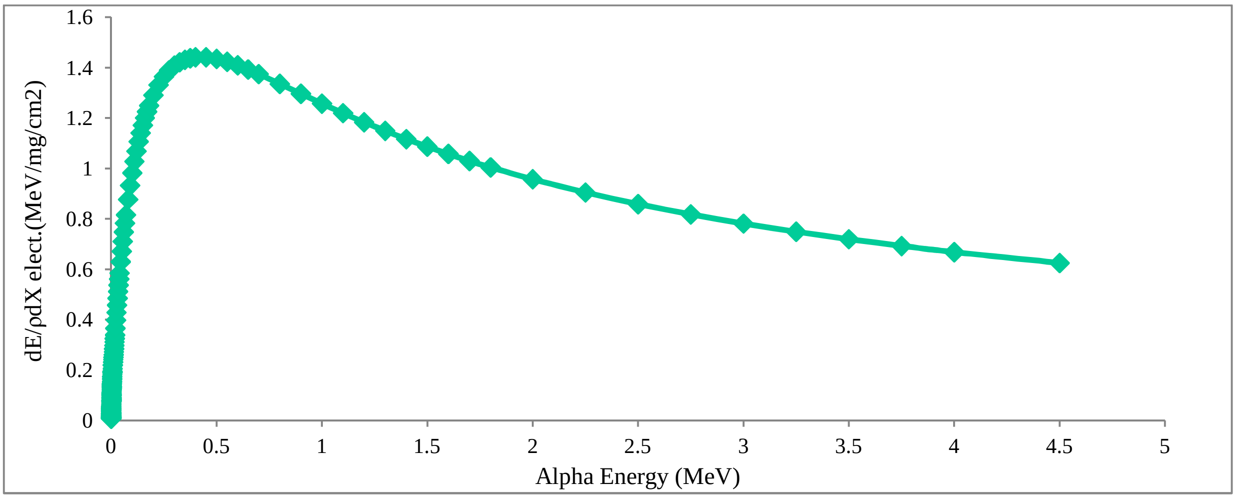

Figure.10 The Electronic Stopping power of Alpha Particles in Phosphor with differences of energy.

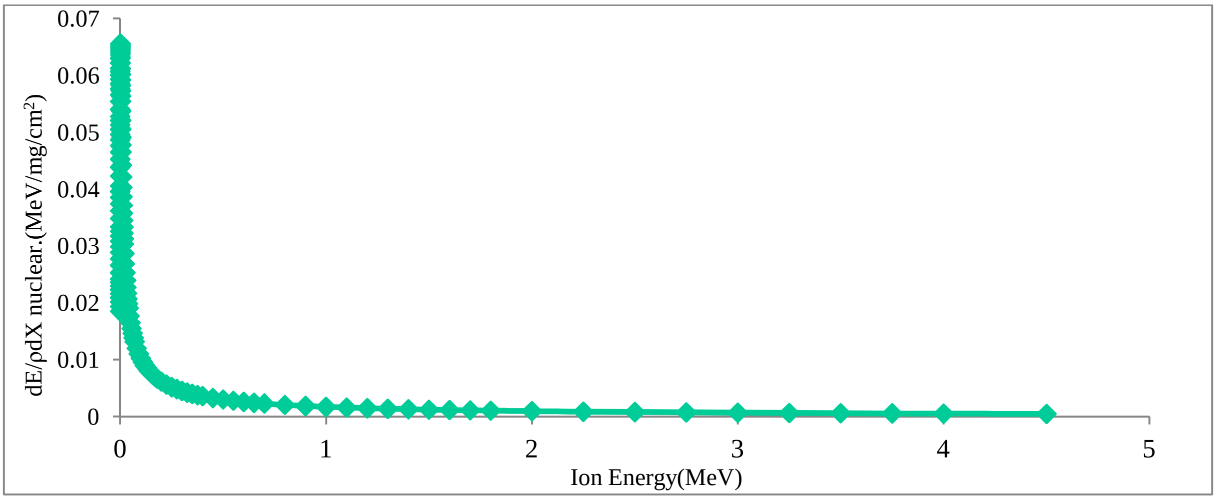

Figure.11 The Nuclear Stopping power of Alpha Particles in Phosphor with different of energy.

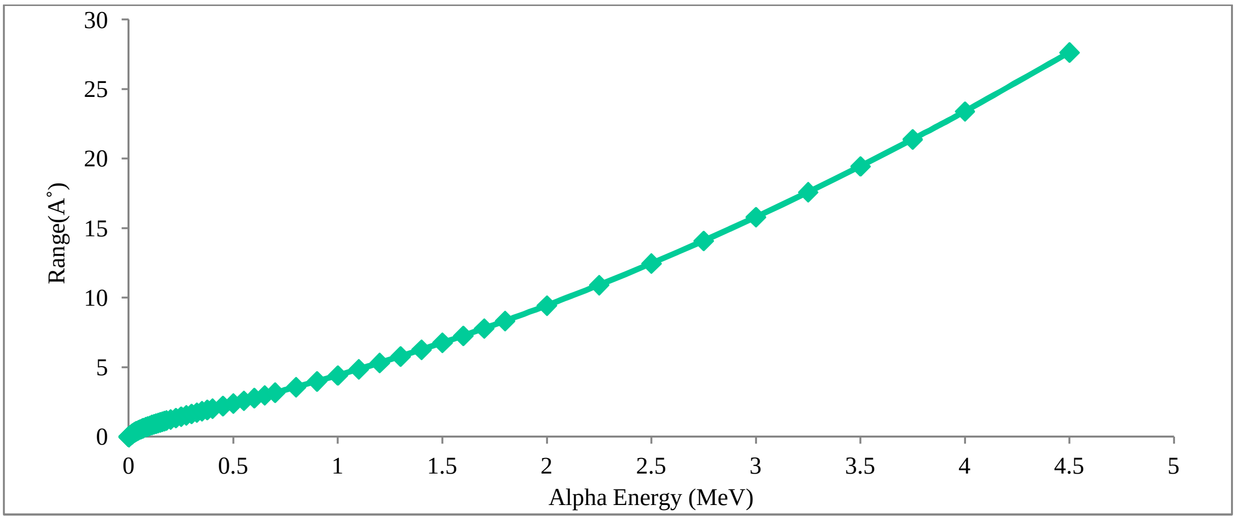

Figure.12 The range of Alpha Particles in Phosphor with differenct of energy

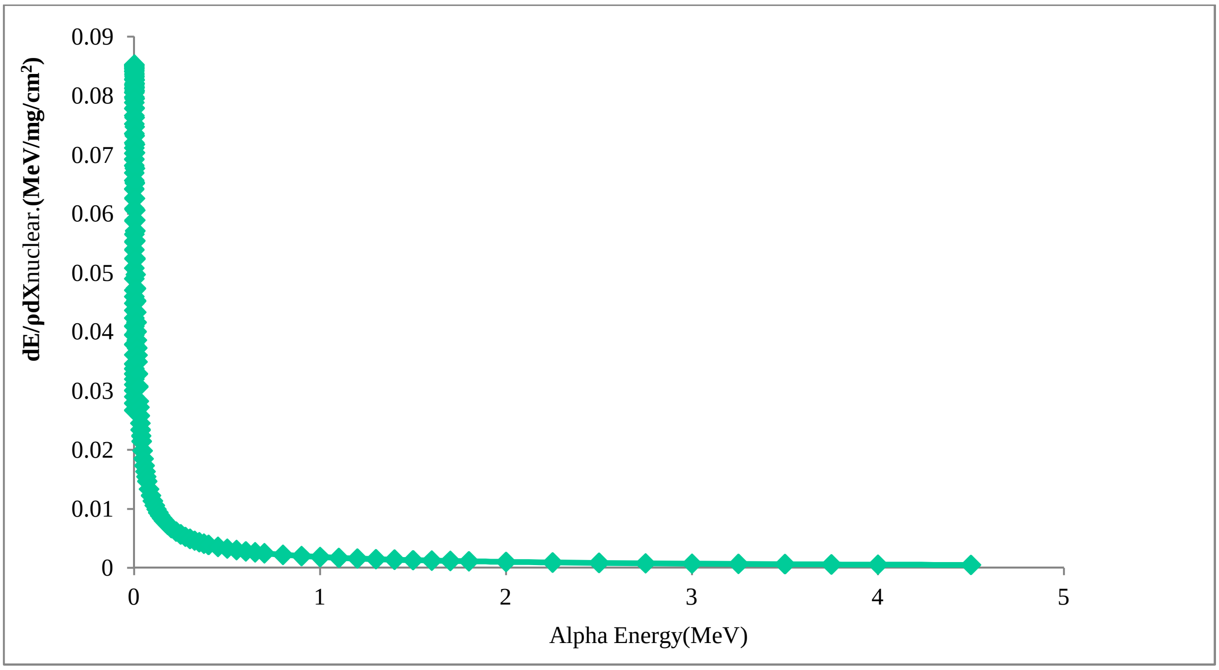

Figure.13 The Nuclear Stopping power of Alpha Particles in Magnesium with differences of energy

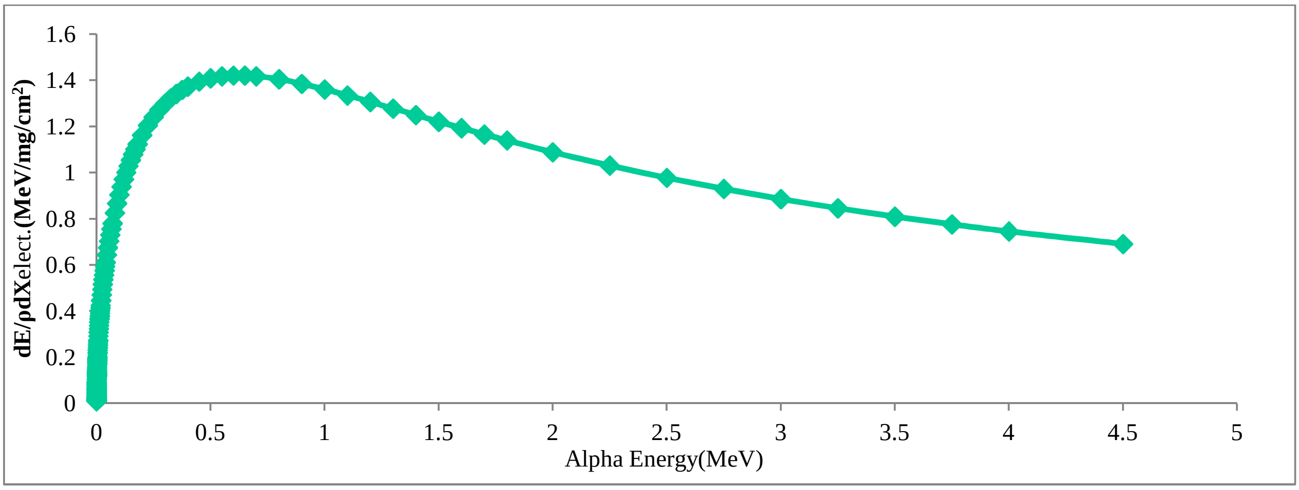

Figure.14 The Electronic Stopping power of Alpha Particles in Magnesium with different of energy.

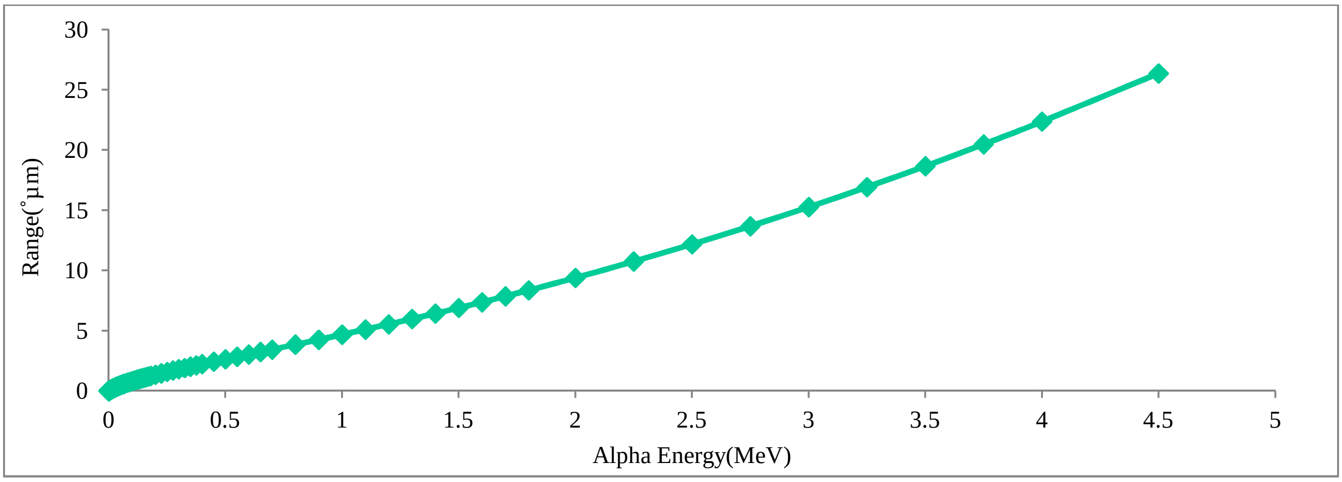

Figure.15 The range of Alpha Particles in Magnesium with different of energy.

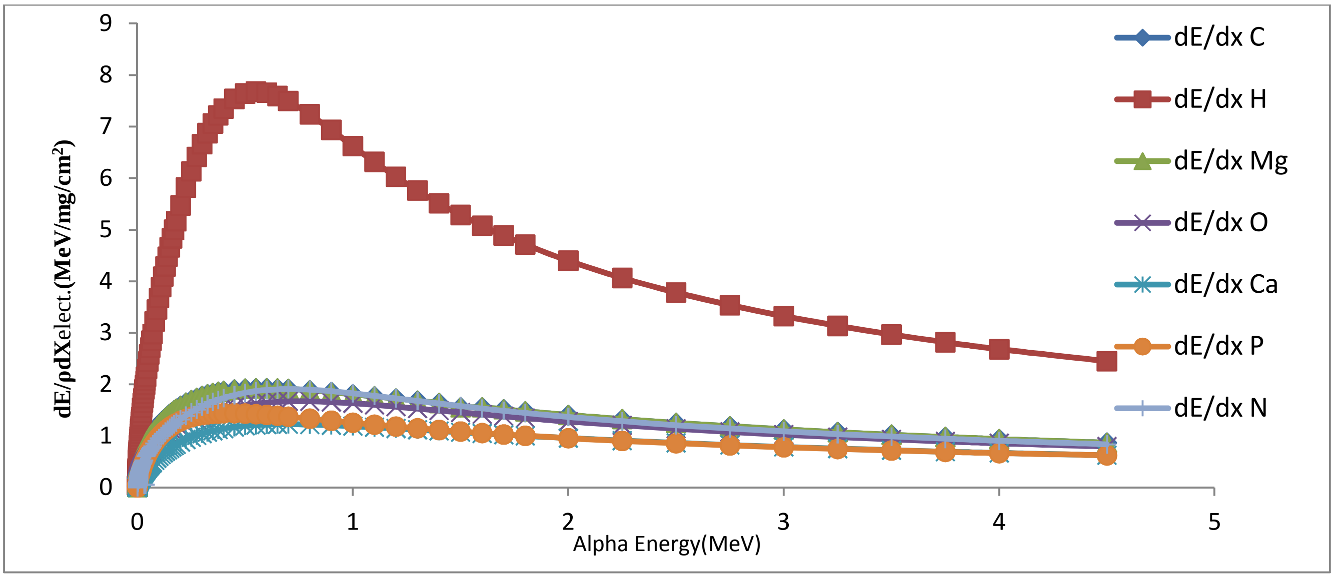

Figure.16 The electronic stopping power for Alpha Particles in different element with different of energy.

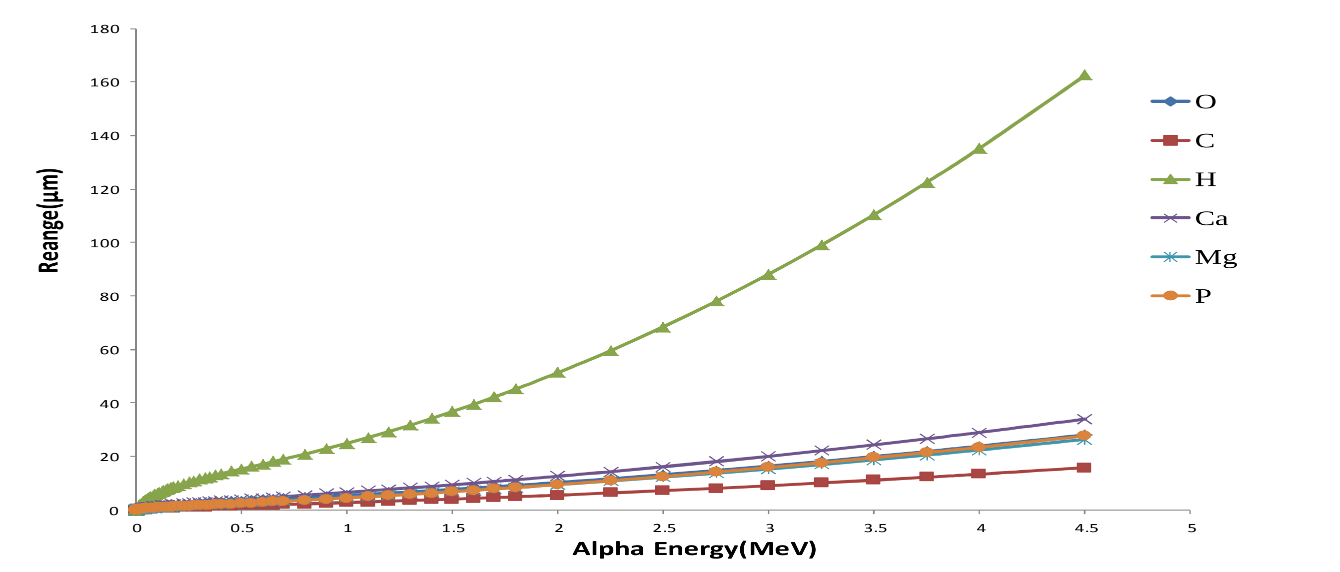

Figure.17 The range of Alpha Particles in different element as function energy.

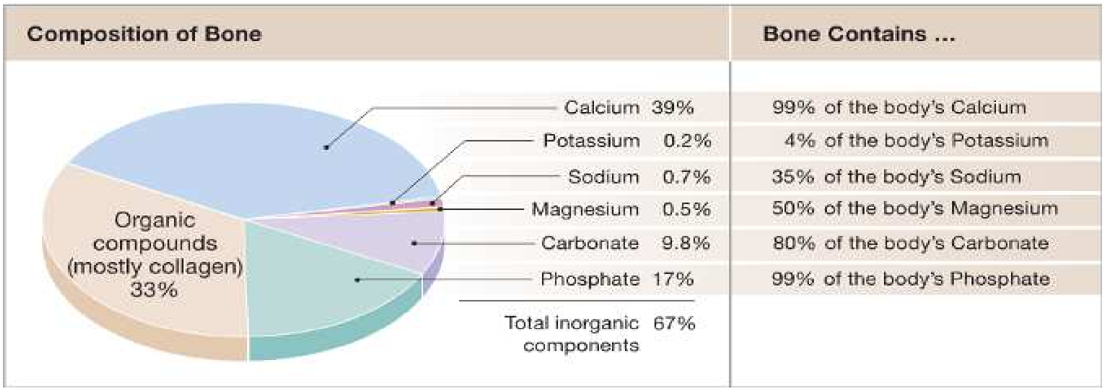

Figure.18 Chemical composition of human bone [13].

4. Discussion

The present work measures the mass stopping and range of alpha particles in the essential elements of human bones as shown in Figure.18 with energy interval (0.1- 4.5) MeV by using SRIM (2013) Computer program code, in order to understand which chemical element responsible for absorbing alpha particles energy. It is known that the chemical compositions of human tissues are of importance in studying microdosimetric distributions in human irradiated with radiation [10].

Table (1) represents the range of incident alpha particles inside each element of the bones tissue such as P, Mg, Ca, C, H, N, O values were ranged from (0.7994, 0.8123, 1.34, 0.4901, 6.16, 1.41 and 1.140)µm to (27.64, 26.36, 33.92, 15.77, 162.49, 36.23 and 28.050)µm respectively, maximum value of range record H and minimum was recorded from C, since the density of H is smaller than C, it means the penetration of alpha particles inside H is greater C as shown in Figure 17. The results indicated that good agreement with ref [11] were reported by (IAEA), as well as the Figures. 6, 9, 12 and 15 represented the range of incident alpha particles inside C, Ca, P, Mg respectively as a function of energy for that particles, they show the range increases in all elements with increasing energy of those particles, it refers to the ref. [1], as well as for the same energy the range of alpha inside the H atom is greater than Ca atom in that medium (bones).

The results of mass electronic and nuclear stopping power were reported in the table (2). The values mass electronic stopping power varied from (0.624, 0.691, 0.626, 0.87, 2.451, and 0.838) Mev/(mg/cm^2) to (1.442, 1.420, 1.229, 1.928, 7.679 and 1.909) Mev/(mg/cm^2) for individual elements P, Mg, Ca, C, H, N, O respectively, results were agreement with ref.[12] . The maximum value of electronic stopping power at same energy is found in H element and minimum value is found from C because of having H gaseous molecules in the traversing path of the alpha particle ions, hence, the more probability of interaction, the more energy lost referred by [12]. The valued mass nuclear stopping power varied from (0.0102, 0.0136, 0.01, 0.0137, 0.0627, and 0.0133) Mev/(mg/cm^2) to (0.00048, 0.00052, 0.0005, 0.00057, 0.0025 and 0.0006) Mev/(mg/cm^2) for each individual element P, Mg, Ca, C, H, N, O respectively, and the results were in agreement with ref.[12] . The maximum value of electronic stopping power at the same energy found in H element and minimum value found from C, Figure (1, 2 and 3) shows a plot of total nuclear and electronic energy loss in human bones as a function of projected energy of alpha particles in the energy range of (0.1- 4.5) MeV. Figures. 5, 7, 11, and 13. This graph reveals that as projected energy of the alpha particles increases the nuclear energy loss decreases exponentially at low energy. This is due to the interaction mechanism by which the ion loses energy by elastic collision with the nuclei of target atoms of media.

The Figures. 4, 8, 10 and 14 shows the electronic stopping power of alpha particles in C, Ca, P, and Mg respectively. From these figures represented, the electronic stopping power of alpha particle increases rapidly as the energy of alpha particle increases nearly at dominates (0.1 to 0.7) MeV. When the energy of the alpha particles increases from (0.7 to 4.5) MeV the behavior of the electronic stopping power is exactly different. As represented, the stopping power of alpha particle decays exponentially due to passing through matter, charged particles ionize. Thus, they lose energy gradually but continuously along its path until their energy is (almost) zero, after traveling a certain distance referred [10].

5. CONCLUSIONS

- Range of alpha particle increases with the increase of energy of alpha particles inside the human bone.
- At a very low energy of alpha, nuclear stopping power contributes in the energy losing of alpha particles in that medium.
- The nuclear stopping power decreases exponentially with increasing energy of alpha particles.
- For alpha particles energy smaller than (0.7) MeV the electronic stopping power is directly proportional with energy.
- For alpha particles energy greater than (0.7) MeV the electronic stopping power is indirectly proportional with energy.
- The Hydrogen atoms are most responsible for energy losing in human bones.

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