Stopping Power Calculation of protons in (CH_4) and (C_2H_4) and (C_3H_8) in energy rang (0.01-1000) Mev

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Abstract

This research investigates the electronic stopping power for heavy charged particles (protons) colliding with the following organic compounds using the Bohr, Beth, and Ziegler equation. Within the energy range, CH4, C2H4, and C3H8 (0.01-1000) Mev. In order to obtain the necessary theoretical results, the mathematical equations were programmed and applied in the Matlab program. These calculated findings were compared by Bohr, Beth, and Ziegler with the results of Srim2013 data as well as with the results of the global code Pstar for botton missiles and with the results from. Calculating the correlation coefficient revealed that the outcomes were consistent with one another.

Key Words: Stopping power, proton, Bethe formula, Ziegler formula, Bohr formula, PSTAR, MATLAB language, SRIM2013

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Introduction

The loss of energy for particles in the matter has been studied for many years as a result for collision phenomena. This is where the charged particle loses its kinetic energy in different ways of reaction dependent on the velocity and nuclear charge for the incident charged particle as well as the nature of the target particles [1].

Ionizing and exciting atoms is the primary means by which the energy of a charged particle that is moving quickly through matter is lost. The prediction of the average rate of energy loss of the particle per unit distance traveled as a function of the particle's energy is an important goal of theoretical understanding of these processes. This can be thought of as a function of the particle's energy. The stopping power of the material for that particle is the fundamental quantity that is being referred to here [2].

The electronic stopping term is what controls the energy losses that are brought on by the electronic interactions. These energy losses can be further subdivided into several different contributions depending on the kind of interaction that is taking place.

As a result, the stopping power can be represented by the symbol [3].

$$\left(\frac{dE}{dX}\right) = \left(\frac{dE}{dX}\right)\text{nuclear} + \left(\frac{dE}{dX}\right)\text{electronic} \quad (1)$$

It is frequently expressed in the units MeV/cm and is denoted by the symbol dE/dx. When the stopping power is divided by the density of the material, the mass stopping power, - dE/dx, is calculated. This value can be expressed in $\frac{Mev.cm^2}{g}$[2]. The ability of a material to halt a particle is contingent not only on the kind of particle and its energy but also on the characteristics of the material through which the particle travels. The density of ionization along the path is proportional to the stopping power of the material. This is because the production of an ion pair (which is typically composed of a positive ion and a negative ion (electron)) requires a fixed amount of energy. The stopping power of a material is a property of the material itself, while energy loss per unit path length is a measure of what happens to the particle [4].

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Stopping power

Commonly referred to as the energy loss of the medium, this quantity is defined as the amount of energy that is lost by a particle heavy per unit path length.

$$S=-\frac{dE}{dX} \qquad (2)$$

Where E represents the kinetic energy of the charged particle and x represents the path length. Specific energy loss is another name for the amount of –dE/dx that accumulates along the path of a particle. Therefore, the term "specific energy loss" is used to refer to the quantity S. This amount may represent the total amount of energy that is lost relative to the number of particles that interact. It is inversely proportional to the incoming particle's velocity and is proportional to the cube of the charge of the particle that is entering the system. Therefore, the power to stop the particle increases when the velocity of the particle decreases. In addition, the term linear energy transfer, which is an approximation of the stopping power of penetrating particles, can be used to refer to the stopping power [6] .

$$\left(-\frac{dE}{dX}\right) elec = \frac{4\pi Z_1^2 Z_2 e^4}{m_e v^2} \mathrm{N}\, L_{ele} \qquad (3)$$

According to the theoretical work that was initiated by Bohr as a classical formula at nonrelativistic velocities, the differential stopping power of charged particles is as follows: [7]

$$\mathrm{L_{elec}} = \mathrm{L_{Bohr}} \approx \ln\left(\frac{\mathrm{C} m_e v^3}{|z_1 e^2| w}\right) \qquad (4)$$

Where: C=2e^{-d}, d=0.5772
and
Z1: atomic number of the projectile
m : mass of electron.
Z2: atomic number of the target material.
I: the mean excitation potential of target material.
V:is the velocity of the projectile
W: is the free electron gas plasma frequency

Ziegler theory

We have used the major Ziegler equation in low and high energies through the use of the program SRIM 2013, which was implemented in the Matlab program. This equation is represented as follows:

$$S1=S_{LOW}S_{HIGH}/(S_{LOW}+S_{HIGH}) \qquad (5)$$

Where: (S1) represents the total amount of stopping power.
(SLOW) Low energy stopping power.
(SHIGH) High energy stopping power.
Ziegler's equation for braking power can be broken down into three distinct regions [8].
1-The first region is the low energy region, which has an energy range of between 1 and 10 KeV and is represented by the following formula

$$S_{LOW} = A_1 E^{0.5} \qquad (6)$$

2- The following formulas illustrate the second region of the Ziegler equation for the stopping power over the energy range of (10-1000) KeV, which has been divided into two distinct regions
a)
n the second region, the equation with the lowest possible energy is as follows

$$S2_{LOW} = A_2 E^{0.45} \qquad (7)$$

b)
n the second region, the high-energy equation looks like this

$$S2_{LOW} = \frac{A_2}{E_2} \ln\left(1+\frac{A_4}{E_2}+E_2 A_5\right) \qquad (8)$$

3- The following equation illustrates the third region of the Ziegler equation for the stopping power with an energy range of (1000 – 100000) KeV

$$\mathbf{S3} = (A_6/\beta^2)\ln\left(\frac{A_7-\beta^2}{1-\beta^2}\right) - \beta^2 - \sum_{i=0}^{4} A_{i+8}(\ln E_3)^i \qquad (9)$$

Bethe's theory

Bethe developed a theory that explains how a point charge traveling through matter at a speed that is not relativistic can be stopped. This theory is predicated on two primary assumptions: -
I The stopping is caused by Coulomb excitation and ionization of the electrons in the stopping medium,
and (ii) The interaction is treated within the first Born approximation.
The following expression can be used to calculate the average amount of energy lost per unit of path length: (stopping power) [9].

$$\left(-\frac{dE}{dX}\right) elec = \frac{4\pi Z_1^2 Z_2 e^4}{m_e v^2} \mathrm{N} \quad L_{ele} \qquad (10)$$

The well-known Bethe formula provides an approximation of the stopping number.

$$\mathrm{LBethe} = \ln\frac{2mv^2}{I} \qquad (11)$$

SRIM

SRIM is an acronym that stands for "Stopping and Range of Ions in Matter," and it is the name of a software package. Since its initial release in 1985, approximately every six years there has been a significant upgrade. At the moment, more than seven hundred scientific citations are added to SRIM each and every year. In a recent textbook titled "SRIM – The Stopping and Range of Ions in Matter," the fundamental physics of the software is described in detail. After this point, adjustments were made in accordance with new data obtained through experiments. [10]

PSTAR

The stopping powers and ranges of electrons, protons, and helium ions in matter for energies ranging from 1 keV to 10 GeV can be calculated using a PC package that has been documented. These databases can also calculate similar results at any other energy grid that falls within the limits of these limits. The units of measure for energies are MeV. Calculations can be done to determine the stopping powers and ranges for electrons for any element, compound, or mixture. It is possible to calculate the stopping powers and ranges of protons and helium ions for 74 different materials (26 elements and 48 compounds and mixtures).Calculations of electron and proton and alpha particle stopping powers and ranges are performed by ESTAR, PSTAR, and ASTAR, respectively (helium ions). The ICRU Reports contain an in-depth explanation of the procedures that were followed when implementing these programs [11, 12] .

Table 1: Correlation coefficient values when comparing the protons stopping power resulting from Ziegler equation and SRIM2013

Project	Organic compound	Ziegler CORREL
Proton	CH_4	0.9999
	C_2H_4	0.9998
	C_3H_8	0.9999

Table 2: stopping power for proton in CH_4

EMev	Bethe	Bohr	Zegler	SRIM	PSTAR
0.01	-6610.972441	-15904.55198	918.4442189	0.8378	0.8627
0.02	-193.3571628	-3284.130272	1196.084883	1.116	1.148
0.03	1084.765846	-368.9461641	1360.969684	1.273	1.325
0.04	1459.423145	692.0395803	1456.382539	1.361	1.436
0.06	1579.821393	1371.636745	1520.585168	1.423	1.528
0.08	1507.824513	1513.141317	1491.455495	1.399	1.514
0.1	1406.679476	1511.123695	1420.902524	1.336	1.447
0.125	1285.69426	1449.405815	1029.500306	1.26	1.338
0.2	1014.695335	1222.547331	894.2608856	0.9779	1.041
0.25	891.9756658	1098.347787	792.4116748	0.8521	0.9046
0.3	797.9482909	997.2266925	651.5473717	0.7566	0.8032
0.4	663.1453324	844.9222024	492.3407366	0.6233	0.6618
0.6	502.9317042	654.5016753	402.2928062	0.4718	0.4998
0.8	409.6162837	539.47847	316.2456025	0.387	0.4074
1	347.8388851	461.7823014	184.0139365	0.3325	0.3464
2	205.346698	277.983686	132.5219931	0.2077	0.2057
3	149.2634144	203.8384338	104.5108289	0.1506	0.1501

4	118.5899174	162.8178638	74.35695556	0.1194	0.1195
6	85.39080586	118.0085497	58.19161073	0.08592	0.08619
8	67.48160755	93.63910705	41.01650072	0.06788	0.06817
12.5	46.71580017	65.18354724	31.92524815	0.0486	0.04722
15	40.17765232	56.173922	26.25999843	0.0404	0.04062
20	31.66850167	44.4065917	18.3931249	0.03184	0.03202
30	22.66906719	31.90224121	14.28994243	0.02279	0.02292
40	17.918515	25.27222694	11.7594292	0.01801	0.01811
60	12.93341351	18.28724054	10.03877531	0.01299	0.01307
70	11.45349213	16.20678158	8.791121296	0..01150	0.01157
100	8.709430066	12.3379466	6.500869977	0.008743	0.008797
200	5.343355377	7.557791686	3.745179779	0.005356	0.005394
300	4.177993707	5.880284151	2.806999083	0.004182	0.004216
400	3.593378057	5.025116322	2.337294892	0.003592	0.003625
600	3.022327952	4.165277902	1.872996161	0.003013	0.003048
800	2.755087385	3.739988263	1.647502529	0.002739	0.002778
1000	2.609436868	3.490464652	1.517176229	0.002588	0.002631

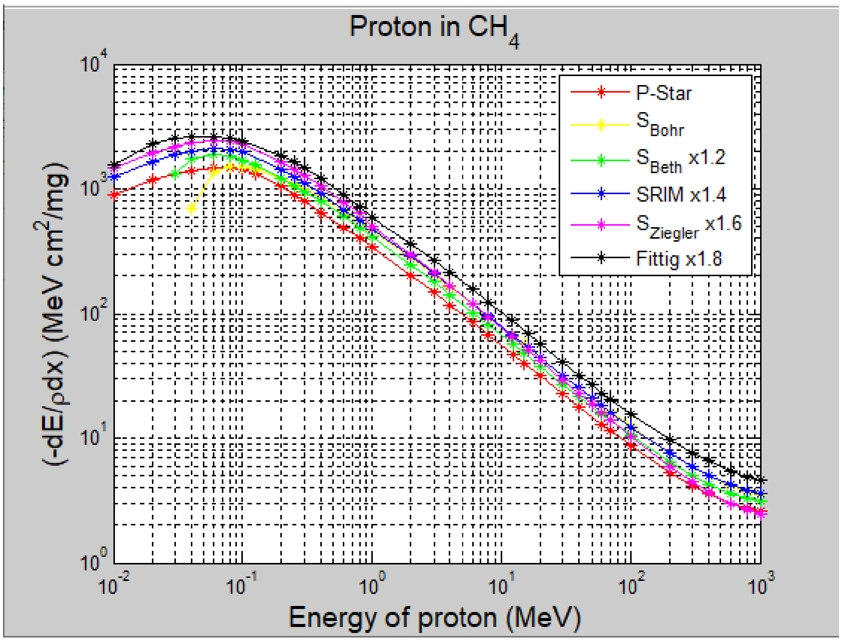

Fig.1: Show the mass Stopping Power and Energy for proton in the CH_4

Table3: stopping power for proton in C_2H_4

E Mev	Bethe	Bohr	Ziegler	SRIM	PASTAR
0.01	-7842.05417	- 16345.47737	705.4471292	0.6561	0.6806
0.02	-1073.511	-3901.50119	922.3260797	0.8729	0.8799
0.03	394.7986734	- 935.3162067	1053.157352	0.9964	0.9961
0.04	887.0294111	184.8901352	1131.144881	1.069	1.071

0.06	1146.618646	956.1342191	1189.439753	1.127	1.145
0.08	1155.456793	1160.321554	1174.100084	1.119	1.148
0.1	1107.739521	1203.30371	1124.886495	1.079	1.115
0.125	1032.903268	1182.695781	833.7757726	0.9381	0.9815
0.2	838.7390275	1028.919084	731.0064447	0.8117	0.8497
0.25	744.3844933	933.2104969	652.9291615	0.7133	0.749
0.3	670.305686	852.6410904	543.5359466	0.6375	0.6724
0.4	561.9066552	728.2285387	416.9843762	0.5302	0.5621
0.6	430.2574136	568.9406415	343.6443181	0.4058	0.4284
0.8	352.3472046	471.1682814	264.421231	0.3349	0.3508
1	300.3050508	404.5607992	154.8538301	0.2888	0.2993
2	178.8934402	245.3547048	111.6915404	0.1796	0.1796
3	130.5669992	180.5019553	88.1022993	0.1311	0.1316
4	103.9956859	144.4632951	62.63122801	0.1045	0.1015
6	75.11348514	104.9580116	48.94909866	0.07552	0.07606
8	59.47408527	83.40762854	34.40000489	0.05983	0.06028
12.5	41.28070864	58.17829565	26.6988531	0.04296	0.04188
15	35.5375169	50.17375584	21.90256165	0.03392	0.03605
20	28.050659	39.7057344	15.2507207	0.02823	0.02846
30	20.11517745	28.56333092	11.78844707	0.02024	0.0204
40	15.91790388	22.64639041	9.657306009	0.01602	0.01614
60	11.50597525	16.40461056	8.210722483	0.01157	0.01166
70	10.19452535	14.54368185	7.163427073	0.01025	0.01033
100	7.760476823	11.08049055	5.245613341	0.007799	0.007862
200	4.769811281	6.795972353	2.949224578	0.004785	0.004828
300	3.733019459	5.2905782	2.170598084	0.003739	0.003777
400	3.212689724	4.522699105	1.780677359	0.003212	0.00325
600	2.704497967	3.75027232	1.393302029	0.002694	0.002735
800	2.466909018	3.368071905	1.202616157	0.00245	0.002494
1000	2.337659	3.143780265	1.090244694	0.002314	0.002362

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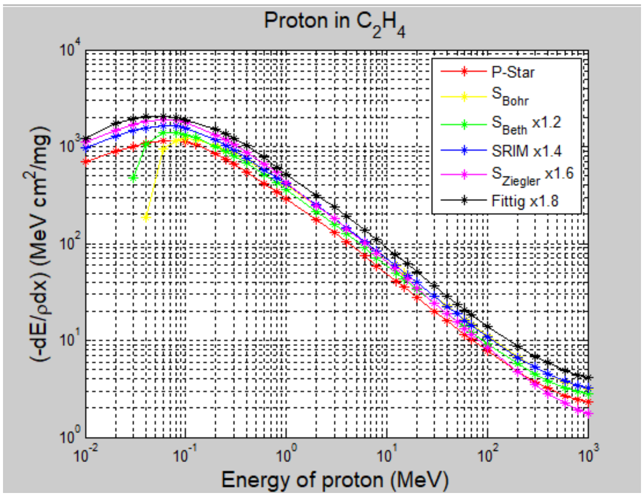

Fig.2: Show the mass Stopping Power and Energy for proton in the C_2H_4

Table 4: stopping power for proton in C_3H_8

E Mev	Bethe	Bohr	Ziegler	SRIM	PSTAR
0.01	-7394.17236	-16185.0636	782.9379406	0.7222	0.6902
0.02	-753.3008267	-3676.89449	1021.922707	0.9612	0.918
0.03	645.8167324	-729.2642169	1165.143048	1.097	1.061
0.04	1095.27289	369.3969848	1249.470113	1.175	1.153
0.06	1304.222829	1107.298857	1309.914295	1.234	1.242
0.08	1283.652256	1288.681476	1289.557663	1.221	1.252
0.1	1216.497343	1315.292191	1232.580559	1.172	1.22
0.125	1124.871562	1279.727984	904.9826275	1.013	1.153
0.2	902.7539726	1099.363286	790.4003036	0.8721	0.9379
0.25	798.0798735	993.2893582	703.6745175	0.7638	0.8222
0.3	716.743546	905.2430092	582.8317557	0.6809	0.7305
0.4	598.7384601	770.6830469	444.399894	0.5641	0.6006
0.6	456.6971633	600.0687379	364.9813182	0.4298	0.4542
0.8	373.1823598	496.0203202	283.2755383	0.3539	0.3712
1	317.598411	425.3786453	165.462615	0.3047	0.3163
2	188.5174422	257.2255066	119.2699007	0.1898	0.189
3	137.3689719	188.9920368	94.07191265	0.1382	0.1383
4	109.3052366	151.1409001	66.89718368	0.1099	0.1103
6	78.85249361	109.7059487	52.31163174	0.07931	0.07973
8	62.38731474	87.12995908	36.80716281	0.06276	0.06313
12.5	43.25805797	60.72688742	28.60027623	0.04501	0.04381
15	37.22565198	52.35668587	23.48784768	0.03552	0.03771
20	29.36687212	41.4159608	16.39396379	0.02955	0.02975
30	21.04431216	29.7780652	12.69852009	0.02117	0.02131

40	16.64574941	23.60170019	10.4220828	0.01674	0.01686
60	12.02529384	17.08953318	8.875789303	0.01209	0.01217
70	10.65255207	15.14873682	7.755601108	0.01071	0.01078
100	8.105717018	11.53796764	5.702290263	0.008142	0.0082
200	4.978473275	7.073131061	3.238802311	0.004993	0.005033
300	3.894906251	5.505120064	2.402128148	0.0039	0.003936
400	3.351188554	4.705484315	1.983181273	0.00335	0.003386
600	2.820128202	3.901256163	1.567820317	0.00281	0.002848
800	2.57175165	3.503379389	1.364470978	0.002555	0.002597
1000	2.43653494	3.269908066	1.245567338	0.002414	0.00246

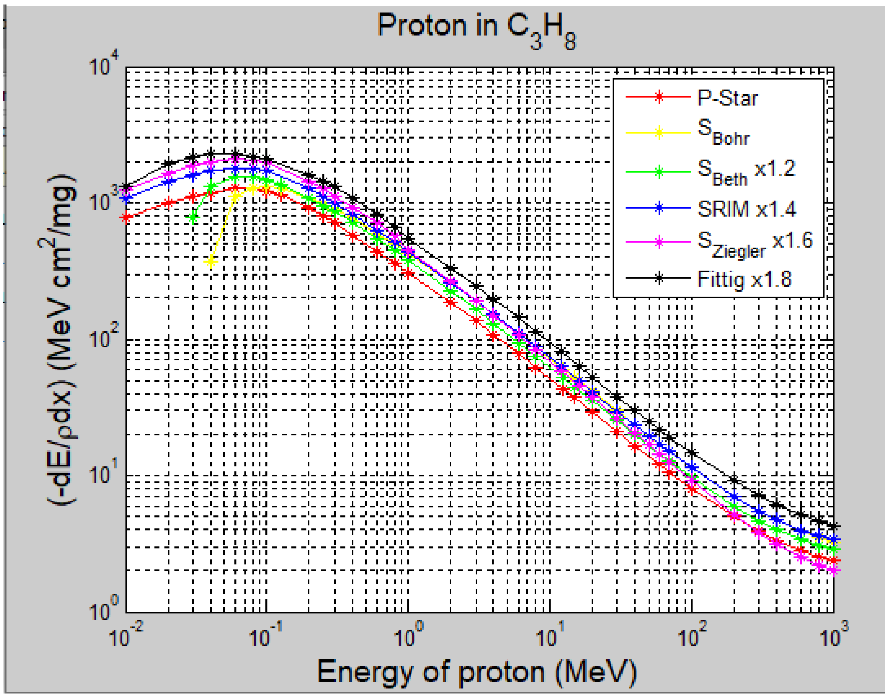

Fig.3: Show the mass Stopping Power and Energy for proton in the C_3H_8

Discussion and results

In Figures (1,2,3), the Bohr, Bethe and Ziegler equation was used to calculate the electronic stopping power of protons in the organic compounds CH_4, C_2H_4, and C_3H_8 and programmed in the Matlab program and compared the calculated results with the results of the SRIM2013 and PSTAR program.

The values of the electronic stopping power in the methane compound(CH_4) are presented in Table2. It was discovered that the most significant value of the stopping power calculated from the Bohr equation occurred at an energy of 0.08 MeV. In contrast, the Bethe and Ziegler equation produced the greatest stopping ability at an energy of 0.06 MeV.

The values of the electrical stopping power of several ethylene compounds(C_2H_4) are shown in Table 3. We discover that the Bohr equation has the most power to halt motion at an energy level of 0.1 MeV, Beth's equation has the greatest power to halt motion at an energy level of 0.08 MeV, and Ziegler's equation has the greatest power to halt motion at an energy level of 0.06 MeV.

The electronic stopping power in the propane compound (C_3H_8)is outlined in Table4, which presents the values. According to the Bohr equation, 0.1 MeV is the most excellent value assigned to the stopping power at energy. According to the Beth and Ziegler equation, the energy equivalent to 0.06 MeV has the most potential to halt motion.

In all the figures, it was seen that the power to stop-starts goes down as the energy goes up. This is because the energy loss is inversely proportional to the square of the particle's speed. Bohr's equation says that all forms with energies less than 0.04 MeV reach the cut-off limit. Regarding Beth's equation, the limit is less than 0.03 MeV.

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