STOPPING POWER CALCULATION OF PROTONS AND α–PARTICLES FOR C2H4 AND C6H6 IN ENERGY RANGE 0.01-1000 MEV

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Reception: 29/11/2022 **Acceptance**: 28/01/2023 **Publication**: 23/02/2023

Suggested citation:

H. A., Ebtehaj and O. K., Rashid. (2023). **Stopping Power Calculation of Protons and α–Particles for C2H4 and C6H6 in Energy Range 0.01-1000 MeV**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(1)*, 191-200. https://doi.org/10.17993/3ctecno.2023.v12n1e43.191-200

ABSTRACT

In this research, a theoretical study was conducted to calculate the total stopping power of some relativistic heavy ions (protons and alpha particles) during their passage through some media (ethylene and benzene) in the energy range (0.01-1000 MeV). The equations were programmed using MATLAB2021, the curve fitting tool was used, and the calculated results were compared with the experimental data of the P-Star and A-Star programs for the same missiles in those organic compounds.

KEYWORDS

Mass stopping power, Bethe formula, Relativistic heavy ions, MATLAB2021, P-Star, A-Star.

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https://doi.org/10.17993/3ctecno.2023.v12n1e43.191-200

INTRODUCTION

Nuclear and electronic stopping power are two categories of stopping power that measure the energy loss rate per unit distance in a material [1]. The mechanism of energy loss depends on the charge and velocity of the charged particle and the nature of the material medium [2]. When passing in the material medium, As is well known, charged particles lose some of their kinetic energy when colliding with the target matter. The continuous operation on the particle path in the medium causes charged particles to lose kinetic energy until they reach zero, at which point they lose all kinetic energy and reach the using Bethe equations. [3] It is denoted by the symbol -dEdx and is measured in MeV.cm^{-1}. The mass stopping power, -dEdx, is calculated by dividing the stopping power by the density of the material and is measured in MeV cm^2 g^{-1} [4]. Electromagnetic force causes an electron to lose energy in collisions with atomic electrons, resulting in excitation and ionization [5]. In an inelastic collision, atomic orbital electrons collide. This is so-called because it causes middle-atom excitations and ionizations (Collisional Stopping Power). In the case of the inelastic nuclear collisional, "Bremsstrahlung" radiation is produced, with a stopping power equal to (radiative stopping power) [6]. The overall stopping power of target materials is calculated when the product of inelastic collisions and excitation is proportional to the stopping power.Combining the collisional and radiative stopping powers produces the total stopping power:

$$\left(-\frac{dE}{dx}\right)_{\mathrm{tot}} = \left(-\frac{dE}{dx}\right)_{\mathrm{col}} + \left(-\frac{dE}{dx}\right)_{\mathrm{rad}} \quad (1)$$

THEORY

The stopping power of a medium is defined as the average unit of energy loss suffered by charge particles per unit path length in the medium under consideration, which can be written as (-dE/dx) depending on the projectile charge and the target matter. [5]. Mass collision-stopping power is widely used to reduce reliance on medium density (ρ). These studies were both theoretical and experimental, employing a variety of methods. [6]. For compounds, the Bragg additive rule has been found to be quite effective. According to the rule, The mass-stopping power of a multi-element substance is equal to the weighted sum of the mass-stopping power of its constituent atoms. [7].

$$\left(\frac{-dE}{\rho dx}\right)_{com} = \sum_i \omega_i \left(\frac{-dE}{\rho dx}\right)_i \quad (2)$$

Where ω_i: the ratio of the weight of the elements in the compound.

$$\omega_i = \frac{n_i A_i}{A_{comp}} \quad (3)$$

https://doi.org/10.17993/3ctecno.2023.v12n1e43.191-200

n_i : number of atoms. A_i: atomic mass of elements in medium, A_{comp}: atomic mass of medium, ρ: the density of the medium, ((-*dE*)/*ρdx*)_com: Mass stopping power of compound, $((-dE)/\rho dx)_i$: Mass-stopping power for the elements in the compound.

Because the radiative stopping power is efficient, increasing the energy at the incident -particle energies (10^0-10^3) MeV reduces the mass stopping power. [8].

$$-\frac{dE}{dx} = K\frac{Z_2 Z_1^2}{A\beta^2} L_{\text{Bethe}} \quad (4)$$

where,

$$L_{\text{Bethe}} = ln\left[\frac{2m_e c^2 \beta^2}{1-\beta^2}\right] - \beta^2 - ln < I > \quad (5)$$

$K = 0.307075\ MeV\,.\,cm^2/g$, Z_2 the atomic number of elements, Z_1 the atomic number of ions (projectile), A atomic mass of elements, β ratio of the velocity of a projectile to the speed of light, m_e Mass of electron, c speed of light, and I ionization potential of the medium in eV [9].

The stopping power is calculated by multiplying the stopping power multiplied by the linear attenuation coefficient for a given type of charged particle at a given energy. (, the probability of an electronic collision per unit distance traveled), as well as the average energy loss per collision (Qavg). [10].

$$-\frac{\mathrm{d}E}{\rho\mathrm{d}x} = \frac{\mu Q_{\text{avg}}}{\rho} = \frac{\mu}{\rho}\int_{Q_{min}}^{Q_{max}} QW(Q)\mathrm{d}Q \quad (6)$$

The maximum possible energy transfer (Qmax), or the energy transfer by head-on collision (2γ^2*m*v2), and the minimum possible energy transfer (Qmin), or the medium's mean excitation energy (I). [11].

Because it accounts for all possible atomic ionizations, as well as atomic excitations, an atom's mean The energy of excitation is always greater than the energy of ionization, whereas the atomic ionization energy is the energy required to remove the least bound atomic electron (i.e., valence electron in the outer shell) [12-13].

RESULTS AND DISCUSSION

The mass stopping power was calculated using the Bethe formula for two materials, ethylene C_2H_4 and benzene C_6H_6, with a proton and α-particle energy range from 10^{-2} MeV to 10^3 MeV. Using “MATLAB2021” program.

The table (1) show the stopping power values for protons and α-particle in ethylene and benzene. Figures (1,2,3,4) showed a strong agreement between the current work with P-Star and A-Star at all energies in target materials, as shown in table.3.

https://doi.org/10.17993/3ctecno.2023.v12n1e43.191-200

Table 1. Mass stopping power for proton and α-particle in ethylene C2H4 and benzene C6H6.

Energy (MeV)	Proton β^2	Proton v (m/sec)	Proton Mass Stopping Power (MeV cm²/g) C_2H_4	Proton Mass Stopping Power (MeV cm²/g) C_6H_6	α-particle β^2	α-particle v (m/sec)	α-particle Mass Stopping Power (MeV cm²/g) C_2H_4	α-particle Mass Stopping Power (MeV cm²/g) C_6H_6
0.01	0.000021	1384599.00	-7852.4	-8611.1	0.000005	694820.70	-304822.6	-306563.1
0.02	0.000043	1958103.04	-1076.8	-1619.4	0.000011	982622.87	-107151.2	-110612.7
0.03	0.000064	2398157.50	393.282	-32.006	0.000016	1203459.90	-53783.89	-57102.12
0.04	0.000085	2769131.64	886.274	533.449	0.000021	1389633.00	-30945.63	-33972.06
0.05	0.000106	3095958.56	1075.954	772.682	0.000027	1553653.81	-18928.33	-21683.17
0.06	0.000128	3391425.60	1146.474	879.440	0.000032	1701939.05	-11805.29	-14328.20
0.07	0.000149	3663129.05	1163.762	924.506	0.000038	1838300.58	-7242.972	-9570.128
0.08	0.000170	3916018.40	1155.540	938.330	0.000043	1965222.03	-4157.814	-6318.883
0.09	0.000192	4153531.58	1134.760	935.521	0.000048	2084428.54	-1986.755	-4005.564
0.1	0.000213	4378171.74	1107.924	923.647	0.000054	2197176.18	-412.133	-2307.846
0.2	0.000426	6191175.36	839.016	730.547	0.000107	3107213.86	4320.087	3113.057
0.3	0.000639	7582004.78	670.562	591.876	0.000161	3805467.69	4645.263	3739.487
0.4	0.000852	8754245.98	562.137	499.727	0.000215	4394087.21	4423.349	3690.215
0.5	0.001064	9786763.18	486.476	434.440	0.000268	4912640.04	4121.660	3501.760
0.6	0.001277	10720006.14	430.447	385.646	0.000322	5381419.30	3831.700	3292.375
0.7	0.001489	11578005.86	387.120	347.676	0.000375	5812480.28	3572.041	3093.279
0.8	0.001702	12376421.14	352.508	317.204	0.000429	6213677.83	3343.647	2912.233
0.9	0.001914	13126129.51	324.151	292.148	0.000483	6590468.06	3143.163	2749.883
1	0.002127	13835051.47	300.446	271.143	0.000536	6946823.60	2966.558	2604.714
2	0.004247	19550123.42	178.982	162.674	0.001072	9822317.05	1936.584	1729.670
3	0.006360	23924853.58	130.633	119.107	0.001607	12027414.67	1468.118	1320.013
4	0.008467	27604077.67	104.049	95.052	0.002142	13885271.85	1195.475	1078.973
5	0.010566	30837790.82	87.044	79.625	0.002677	15521087.77	1015.060	918.483
6	0.012659	33754316.50	75.153	68.817	0.003211	16999085.82	885.915	803.130
7	0.014746	36429950.03	66.331	60.788	0.003744	18357425.61	788.426	715.791
8	0.016826	38914444.53	59.505	54.569	0.004278	19620975.41	711.953	647.124
9	0.018899	41242388.30	54.055	49.598	0.004810	20807012.35	650.195	591.568
10	0.020966	43438986.55	49.593	45.526	0.005343	21928118.41	599.173	545.599
20	0.041280	60952149.63	28.066	25.835	0.010643	30949015.06	346.153	316.661
30	0.060967	74074752.06	20.126	18.551	0.015900	37829067.08	249.383	228.630
40	0.080055	84881964.82	15.926	14.693	0.021116	43594415.15	197.198	181.032
50	0.098566	94185858.35	13.308	12.285	0.026291	48643452.36	164.229	150.910
60	0.116525	102407122.21	11.512	10.632	0.031425	53180963.13	141.379	130.009
70	0.133952	109798179.81	10.200	9.424	0.036518	57328875.04	124.546	114.596
80	0.150868	116525142.64	9.197	8.500	0.041571	61166812.12	111.594	102.729

90	0.167293	122704532.11	8.406	7.771	0.046584	64750208.80	101.300	93.291
100	0.183247	128422011.09	7.764	7.179	0.051559	68119520.35	92.909	85.593
200	0.320379	169806066.13	4.772	4.418	0.099230	94502418.39	52.924	48.856
300	0.425665	195729016.46	3.734	3.460	0.143396	113602884.92	38.452	35.532
400	0.508253	213875689.79	3.214	2.979	0.184391	128822328.17	30.889	28.562
500	0.574229	227333673.23	2.905	2.694	0.222512	141513629.59	26.219	24.255
600	0.627766	237694985.92	2.705	2.509	0.258022	152387617.68	23.043	21.325
700	0.671805	245891097.08	2.567	2.382	0.291154	161875929.18	20.742	19.201
800	0.708467	252511435.02	2.467	2.290	0.322114	170265367.43	18.998	17.591
900	0.739312	257949799.09	2.394	2.222	0.351090	177758605.24	17.631	16.329
1000	0.765509	262480130.00	2.338	2.170	0.378247	184505413.74	16.532	15.314

Table 2. Rates of elements in ethylene C2H4, and benzene C6H6.

Target	C	H
C_2H_4	0.8563	0.1437
C_6H_6	0.9226	0.0774

Table 3. Correlation coefficient between positive calculations Bethe relative equation and values P-star for the proton and values A-star for α-particle.

Target	Proton	α-particle
C_2H_4	0.9745	0.9711
C_6H_6	0.9877	0.9823

https://doi.org/10.17993/3ctecno.2023.v12n1e43.191-200

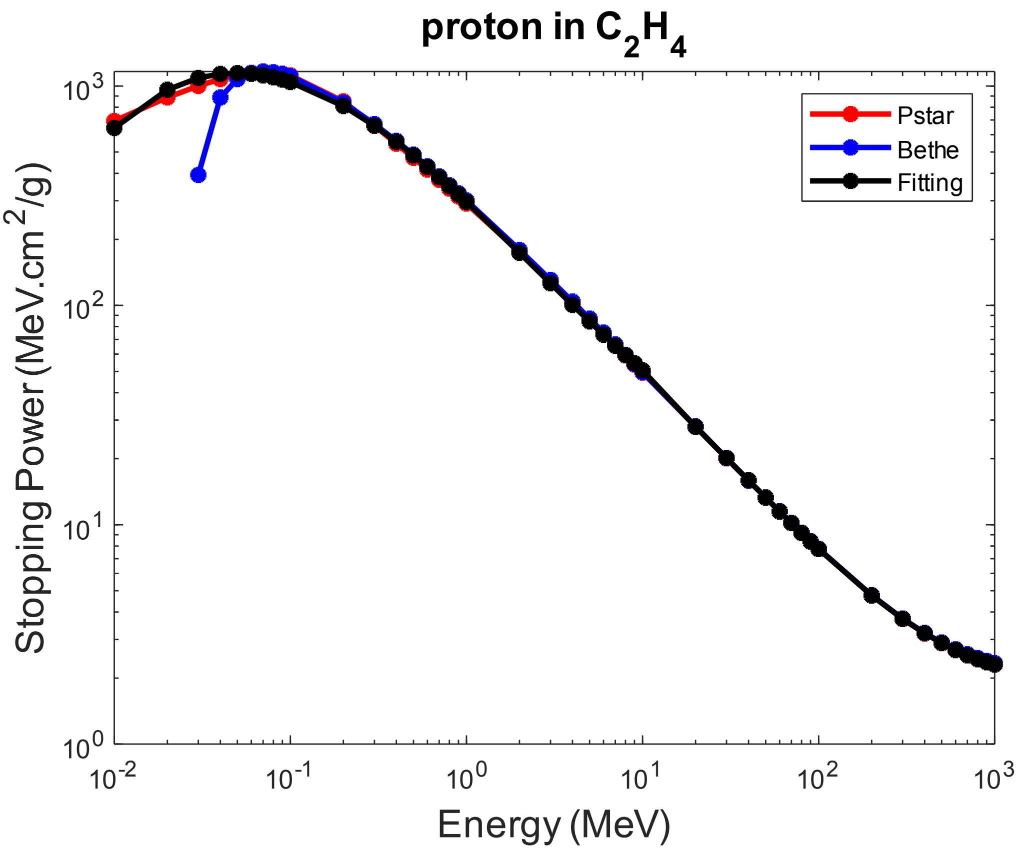

Figure 1. Show the P-Star mass stopping power in C2H4 as a function of proton energies

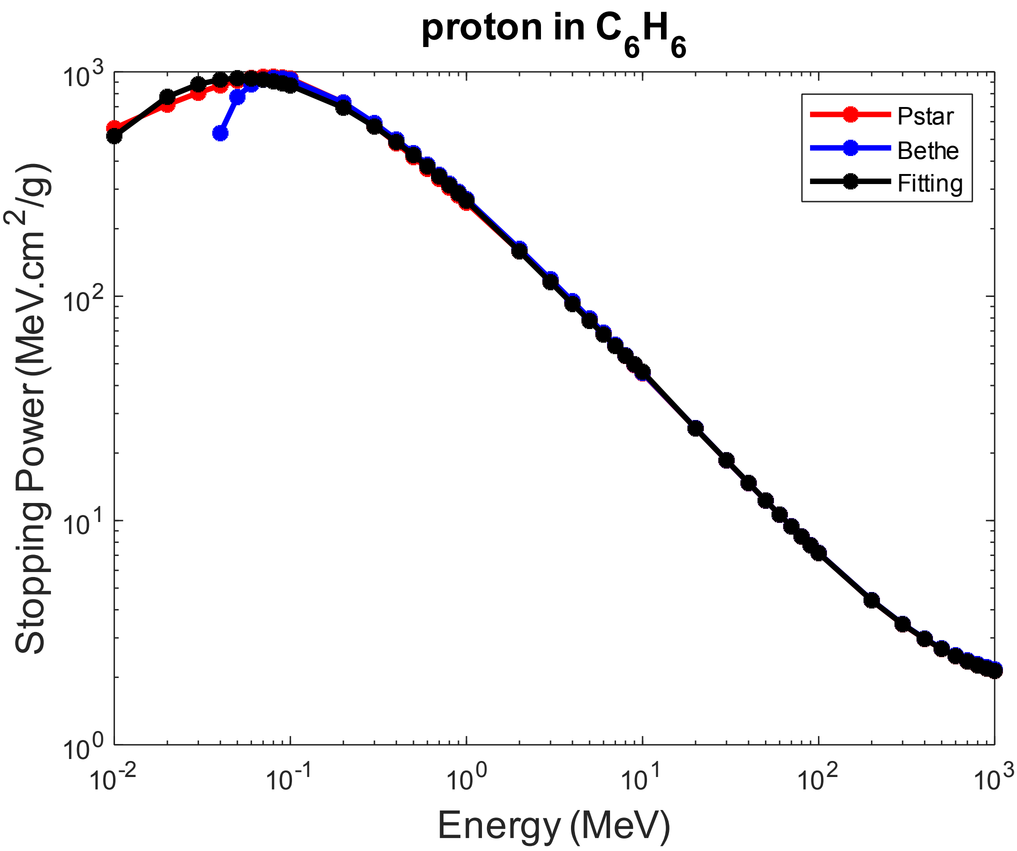

Figure 2. Show the P-Star mass stopping power in C6H6 as a function of proton energies.

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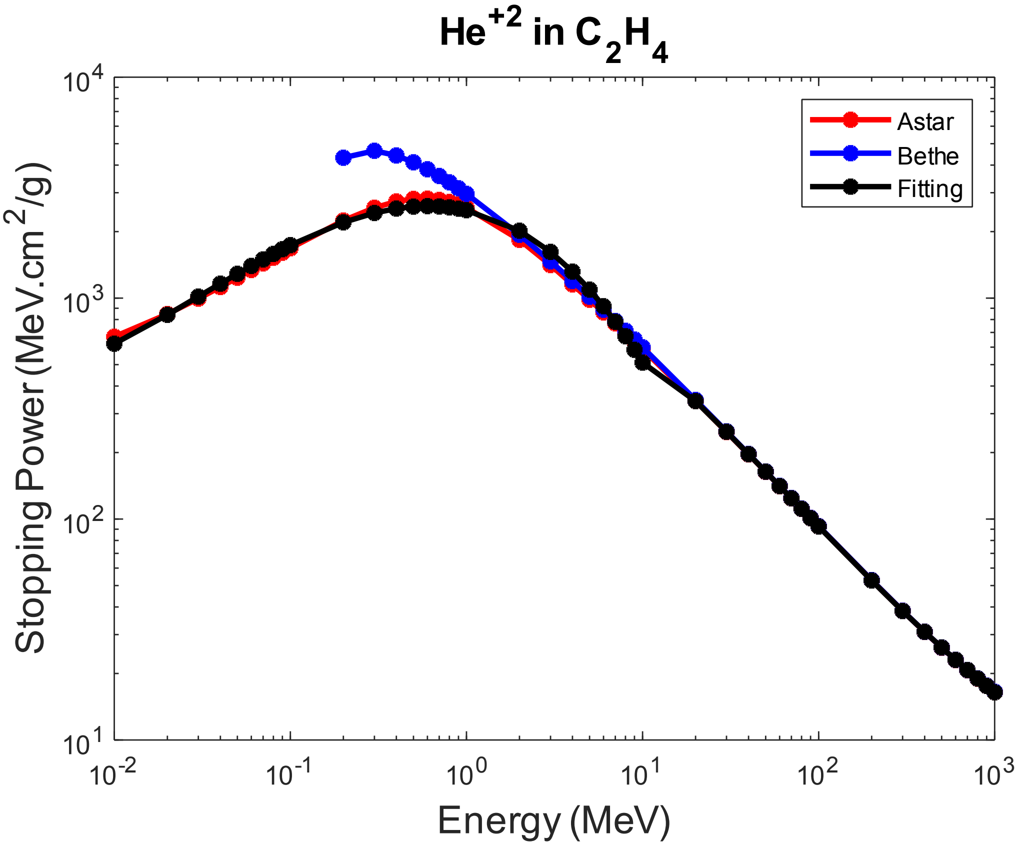

Figure 3. Show the A-Star mass stopping power in C2H4 as a function of -particle energies.

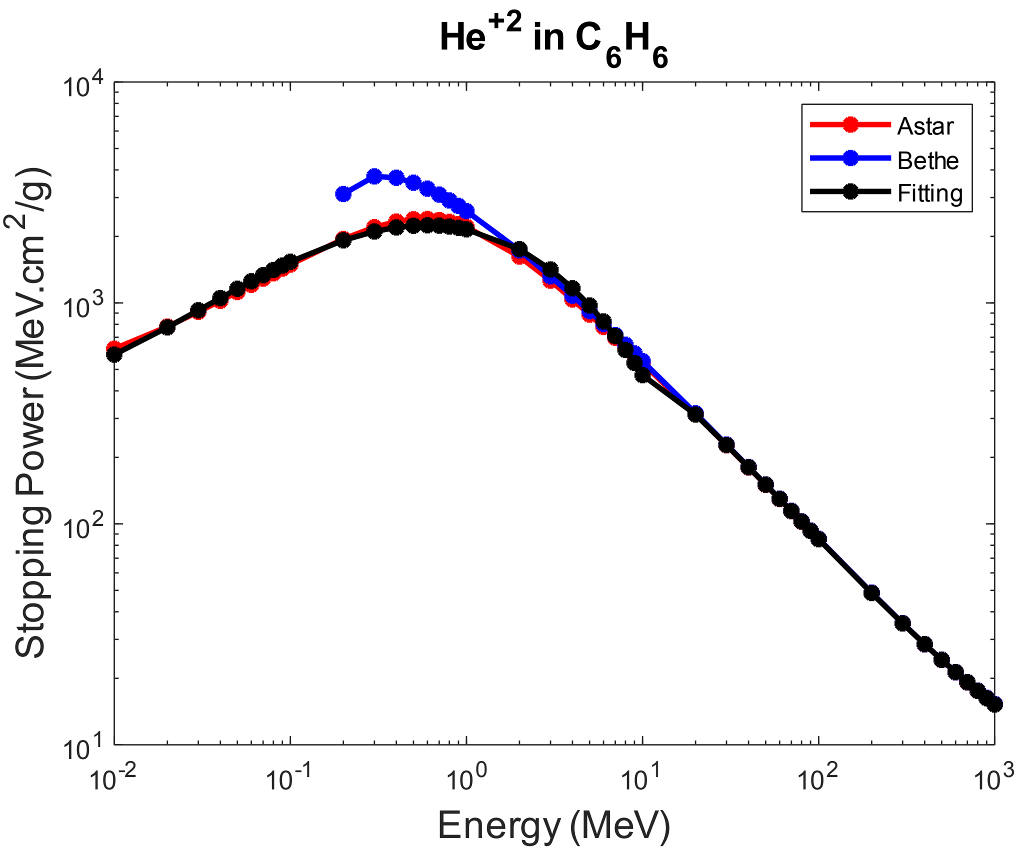

Figure 4. Show the work with A-Star mass stopping power in C6H6 as a function of α-particle energies.

https://doi.org/10.17993/3ctecno.2023.v12n1e43.191-200

CONCLUSIONS

1. The Bethe formula is adequate for regulating the mass-stopping power of the organic compounds investigated.
2. Calculations show that the mass-stopping power increases with increasing energy at incident proton energies (10^{-1}-10^{1}) MeV due to the collision-stopping power.
3. Because the radiative stopping power is efficient, the mass stopping power decreases as the energy at the energies of incident particles (10^{-1}-10^{3}) MeV increases.
4. Calculations show the mass-stopping power increases with increasing energy at incident-particle energies (10^{-2}-10^{0}) MeV because the collision-stopping power is the result.
5. Because the radiative stopping power is efficient, increasing the energy at the incident-particle energies (10^{0}-10^{3}) MeV reduces the mass stopping power.

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