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Analytical Study of the Specific energy loss and radiation length X_0 of Positron for Chromium ${}^{52}_{24}Cr$

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Abstract:

We report in this research work the values of Specific energy losses which are the same as radiative S_{Rad} and collisional S_{Coll} stopping power ,total stopping power S_{Total} in additional to the radiation length X_0 of positron's β^+ for Chromium by employing Bethe-Bloch relativistic formula which are performed by writing all the related equations by MathCad2012with using the ionization potential I value for Chromium in the energy range of 0.1MeV-10MeV ,the results showing a that the collisional stopping power dominate more than radiative stopping power in the values of total stopping power which are in good agreement with Estar program results especially at the energies greater than 1.5MeV with respect to S_{Coll} .

Keywords: positrons Bethe-Bloch ,stopping power, radiative ,collision, mean excitation energy.

Introduction:

The Stopping Power (SP) of a medium for positrons are important in a wide of applications involving energy depositing. In radiation physics ,Chemistry ,biology and medicine , it is often important to have simple but accurate information about SP of different media for energetic positrons [1].Hence SP is defined as penetrating charged particle is the energy loss suffered by the particle per unit path length [2].The Study of (SP)of positron and electron through matter is an effective tool for exploring the structure of matter[2,3] . Chromium ${}^{52}_{24}Cr$ of the density 7.9 g/cm^3 and of melting point of 1867^{0}C[4].Here in this paper ,the stopping power calculations for β^+ are studied in two different ways : the first is to consider the interactions of incoming of the electron and positron with target electron , which is called collisional stopping power while the second is considered the fact that accelerated charged particles is radiated ,which is called radioactive stopping power or Bremsstrahlung(radiative) Loss which will discussed in next section in details .The total stopping power is given as following [5]:

$$S^{\pm}_{Total}(E) = S^{\pm}_{coll}(E) + S^{\pm}_{rad}(E) \quad \text{--------------(1)}$$

Where the signs (+) and (-) refers to positron and electron respectively. An extensively study [5-14] in the literatures ,Berger and Seltzer [6] had modified the Bethe –Heitler theory and introduced empirical corrections to calculate the mean energy loss by Bremsstrahlung .Btra[12] calculated the stopping power for positron with two parameter approximation and it is valid for positron energy between 1KeV-5000KeV ,besides its found that there a multiple scattering distribution which exhibits differences between β^- and β^+ . Jablonski et al [13] report an improved predictive formula for electron stopping power based on analysis and fit stopping power calculated from the optical data for 37 elements in energy range 200keVto 30keV. Zhenya et al [14] studied systematically the stopping power and mean free path in amino acids. The aim of this work is to use this Bethe-Bloch relativistic equation to obtain the positron Collisional and Radiative stopping power of tungsten which is of a huge importance in various applications.

Theoretical Basis

We will concern ourselves primarily with two types of interaction collisional and radiative and as following :

The Collisional Stopping Power S_{Coll}

The collisional stopping power is defined as inelastic collision with atomic electrons, this results in excitation or ionization these ultimately end with the heating of the absorber (through atomic and molecular vibrations) unless the ions and electrons can be separated using an electric field as done in radiation detectors . The collisional stopping power of Beta particles is different from the heavy charged particles because of two physical reasons : firstly, a electron can lose a large fraction of its energy in single collision with an atomic electron which has an equal masses ,secondly β^- particle is identical to the atomic electron with which it collides and β^+ is electrons antiparticle that in quantum mechanics , the identity of particles implies that one can not distinguishes experimentally between the incident and struck electron after collision .energy loss is defined in such a way that the electron of lower energy after collision is treated as struck particle unlike heavy charged particles, the identity of β^- particle and the relation of β^+ to atomic electrons imposes certain symmetry requirements that described their collisions with atom . The collisional stopping power of Beta particles can be written as the following [17]

$$-\left(\frac{dE}{dx}\right)^{\pm}_{coll} = \frac{4\pi k^2 e^4}{mc^2\beta^2}\left[\ln\frac{mc^2\tau\sqrt{\tau+2}}{I\sqrt{2}} + F^{\pm}(\beta)\right] \text{----------------(2)}$$

Where

For positron

$$F^{+}(\beta^{+}) = \ln 2 - \frac{\beta^2}{24}\left[23 + \frac{14}{\tau+2} + \frac{10}{(\tau+2)^2} + \frac{4}{(\tau+2)^3}\right] \text{--------------- (3)}$$

Equations (3) is a dimensionless functions depending on the kinetic energy T in MeV of the incident electron and the atomic number Z of the stopping medium and

$\tau = T/mc^2$ is the kinetic energy of for β^+ expressed in multiples of electron rest mass energy mc^2 and the other symbols in equation (2) are defined as following:

v = velocity of particle.
c = speed of light in vacuum .
E= energy of the incident particle .
x= distance traveled by the particle in material.
I= mean excitation potential of target material.
k = Coulomb constant .
n= electron density of material which can be calculated by the equation[17]:
$n = N_A Z \rho / A M_u$--------------------(4)

Where N_A is Avogadro's number , ρ density of target material and M_u is the molar mass constant . In the equation (2) after substitution the above values , we obtain a more simplified formula [11].

$$\left(-\frac{dE}{dx}\right)^{\pm}_{Coll}=\frac{5.08\times10^{-31}n}{\beta^2}\left[\ln\frac{3.61\times10^{5}\tau\sqrt{\tau+2}}{I}+F^{\pm}(\beta)\right] \text{---------} (5)$$

Where(–dE) is the energy increment lost in the infinitesimal material thickness of dx .Hence higher stopping power means shorter range in material that the particle can penetrate . The stopping power is proportional inversely with the incident particle velocity and ionization energy .In the other hand , the mass stopping power of a material is obtained by dividing the stopping power by density .Common units for mass stopping power –dE/ρdx are MeV .g^{-1}.cm^{2} .The mass stopping power is a useful quantity because it expresses the rate of energy loss of charged particle per g.cm^{-2} of the medium traversed.

The Radiative Stopping Power S_{rad}

It is defined as inelastic collision with nucleus a quanta of electromagnetic radiation is emitted (a photon) energy loss is experienced by particle .important for electrons probability of nuclear excitation is negligible ,this process is known as radiative energy loss .The acceleration of electron near a nucleus is known as beam braking or Bremsstrahlung. Bethe and Heitler obtained an approximate relation between the collisional S_{Coll} and radioactive S_{Rad} stopping powers by the relation [7].

$$S^{\pm}_{Rad}=S^{\pm}_{Coll}\left(\frac{TZ}{800}\right) \text{------------------------------}(6)$$

Where Z is the atomic number of the target atom and T is the energy of the incident positron or electron in MeV. By combining the equations (1) and (10) we get [5]:

$$S^{\pm}_{Total}=S^{\pm}_{Coll}\left(1+\frac{TZ}{800}\right) \text{------------------------} (7)$$

The mean excitation energy I

The mean excitation energies I for a number of electrons has been calculated from the quantum mechanics definition that obtained in derivation of Bethe formula, the following approximates empirical formula can be used to estimate I values in eV for element with atomic number Z [1]:

$I= 52.8+ 8.71\ Z \qquad Z > 13$-------------------(8)

Here we had employed the mean ionization energy because the value of I is different for different electronic shells, so we take into consideration in the present calculations ,the mean value which is given in eq.(8).

Radiation Length X_0:

Radiation length can be defined as the thickness of a material that an electron travels such that it loses 1-1/e. Radiation length is an extensively quoted quantity since it relates the physical dimension of the material (such as its depth) to a property of radiation (such as its rate of energy loss)[9]. It is almost universally represented by the symbol X_0. The used semi-empirical relation to calculate the X_0 of positrons in any material is given by[16]:

$$X_0\approx\left(\frac{T}{S_{Rad}(T)}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(9)$$

The dimensions of X_0 are g/cm^2.

Results and Discussion:

The results here has been calculated by using the computer program Mathcad 2012 for tungsten in the energy range between 0.1MeVto 10MeV.The positron during transmission gradually lose their kinetic energy and finally undergo an annihilation process with atomic electrons. The probability of annihilation falls off rapidly with increase of the positron velocity .The positron behavior during penetration throughout matter is the same as electron behavior in regard to loss of energy , but the absorption of positrons in a medium important for checking the phenomena of annihilation which causes the difference between the stopping powers both electrons and positrons . That is the biggest difference between e^- and e^+ is the annihilation radiation which could be produced when positrons are present in matter. The resulting 0.511 MeV photons are very penetrating compared with the range of positrons and can lead to the deposition of energy far from the original positron track.

Figure (1)and table 1, shows the numerical results of the present work with that of Estar program ,the collisional stopping power as a function of the projectiles incident energy ,the maximum values is equals to 3.0334MeV-cm^2/g at kinetic energy 0.1MeV which is greatest than radiative stopping power for the same kinetic energy , the S_{Coll} values decreases till 1.37MeV-cm^2/g at T=3.5MeV.In the same figure, the discrepancy between the present work and Estar approximately at the energy T=1.5MeV . However the deviation is not too large which may be due to adopting various ionization relation of present work (eq.8) with that dependent in Estar program calculations . If we analyzing the radiative stopping power figure (2) and table 2 it is illustrates the values of S_{Rad} increasing this two situation can be explained that the nuclear braking begin due to the incident positrons approaches the nuclear field of the target atoms thus suffering from columbic repulsion , the result is the decelerating of β^+ . In the same table , the results shows that X_0 proportional to the values of incident energy T, which reflects the fact that more dense the material, the shorter the “radiation (attenuation) length” due a tremendous of interaction with high Z element in comparison to low Z. In table 3, figure 3 the total stopping power which has the same behavior of the S_{Coll} in figure (2) which we can conclude that for S_{Total} values , the S_{Rad} has a little contribution due to that we had used low and moderate electron energies.

Conclusions

1- The present calculations indicates to that the S_{Total} decreases with increasing particle incident energies and this energy depends upon the particle velocity which limit the type of interactions with target . In other words, a slower projectile spends more time in the proximity of the target, hence has a higher probability of interaction, while a swift particle(more energetic) can sweep through the target or its potential field without being affected much.

2- With increasing particle incident energies , S_{Rad} values increasing due to the positrons reaches the nuclear field (charge decelerating)and production of Bremsstrahlung ray .

3-The most interactions of the incident positrons of low energy with the valence electrons of Tungsten is the radiative while of higher energies is collisional of both type hard and soft .

4- The S_{Total} values mostly produced from the collisional stopping power S_{Coll} especially at lower energies and S_{Rad} had a little impact .

5- The S_{Total} values sensitive to particle incident energies and atomic number Z of the target.

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Table (1) : The comparison of the present work collisional and Estar stopping power values for Chromium.

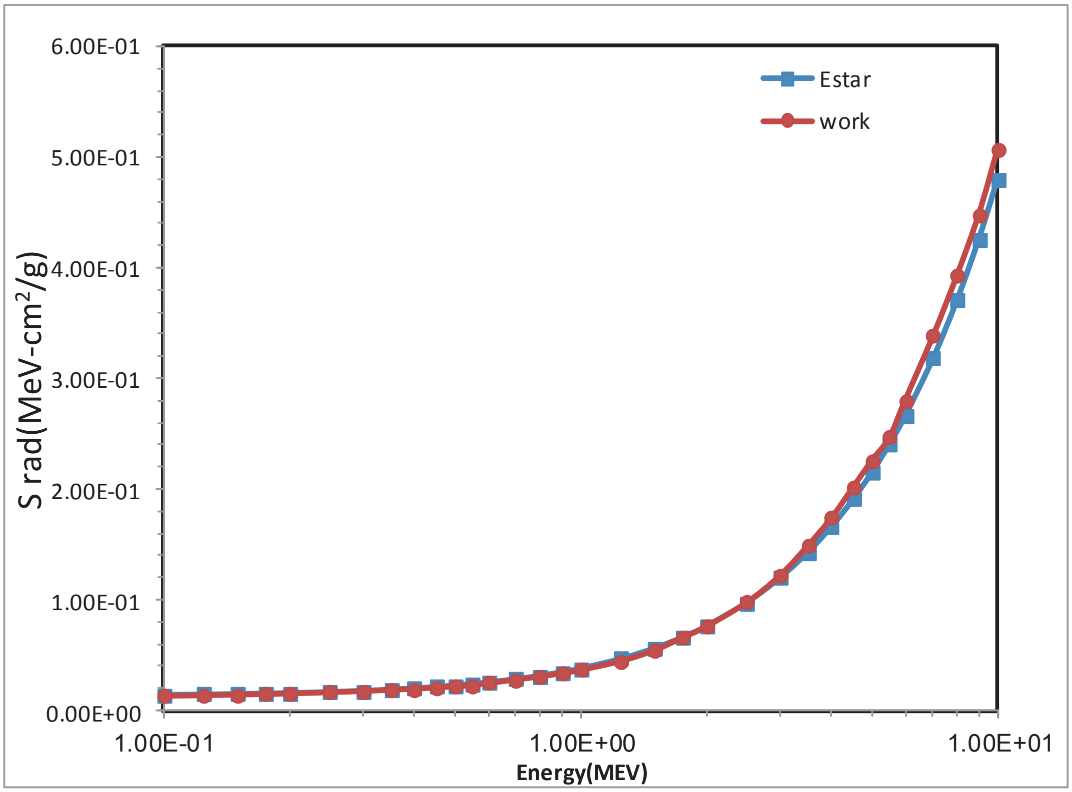
Electron energy T(MeV)	S_{Coll} Estar (MeV-cm^2/g)	S_{Coll} present work (MeV-cm^2/g)
0.1	2.83E+00	3.0334
0.125	2.48E+00	2.6419
0.15	2.24E+00	2.3768
0.175	2.07E+00	2.1862
0.20	1.95E+00	2.0432
0.25	1.77E+00	1.8449
0.30	1.65E+00	1.7159
0.35	1.57E+00	1.6271
0.4	1.51E+00	1.5636
0.45	1.46E+00	1.5169
0.5	1.43E+00	1.4818
0.55	1.40E+00	1.4552
0.6	1.38E+00	1.4348
0.7	1.35E+00	1.4069
0.8	1.34E+00	1.3905
0.9	1.32E+00	1.3814
1.0	1.32E+00	1.3771
1.25	1.31E+00	1.3782
1.5	1.31E+00	1.3879
1.75	1.32E+00	1.4012
2.00	1.32E+00	1.4159
2.5	1.34E+00	1.446
3.00	1.35E+00	1.4746
3.50	1.37E+00	1.501
4.0	1.38E+00	1.5252
4.50	1.40E+00	1.5474
5.0	1.41E+00	1.5678
5.5	1.42E+00	1.5867
6.0	1.43E+00	1.6042
7.0	1.45E+00	1.6358
8.0	1.46E+00	1.6637
9.0	1.47E+00	1.6885
10	1.49E+00	1.7109

Table (2) : The comparison of the present work Radiative and Estar stopping power values for Chromium.

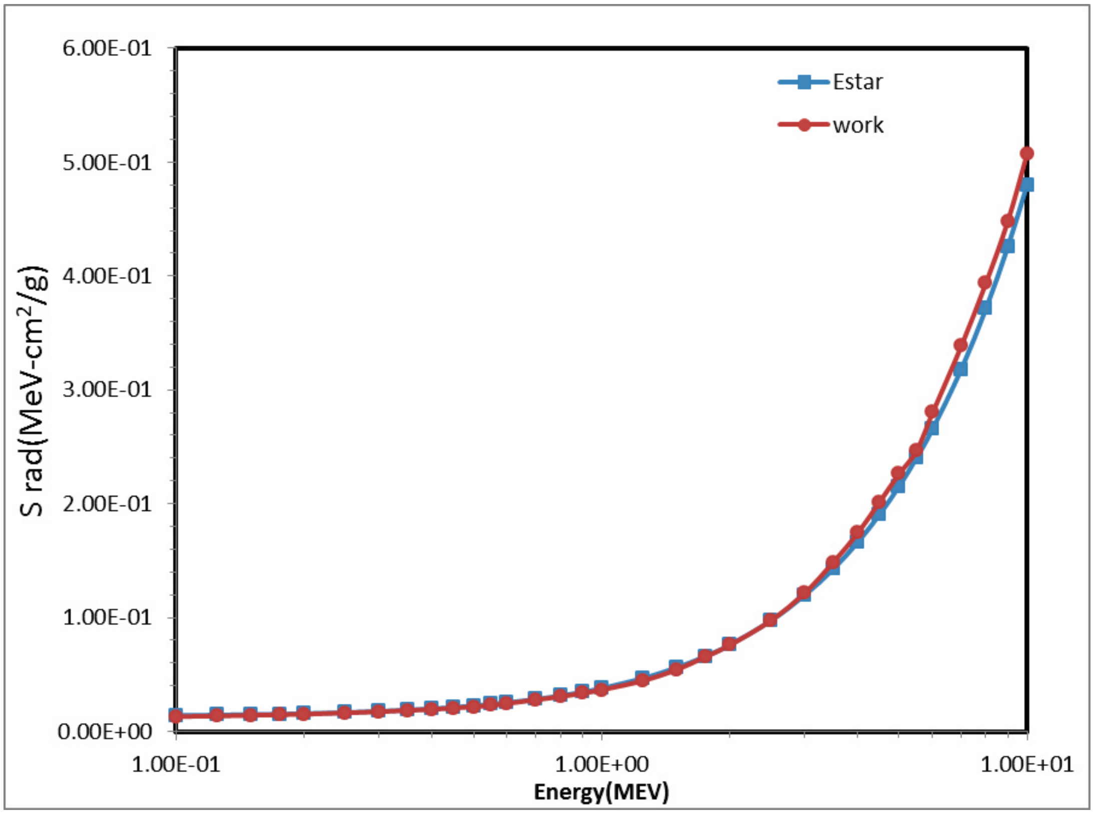
Electron energy T(MeV)	S_{Rad} -Estar (MeV-cm^2/g)	$S_{Rad.}$ – present work (MeV-cm^2/g)	X_0 (g/cm^2)
0.1	1.41E-02	0.0131	7.63358
0.125	1.45E-02	0.0136	9.191176
0.15	1.49E-02	0.0142	10.56338
0.175	1.53E-02	0.0147	11.904
0.20	1.57E-02	0.0152	13.1578
0.25	1.67E-02	0.0163	15.3374
0.30	1.77E-02	0.0174	17.24138
0.35	1.88E-02	0.0185	18.9189
0.4	2.00E-02	0.0195	20.51282
0.45	2.13E-02	0.0206	21.84466
0.5	2.26E-02	0.0217	23.0414
0.55	2.40E-02	0.0228	24.1228
0.6	2.54E-02	0.0246	24.390
0.7	2.83E-02	0.0278	25.1798
0.8	3.14E-02	0.0306	26.1438
0.9	3.46E-02	0.0335	26.8656
1.0	3.79E-02	0.0365	27.3972
1.25	4.67E-02	0.0446	28.0269
1.5	5.61E-02	0.0542	27.6752
1.75	6.59E-02	0.0655	26.71755
2.00	7.61E-02	0.0758	26.38522
2.5	9.74E-02	0.0975	25.6410
3.00	1.20E-01	0.1215	24.69135
3.50	1.43E-01	0.1485	23.569
4.0	1.66E-01	0.1743	22.9489
4.50	1.91E-01	0.2016	22.32142
5.00	2.15E-01	0.2262	22.1043
5.5	2.41E-01	0.2467	22.2942
6.0	2.66E-01	0.2803	21.4056
7.00	3.18E-01	0.3385	200.6794
8.00	3.71E-01	0.3938	20.3143
9.00	4.25E-01	0.4478	20.09825
10	4.80E-01	0.5075	19.704433

Table (3) : The comparison of the total stopping power values of present work and Estar for Chromium

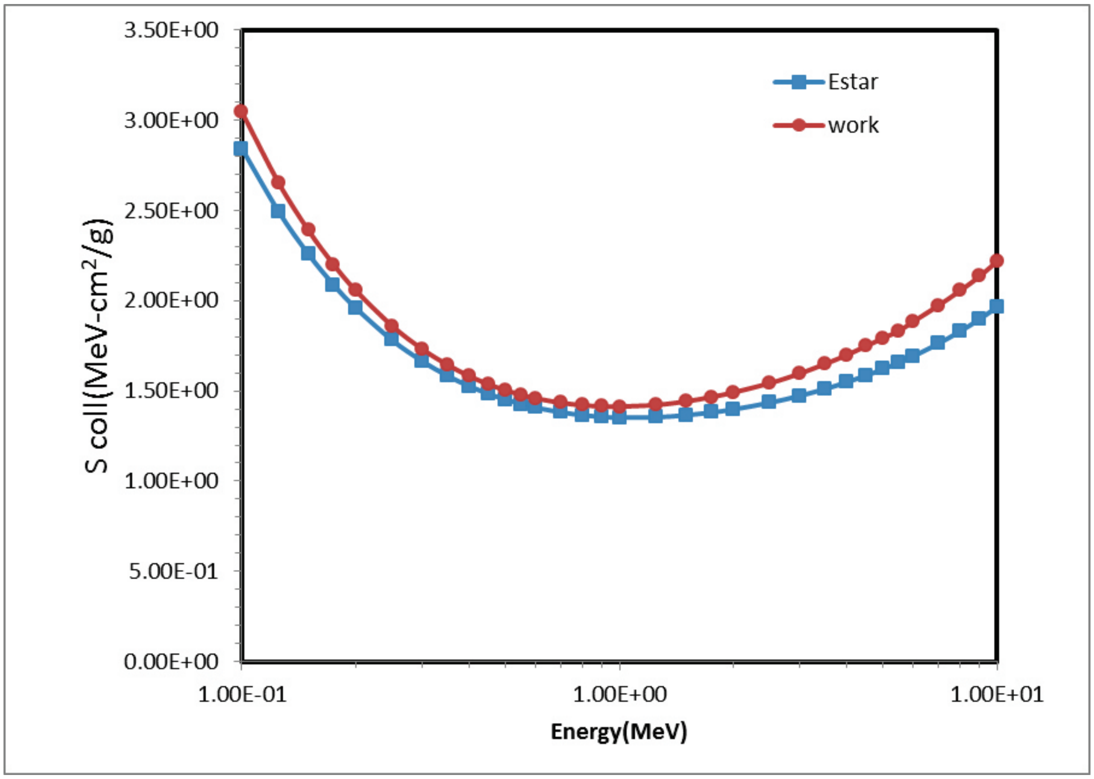
Electron energy T(MeV)	S_{Total} Estar (MeV-cm^2/g)	S_{Total} present work (MeV-cm^2/g)
0.1	2.84E+00	3.0465
0.125	2.50E+00	2.6555
0.15	2.26E+00	2.391
0.175	2.09E+00	2.2009
0.20	1.96E+00	2.0584
0.25	1.78E+00	1.8612
0.30	1.67E+00	1.7333
0.35	1.59E+00	1.6456
0.4	1.53E+00	1.5831
0.45	1.48E+00	1.5375
0.5	1.45E+00	1.5035
0.55	1.43E+00	1.478
0.6	1.41E+00	1.4594
0.7	1.38E+00	1.4347
0.8	1.37E+00	1.4211
0.9	1.36E+00	1.4149
1.0	1.35E+00	1.4136
1.25	1.36E+00	1.4228
1.5	1.37E+00	1.4421
1.75	1.38E+00	1.4667
2.00	1.40E+00	1.4917
2.5	1.44E+00	1.5435
3.00	1.47E+00	1.5961
3.50	1.51E+00	1.6495
4.0	1.55E+00	1.6995
4.50	1.59E+00	1.749
5.00	1.62E+00	1.794
5.5	1.66E+00	1.8334
6.0	1.69E+00	1.8845
7.00	1.76E+00	1.9743
8.00	1.83E+00	2.0575
9.00	1.90E+00	2.1363
10	1.97E+00	2.2184



Fig(2):The collisional stopping power for Chromium .



Fig(3): The radiative stopping power for Chromium**.**



Fig(4): Comparison of The total stopping power of present work and Estar for Chromium

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