Shell Correction Dependence of the Electronic Energy Loss of Protons and Carbon Ions in Collisions with Cobalt and Lead

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Abstract

In this research stopping power was calculated theoretically by using Bohr and Bethe theories. Protons and Carbon stopping power were calculated in Cobait ,Lead by using Bragg's Rule for compounds. The equations were programmed by using (MATLAB) language. The values of shell corrections, using kinetic theory of energy range (10-1000) MeV have been calculated. The calculations were compared with the practical results of the SRIM 2013 and there were some differences between practical and theoretical results .

Keywords: Shell Correction, Bohr theory, Bethe theory

1. Introduction

Fast charged particles passing through matter, ionize the atoms or molecules which they encounter, they lose their energy gradually in many small steps [1] [2]. Generally, ionizing radiation is divided into three groups :

1- Charged particles: electrons (e^-), positrons (e^+), protons (p), deuterons(D), alpha particles (α), and heavy ions (A > 4).
2- Photons: Gamma rays (γ) and x rays.
3- Neutrons (n).

Charged particle passing through neutral atoms interacts mainly by means of the coulomb force with the electrons in the atoms, Even though in each collision the particle loses on the average no more than few electron volts of kinetic energy ionization and excitation of atoms give the greatest energy loss per unit path length of the particle [3]

P. Sigmund, A. Schinner [4] studied the shell and correction in the stopping force on a point charge consists of two distinct contributions, a kinematic correction for the neglect of orbital motion and a mathematical correction for an asymptotic expansion limited to high projectile speed. The latter can be identified by separating Bloch's expression for the stopping number into the classical Bohr contribution and an inverse-Bloch correction. Awfa Zuhair Khudiar et al. [5] calculated the shell corrections in a self-consistent manner through analytic dispersion relations for the momentum dependence of the dielectric function, The shell correction prevents the stopping number L(v) from being negative at low velocity and corrects the assumption that the ion velocity is much larger than the target electron velocity. This emplies that for high-z materials, shell corrections may be non-negligble even at rather high projectile speed. K.A. Ahmad et al. [6] studied the shell correction of stopping power determined using kinetic theory of stopping, find our that the Bohr and Bethe shell correction are not equivalent. E. H. Abdullah [7] studied effect of the speed of the projectile on the ability of the stop electronic using the equation Port equation Beth is then calculated based on the impact of Parker in the velocities of the charged particles of heavy [protons, alpha particles and heavy ions (c, o)] falling on the objectives of the atomic (La, Sm, Er, Ta, Au, Pb, U).

Stopping power

The electronic energy loss (dE/dx) of a unitary charge particle with a velocity v [8] [9]

$$-\frac{dE}{dx}=\frac{4\pi z_2 e^4 z_1^2}{m_e v^2}L(v) \qquad (1)$$

Where z_1 and z_2 denote the atomic number of projectile and target respectively, v the projectile velocity and L(v) is stopping number ,m_e , e are the electron mass and charge. In general, the shell correction can be expressed as [10]

$$\left(-\frac{C}{Z_2}\right)=\ln\left(\frac{2m_e v^2}{\hbar w}\right)-L(v) \qquad (1-a)$$

In the system of kinetic theory the stopping number to Bethe L(v) can be written as [11]:

$$L(v)_{Bethe}=\ln\epsilon^{-1}-\frac{\langle v_2^2\rangle}{v^2}-\frac{\langle v_2^4\rangle}{2v^4}-\frac{\langle v_2^6\rangle}{3v^6} \qquad (2)$$

v_2 and v_1 are the target electron velocity and projectile velocity respectively.

Where ϵ is the energy variable

$$\epsilon=\frac{\hbar\, w}{2m_e v^2}$$

Then one find that

$$\langle\frac{v_2^2}{v^2}\rangle=3\epsilon$$
$$\langle\frac{v_2^4}{v^4}\rangle=5\epsilon^2 \qquad (3)$$
$$\langle\frac{v_2^6}{v^6}\rangle=7\epsilon^3$$

Then one find that

Applying values obtained in equ. (3) in equ. (2) we get

$$L(v)_{Bethe} = \ln \epsilon^{-1} - 3\epsilon - \frac{5}{2}\epsilon^2 - \frac{7}{3}\epsilon^3 \qquad (4)$$

applying equ. (4) into equ. (1-a) on can find the shell correction in Bethe formula:

$$(-\frac{C}{Z_2})_{Bethe} = \epsilon\left[3 + \epsilon\left(\frac{5}{2} + \frac{7}{2}\epsilon\right)\right] \qquad (5)$$

and

Bohr derived an expression for the stopping number cross section per target electron of a material [12]

$$L(v)_{Bohr} = \mathrm{Ln}\frac{1.1229\, m_e v^3}{z_1 e^2 w} \qquad (6)$$

And to calculate the stopping number to Bohr by using the kinetic theory

$$L(v)_{Bohr} = \mathrm{Ln}\left(\frac{1.1229\, m_e v^3}{z_1 e^2 w}\right) - \frac{3\epsilon}{2}\left[3 + \frac{5\epsilon}{2} + \frac{7\epsilon^2}{3}\right] \qquad (7)$$

Then by applying equ.(7) into equ. (1-a) on can write the shell correction in Bohr formula

$$\left(-\frac{C}{Z_2}\right)_{Bohr} = -\frac{3\epsilon}{2}\left[3 + \frac{5\epsilon}{2} + \frac{7\epsilon^2}{3}\right] \qquad (8)$$

2. Results and Discussion

Figure (1) represents the relationship between the calculated stopping power by shell correcting as a function of energy. The lead were projected to proton of (1) atomic number ,where the equation (4 and7) was programmed after compensating it with equation no.(1) . The Bohr stopping power was found by shell correcting giving values that are higher than those of the Bethe stopping power ,The value of Bethe stopping power is mostly closer to the practical results of the SRIM 2013 ,where the difference was slight from the beginning of the range and gradually decreased by increasing the velocity of the projectiles. It started to approach 20 MeV at the end of the range energy. However, the Bohr stopping power deviated from the practical results of the SRIM 2013 program, but it slowly approached as the used range is increased.

Figure (2) represents the relationship between the calculated stopping power by shell correcting as a function of energy. The cobalt was projected to proton of (1) atomic number ,where the equation no.(4 ,7) was programmed after compensating it with equation no.(1) The Bohr stopping power was found by shell correcting giving values that are higher than those of the Bethe stopping power.

It was noticed that it behaves in a way that is similar to that of the Lead when being projected by other protons ,but the Bohr stopping power started to deviate from that oh Bethe and the approach of Bethe stopping power and the practical results were more from the beginning of the used range to the end of it .

Figure (3) represents the relationship between the calculated stopping power by shell correcting as a function of energy. The lead was projected to carbon of (6) atomic number, where the equation (4 and 7) was programmed after compensating it with equation no.(1) . It was noticed that the Bethe stopping power is higher from Bohr stopping power at the beginning of the range and deviates from the practical results of the SRIM 2013. However.

At the 30MeV, the Bethe stopping power becomes less than Bohr , and started to notably and slowly approach the practical results of the SRIM 2013 as the used range increased.

Figure (4) represents the relationship between the calculated stopping power by shell correcting as a function of energy. The cobalt was projected to carbon of (6) atomic number, where the equation(4 and7) was programmed after compensating it with equation (1) .

We noticed that they behave in the same way in which the atoms of the lead behaved when sending carbon projectiles against them. However, the Bohr stopping power were closer to the practical results of the SRIM 2013 at the beginning of the 30MeV . After that, the Bethe stopping power were closer to the practical results to the extent of being identical.

The results are all shown in Table (1) and (2)

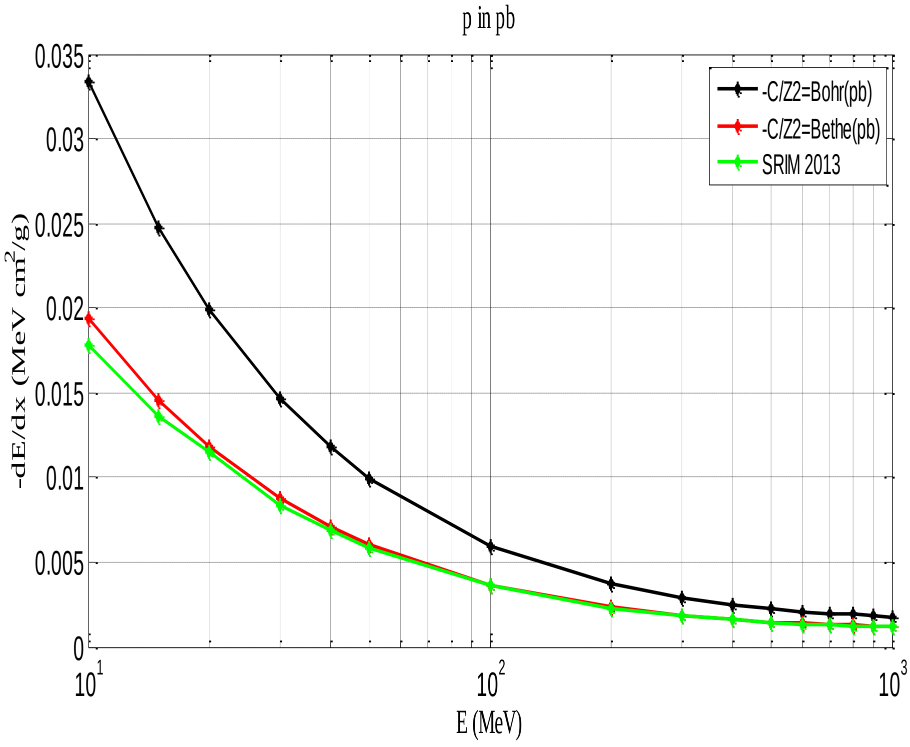

Fig.(1) stopping power for proton in (pb)

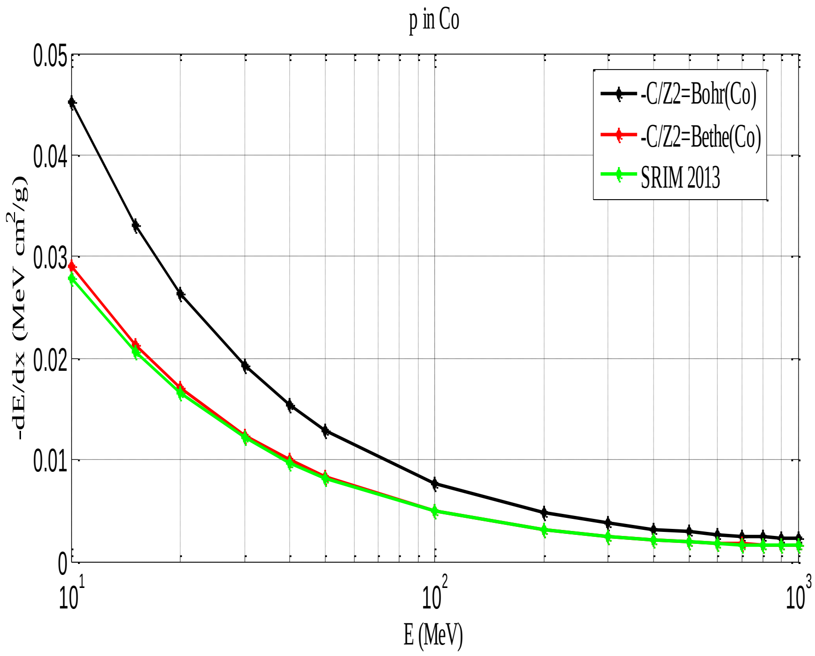

Fig.(2) stopping power for proton in (Co)

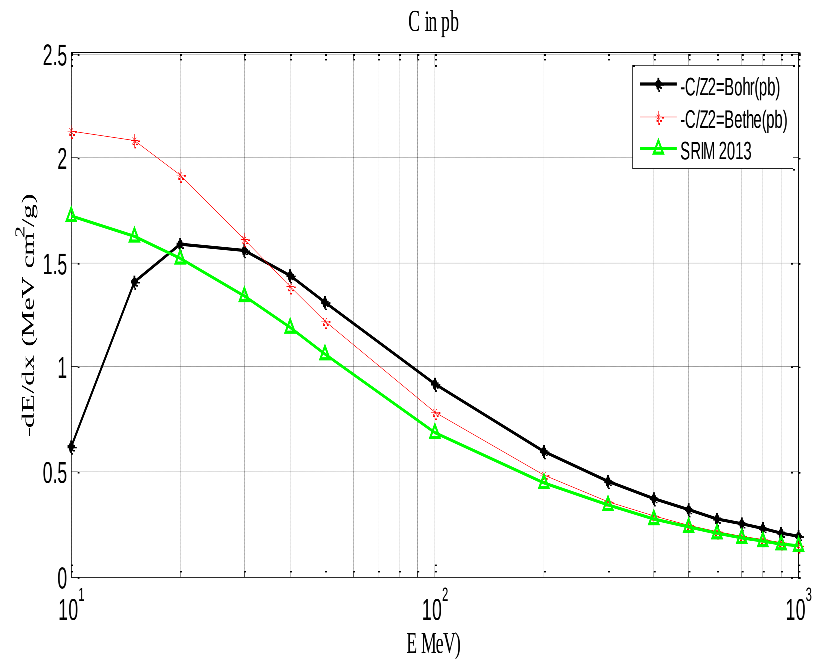

Fig.(3) stopping power for Carbon in (pb)

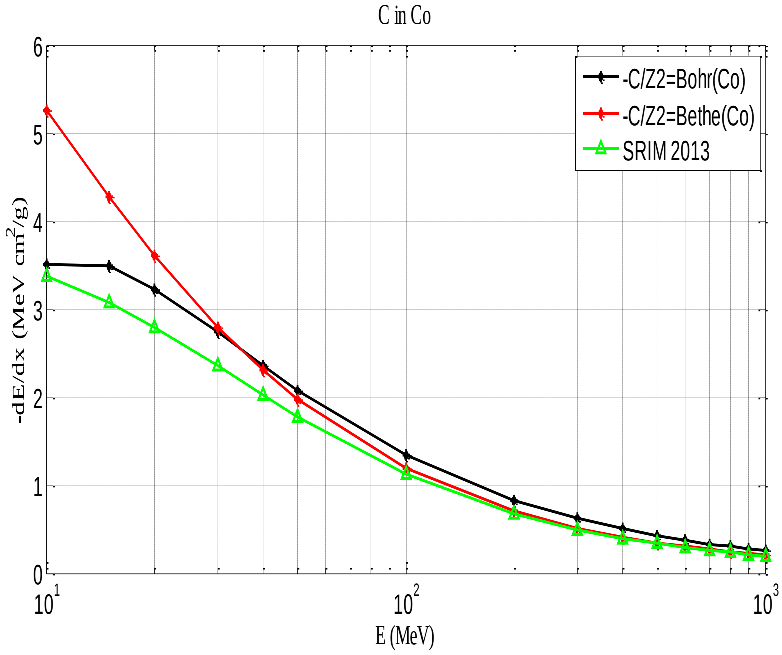

Fig.(4) stopping power for Carbon in (Co)

Table (1) Stopping power and SRIM 2013 results for proton in (Pb , Co)

E(MeV)	$-\frac{dE}{dX}$ (Pb) (MeV cm^2/g)			$-\frac{dE}{dX}$ (Co) (MeV cm^2/g)		
	Bohr	Bethe	SRIM 2013	Bohr	Bethe	SRIM 2013
10	0.0333	0.0193	0.01777	0.0451	0.0290	0.02781
15	0.0247	0.0145	0.01358	0.0330	0.0213	0.02058
20	0.0199	0.0118	0.0115	0.0264	0.0170	0.01656
30	0.0147	0.0088	0.008392	0.0192	0.0124	0.01216
40	0.0118	0.0071	0.006841	0.0154	0.0099	0.009756
50	0.010	0.0060	0.005835	0.0129	0.0084	0.008232
100	0.0060	0.0037	0.003587	0.0077	0.0050	0.004922
200	0.0037	0.0023	0.002291	0.0048	0.0031	0.003077
300	0.0029	0.0019	0.001825	0.0037	0.0025	0.002426
400	0.0025	0.0016	0.001588	0.0032	0.0021	0.002096
500	0.0023	0.0015	0.001448	0.0029	0.0019	0.001899
600	0.0021	0.0014	0.001356	0.0027	0.0018	0.001771
700	0.0020	0.0013	0.001294	0.0025	0.00178	0.001683
800	0.0019	0.001266	0.001249	0.0024	0.00172	0.001619
900	0.00182	0.001234	0.001217	0.0023	0.00169	0.001572
1000	0.00177	0.00121	0.001192	0.0022	0.0016	0.001536

Table (2) Stopping power and SRIM 2013 results for carbon in (Pb , Co)

E(MeV)	$-\frac{dE}{dX}$ (Pb) (MeV cm^2/g)			$-\frac{dE}{dX}$ (Co) (MeV cm^2/g)		
	Bohr	Bethe	SRIM 2013	Bohr	Bethe	SRIM 2013
10	0.6162	2.1318	1.720	3.5012	5.2551	3.367
15	1.4071	2.0862	1.623	3.4883	4.2741	3.071
20	1.5860	1.9190	1.519	3.22313	3.6166	2.787
30	1.5570	1.6132	1.342	2.7336	2.7987	2.355
40	1.4344	1.3883	1.188	2.3597	2.3063	2.029
50	1.3135	1.2218	1.060	2.0806	1.9744	1.779
100	0.9174	0.7858	0.6886	1.3438	1.1915	1.117
200	0.5934	0.4839	0.4450	0.8296	0.7029	0.6764
300	0.4509	0.3603	0.3441	0.6183	0.5135	0.4968
400	0.3692	0.2916	00.2765	0.5006	0.4108	0.3980
500	0.3157	0.2474	0.2354	0.4248	0.3457	0.3349
600	0.2777	0.2163	0.2063	0.3715	0.3005	0.2911
700	0.2492	0.1933	0.1847	0.3319	0.2672	0.2587
800	0.2269	0.1754	0.1678	0.3012	0.2416	0.2338
900	0.2091	0.1612	0.1543	0.2766	0.2212	0.2140
1000	0.1944	0.1495	0.1432	0.2565	0.2046	0.1978

3. Conclusions

1- The calculated values of the Bethe stopping power by shell correcting of the kinetic theory are close to the practical results of the SRIM 2013 at the (30-1000)MeV

2- the Bethe stopping formula for shell correcting is valid when calculating the stopping power at the used range in the research , and gives results near that of practical of the SRIM 2013

3- The stopping power slowly declines as the projectiles increase their velocity.

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الخلاصة

في هذا البحث تم حسب قدرة الايقاف نظريا بأستخدام نظرية بور وبيث. وحسبت قدرة الايقاف للبروتونات والكاربون في الرصاص والكوبلت بأستخدام قاعدة براك للمركبات. وبرمجت المعادلات بأستعمال لغة الماتلاب حيث حسب تصحيح القشرة بواسطة النظرية الحركية عند مدى الطاقة MeV(10−1000) . قورنت الحسابات مع النتائج العملية لبرنامج SRIM 2013 واظهرت بعض الاختلافات البسيطة بين النتائج النظرية والعملية.

الكلمات المفتاحية: تصحيح القشرة, نظرية بور ,نظرية بيث , قدرة الايقاف , النظرية الحركية