



CALCULATIONS OF STOPPING POWER AND RANGE OF ALPHA PARTICLES OF SEVERAL ENERGIES IN DIFFERENT MATERIALS

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Abstract

In the present work we compared some new constants for the empirical relation of stopping powers of alpha particles in the energy range $4 - 15\text{Mev}/amu$ for elements Al,Cu,Ge,Ag and Au obtained from calculation of empirical formula and measurements of stopping and range of ions in matter (SRIM-2000). The range formulas were obtained by directly integrating the stopping power formula of alpha particles and the values of the ranges for the elements are calculated and compared with SRIM-2000. The alpha energy losses have been obtained from calculation for the elements source using alpha particle target; such losses are deviated significantly from SRIM-2000 result. The deviation suggested that the stopping powers and range given from SRIM-2000 is too small. These relations have been also used to find out stopping powers and ranges in semiconductors.

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Introduction

Over the years, the study of the interaction of fast heavy ions with matter has evolved into a large research field due to new powerful experimental methods and facilities around the world. The interaction of fast heavy ions with matter is a unique method to investigate the processes in complex atomic systems, which play a very important role in the development of modern physics. [12]

In particular, the simplicity of empirical relations allows a broader class of researchers to calculate useful properties, and often trends become more evident.

In this thesis we have presented empirical relation for the study of slowing down process of fast heavy ion (He) in side matter. A knowledge of the Stopping power and range energy relationship for heavy charged particles has been a subject which has received great theoretical and experimental interest. In the modified proposed empirical relation only the values of the constants “a” and “b” of the previous empirical formula is changed, thereby the computation of the stopping power and range becomes trivial; and the results reveals are comparable to (SRIM-2000)

The most updated stopping powers and range in different media have been comprehensively available in the soft ware for stopping and range of ions in matter (SRIM-2000).

In conclusion, the main results of the work are resumed in chapter 6 and some suggestions for further energy loss investigations are proposed.

Chapter 1

INTERACTION OF ALPHA PARTICLES WITH MATTER

1.1 Nature of interaction

Heavy charged particles, such as the alpha particle, interact with matter primarily through Coulombs forces between their positive charge and the negative charge of the orbital electrons with in the absorber atoms.

The interaction of α particle with matter depends on the following[18].

- the type of energy of radiation.
- nature of absorbing medium.

1.2 Interaction of heavy ions with matter

The presented chapter is an overview of the research on the interaction of fast heavy ions with matter. A general survey of the most important theoretical and experimental

investigations of this field of science is summarized.

A significant part of the chapter is given to the attention to atomic processes between projectile ions and target atoms during their interaction. These processes are responsible for the slowing down of heavy ions in matter. Charged particles interact with electrons and nuclei via coulomb interaction. These particles move at high speed. For example an α - particles move with 1Mev kinetic energy is moving with a speed of $6.9 \times 10^6 m/s$.

The number of ion pairs per unit volume or per unit length on the path produced by an α - particle is very high. Multiple ionization also takes place. In this ionization process, secondary electrons are also produced by primary electrons.

Due to coulomb interaction, α - particles may excite an electron to higher energy state. Ionization and excitation break chemical bond and generate reactive species the cause for further chemical reactions.

1.3 Historical review

The penetration of charged particles through matter is one of the principal ways to investigate nature. The charged particles lose their energy during the passage through the medium in collisions with target atoms. The theory of the slowing down process is complicated because of a difficult description of the ion and target charge states during the stopping process. The greatest scientists of the last century have worked on the subject of interaction of heavy ions with matter, charged-particle penetration in matter. In 1900 Marie Curie found that energetic particles having left radioactive materials could penetrate thin foils. Than further experiments on the interaction of α -particles with different gases gave rise to the discovery of the energy deposition maximum, the so called Bragg peak. The first theoretical treatment about scattering of electrically charged particles was published by J.J.Thomson in his book on electricity [10]. This work did not demonstrate

directly the calculations of the energy loss, but the author was interested in the problem of charged particle stopping. In 1911 Rutherford published his famous discovery about the atomic structure [2]. He started to investigate the penetration of α -rays in matter. Niels Bohr continued the validity of Rutherfords investigations. His work in 1913 was the first sufficient theory on the energy loss of ions passing through matter [3]. Bohrs classical approach for the electronic stopping power served as a basis for the quantum mechanical description of the stopping problem. The discovery of the nuclear fission gave the possibility for a detailed investigation of the penetration of high speed particles through matter [6]. Bohr and Lindhard understood the difficulty to describe collisions between interacting particles. They connected the energy loss of fission ions along stopping path with the capture and loss of electrons by such particles [19]. Bohr also recognized that the study of the stopping process is limited by knowledge of the ion charge state inside matter, which is estimated by the balance between electron capture and loss processes. In the 1920s with the discovery of quantum mechanics, Bohrs classical stopping model showed inconsistencies to describe the atomic phenomena because the energy transfer occurs in discrete quantities. Hans Bethe used Bohrs approximation and recreated the classical result in the quantum-mechanical treatment [7]. His calculations are valid for relativistic energies [8]. Later Felix Bloch investigated the classical and quantum-mechanical approaches and found conditions in which these theories could be used. Bloch made corrections to Bethes model and got the formula, which is valid for Bethes result as well as for Bohrs [9]. The Bohr-Bethe-Bloch formula is a unique instrument to estimate the energy loss process of projectiles. However, this theory was modified due to further development of physics. Some features of projectile ions and target atoms such as energy region of incident particles, type of ions, target density and many other can significantly change the ion energy loss in matter. Therefore, several corrections to the basic stopping formula were applied.

1.4 ENERGY LOSS MECHANISM

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 effect is to decrease its velocity continuously until the particle is stopped.

1.4.1 ALPHA PARTICLES

Matter is made up of atoms. Each atom consists of a nucleus and some orbiting electrons with the exception of hydrogen atom. In the case of hydrogen atom there is only one orbiting electron. When a fast moving α - particle penetrates matter, the major interaction is the collision between the α - particle and the orbiting electron. Very rarely an α - particle will collide 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 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 an α - particle has a head on collision with an electron. We can assume the velocity of the orbiting electron is negligible to the velocity V of the incident α - particle. After the collision the electron moves with a velocity U and the α - particle moves with the velocity V' [11]. Using conservation of energy and momentum for the elastic collision for the electron and α - particle we get

Conservation of kinetic energy

$$\frac{1}{2}MV^2 = \frac{1}{2}MV'^2 + \frac{1}{2}mu^2 \quad (1.4.1)$$

Conservation of momentum

$$MV = MV' + mU \quad (1.4.2)$$

where m and M are the mass of the electron and α - particle. By solving equations (1.4.1) and (1.4.2) we get

$$V' = \frac{(M - m)V}{M + m} \quad (1.4.3)$$

Therefore, the energy lost (E) by an α - particle in a single collision with an electron is

$$E = \frac{1}{2}MV^2 - \frac{1}{2}MV'^2 = \frac{1}{2}MV^2 - \frac{1}{2}M \left[\frac{(M - m)V}{M + m} \right]^2 \quad (1.4.4)$$

That is

$$E = E_\alpha \left[\frac{4mM}{(M + m)^2} \right] \quad (1.4.5)$$

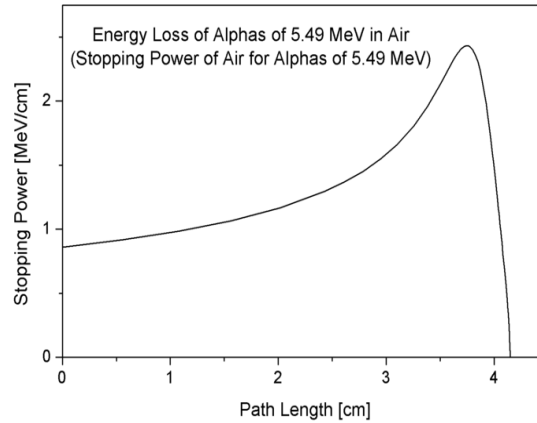
where E_α is the energy of the incident α - particles.

Energy lost by an α - particle in a single collision is very small. However the energy gained by the orbiting electron is often more than the binding energy of the atom and is therefore removed from the atom. The interacting atom is said to be ionized due to this α - particle electron collision.

α - particle can transfer only a small fraction of its energy in a single collision with an electron. thus heavy charged particles

- travel almost in straight lines.
- lose energy almost continuously in small amounts.
- have very small range.

1.4.2 The Bragg curve



A curve showing average number of ions per unit distance along (or a specific ionization) a beam of mono-energetic ionizing particles, usually α - particles passing through a gas. Also known as Bragg ionization curve. The general appearance of the heavy particle Bragg curve can be explained from principles developed in chapter 2. The increase in ionization near the end of the path occurs because the ionization loss is inversely related to the square of the particles speed. Thus ionization density rises as the particle slows, of course, the ionization must drop to zero when the energy of the incident particles has been dissipated and near the end of the track, the charge is reduced through electron pick up and the curve falls off.

For most of the α - particles track, the charge on the α is two electron charges, and the rate of energy loss increases roughly as $1/E$ as predicted by the equation of stopping power.

Chapter 2

STOPPING POWER

2.1 Stopping Power definition

When fast ion passes through matter, it loss energy principally by scattering electrons with in the matter it passes through and more importantly at low energies, by scattering from the nuclei of the atoms. The energy loss by an α - particle per unit distance is an important term in radiation physics. It enables us to determine the energy absorbed by interacting or stopping medium which is important to find out the damage done to medium. The linear rate of energy loss is also used to determine the range of alphas in the given medium. This quantity is denoted by $-dE/dx$ or commonly known as the stopping power of the medium for alphas. Stopping power refer to the property of the material while energy loss per unit length describes what happens to the particles. But numerical values and unit are identical for both quantities.

2.2 Linear Energy Transfer

Another measure of energy deposited in an absorber by a charged particle is the Linear Energy Transfer (LET). The LET is the average energy locally deposited in an absorber resulting from a charged particle per unit distance of travel (keV/cm). The LET is

therefore a measure of the local concentration of energy per path length resulting from ionization effects.

This quantity can be calculated by considering the coulomb interaction (KZb^2/r^2) acting on the electron due to the rapidly passing α - particle. This results in a net force being produced in a direction normal to the direction of motion of the α - particle. This net force causes the electron to accelerate for a short time towards the alpha path. The final result is the orbiting electron pulled away (most cases) from its atom and gained sufficient kinetic energy to move away. From conservation of energy the α - particle would have lost that much energy.

2.3 Calculations of Stopping Power

2.3.1 N.Bohr's Formula for energy loss of α - particle in matter

The baseline for all theoretical approaches of the stopping process in matter was Bohrs work [3]. He characterized ion-atom collisions by impact parameter on the basis of classical mechanics. Bohr treated the collisional process as binary process, at which the projectile ion interacts with a target electron assumed to be free at the moment. The distance from the electron to the initial travel of the projectile ion, which is far from the electron, was defined as the impact parameter (b) [12]. The non relativistic formula that Bohr obtained gave the correct features of stopping power. He derived the formula based on the following assumptions.

- for maximum energy transfer the collision is head on.
- mass of α - particle is much greater than mass of electron.

- the velocity of electron in its orbit is much smaller than the velocity of heavy ion.
- the energy loss may be consider classically, because if $P_i \times b \gg \hbar$ this domain is classical physics domain. but $P_i \times b \approx \hbar$ uncertainty principle comes in to play. For such cases the formula has to be modified.
- the binding energy of electron in side the atom is very low as compared to the energy of incoming particle so that the electron can be treated as free.
- energy loss per collision of incoming particle is so small that its velocity after the collision may be taken the same.

The Bohr formula for heavy particle is given by

$$\frac{-dE}{dx} = \frac{4\pi n z^2 K_o^2 e^4}{m_o V^2} \ln \left(\frac{2m_o V^2}{I} \right) \quad (2.3.1)$$

where

z = charge of incoming particle.

n = number of electrons per unit volume in the stopping material.

m_o = rest mass of electron.

V = the velocity of the particle.

e = electron charge.

$K_o = 1/4\pi\epsilon_o$

I = mean excitation energy of the medium and is normally treated as an experimentally

determined parameter for each element.

2.3.2 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 Born approximation [7]. He used the momentum transfer rather than impact parameter to characterize collisions [12]. Bethe-Bloch expression for the stopping power of a heavy charged particle derived using relativistic quantum mechanics is given by

$$\frac{-dE}{dx} = \frac{4\pi n z^2 K_o^2 e^4}{m_o V^2} \left[\ln \frac{2m_o V^2}{I} - \ln \left(1 - \frac{V^2}{C^2}\right) - \frac{V^2}{C^2} \right] \quad (2.3.2)$$

The formula shows dependence of dE/dx on the velocity of the particle but $\ln \left(\frac{2m_o V^2}{I}\right)$ gives almost no variation or negligible change on V .

For α - particles having an energy $< 10 \text{ Mev}$, the velocity (V) is less than 2.3% of the speed of light. Consequently, the V^2/C^2 term in the above equation are negligible, and can be ignored. The above equation is a seemingly simple equation that identifies the dependence of the stopping power on the charge and velocity of the charged particle, and on the atomic density and charge per atom in the absorber.

2.4 Mass Stopping Power

The mass stopping power of a material is obtained by dividing the stopping power by the density (ρ). Common unit for mass stopping power ($\frac{-dE}{\rho dx}$) are $MeVcm^2g^{-1}$. The mass stopping power is a useful quantity because it expresses the rate of energy loss of charged particle gcm^{-2} of the medium traversed. In a gas, for example, $(-dE/dx)$ depends on pressure, but $\frac{-dE}{\rho dx}$ does not, because dividing by the density exactly compensates for the pressure.

Mass stopping power does not differ greatly for materials with similar atomic composition. Generally, heavy atoms are less efficient on a g/cm^2 basis for slowing down heavy charged particles, because many of their electrons are too tightly bound in the inner shells to participate effectively in the absorption of energy.

2.5 Energy Straggling

Energy loss in a material is a statistical or stochastic process. Therefore, a spread of energies always results when an initially mono energetic beam of particles encounters an absorber. Many particles lose the "average energy", although some will lose not so much and some will lose more than the average. This results in a finite width to the energy distribution curve known as "energy straggling".

Energy straggling is the broadening of the distribution of kinetic energies in a beam of initially mono energetic charged particles due to statistical nature of energy deposition process as the particles pass through the material. The straggling peak is approximately Gaussian shaped, with a width that increases with the ratio Z/A , in other words at lower atomic numbers.

2.6 Energy Loss Minima

For particles with speeds less than about $0.6C$ the relativistic terms involving V/C nearly cancel and can be ignored. Because the $1/V^2$ factor varies more rapidly with V than $\ln\left(\frac{2m_0V^2}{I}\right)$, the rate of energy loss $-dE/dx$ at first decreases with increasing energy approximately as $1/E$. As V approaches C , the relativistic term become of greater importance and the rate of energy loss then begins to increase with increasing energy; The minimum rate of energy for α - particles is 4 times greater than for singly charged particles because $-dE/dx$ is proportional to the square of the particle's charge [14]

Chapter 3

Range Energy Relations

3.1 Definition of Range

In passing through matter, charged particles ionize and thus loss energy in many steps, until their energy is (almost) zero. Because coulomb force has infinite range, the particle interacts simultaneously with many electrons and thus loss energy gradually but continuously along its path. After traveling a certain distance, it has lost all of its energy; this distance is called the range of the particle. Therefore for heavy particles like alpha, the range is the average distance traveled before a particle has lost all of its original kinetic energy [15].

The range of charged particle is computed by numerical integration of the stopping power.

The range R is continuous slowing down approximation (*csda*) is given by

$$R = \int_0^R dx = \int_{T_o}^0 \frac{-dE}{\frac{-dE}{dx}} = \int_{T_1}^{T_o} \frac{dE}{S} = \int_{T_o}^{T_1} \frac{dE}{S} + R_1(T_1) \quad (3.1.1)$$

where

dx = the path length variable of integration.

S = the stopping power.

T_o = the initial kinetic energy of the charged particles

T_1 = some lower limit of energy below which the calculations can not be performed because of poor knowledge of the stopping power.

The last part of the path length is usually not accurately calculated when an analytical expression is used for the stopping power. Most such expressions are inaccurate at low energies. Because of this, a finite lower limit can be utilized, and $R_1(T_1)$ can be estimated from experimental results. The range is expressed in g/cm^2 ; this is the range in cm multiplied by the density of the substance.

3.2 Factors Which Affect Range (R)

Energy: Range is approximately linear with energy since Bethe-Bloch equation for stopping power is inversely proportional to E .

Mass: for the same kinetic energy, the electron is much faster than the alpha due to its smaller mass, and therefore the electron has less time to spend near orbital electrons. This reduces the effect of coulomb interactions (hence stopping power) and increases range.

Charge: The more charge, the more stopping power and lower range. Range is inversely proportional to the square of the charged particle.

Density: stopping power increases with increasing density. The range is inversely proportional to the density of the absorbing medium.

3.3 Range Straggling

The statistical distribution of the range in which a charged particle travels while losing its kinetic energy in an absorbing medium. That is for uniform, same energy particles, after passing through a distance dx in any element energy is changing to $T - dT$ but intensity (number of particles) remains the same.

When number of particles (N_o) falls to $N_o/2$ the thickness x is called experimental mean range(R). Around the mean range there is a distribution of range. The tangent drawn at

the mean range point gives extrapolated (R_{ex}) range. The phenomena due to which it is happening is called straggling. Around the zero point energy of heavy ion straggling takes place, that is number of collision required to have same energy loss are not same or also in one collision energy loss is not same.

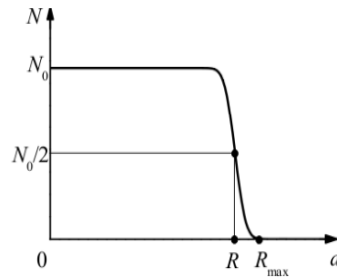


Figure 3.1: A diagram showing number of particles left versus depth in to an absorber

Chapter 4

Empirical Relation For Stopping Power and Range of α - particle

4.1 Empirical Relation For Stopping Power

Empirical relation for the stopping power of proton [16] is given by

$$\left(\frac{-dE}{\rho dx}\right) = \frac{a}{A} E^{-b} Z^{c \log E + d} \quad (4.1.1)$$

The appropriate values of the constants a,b,c, and d are $a = 915.0$, $b = 0.85$, $c = 0.145$, $d = 0.635$. Here ρ , A and Z denote the density, atomic weight and atomic number of the stopping material while E is the kinetic energy of the α particle in Mev/amu . The stopping power for the ions heavier than proton can be found by the expression given by Pierce and Blann (Which is mass stopping power).

$$\left(\frac{-dE}{\rho dx}\right)_H = \frac{Z_{eff}^2}{\gamma_p^2} \left(\frac{-dE}{\rho dx}\right)_p \quad (4.1.2)$$

where

$$Z_{eff}^2 = \gamma^2 Z^2$$

Here we are concerned with the energy $1Mev$ and above,for protons, $\gamma_p = 1$, substituting

equation (4.1.1) in to equation (4.1.2) we get

$$\left(\frac{-dE}{\rho dx}\right)_H = \frac{\gamma^2 z^2}{A} a E^{-b} Z^{c \log E+d} \quad (4.1.3)$$

For the calculation of the stopping power of α - particle from equation (4.1.3) we assumed that above $4Mev$ the fractional effective charge of the α - particle is $\gamma^2 = 1$. Below $4Mev$ that is, for $1Mev/amu$, we have fitted Northcliffe Schilling (NS) data for α - particles by the least square method keeping c and d constant and got $a = 3574, b = 0.84$, therefore for $1Mev/amu$ of α - particles equation (4.1.1) is modified as

$$\left(\frac{-dE}{\rho dx}\right) = \frac{3574}{A} E^{-0.84} Z^{c \log E+d} \quad (4.1.4)$$

Above $1Mev/amu$ we can use equation (4.1.3) by simply putting $z = 2$ and $\gamma = 1$.

4.2 Present Empirical Relation for stopping power

Present empirical relation for stopping power of alpha particle is obtained by changing the constants a and b in equation (4.1.1), that is $a=918$, and $b=0.82$ and it is given by

$$\left(\frac{-dE}{\rho dx}\right)_H = \frac{\gamma^2 z^2}{A} 918 E^{-0.82} Z^{c \log E+d} \quad (4.2.1)$$

4.3 Range

The range of a charged particle is computed by numerical integration of the stopping power. The range R in the continuous slowing down approximation [16] is given as

$$R = \int_{E_{min}}^{E_{max}} \left(\frac{-dE}{\rho dx}\right)^{-1} dE + R(E_{min}) \quad (4.3.1)$$

where $R(E_{min})$ is the measured range at energy E_{min} which is added to the integral equation (4.2.1) and treated as a constant for a particular particle and material.

The range of α - particle for $1Mev/amu$ can be calculated from the integration of equation (4.1.1)

$$R_{\alpha} = m_{\alpha} \left[\frac{A}{1.84 \times 3574 \times Z^{0.635} \left(1 - \frac{0.145 \log Z}{1.84}\right)} \right] \times \left[E^{1.84} Z^{-0.145 \log E} - E_2^{1.84} Z^{-0.145 \log E_2} \right] + R_2(E_2) \quad (4.3.2)$$

or

$$R_{\alpha} = m_{\alpha} G_{\alpha} E^{1.84} Z^{-0.145 \log E} + F_{\alpha} \quad (4.3.3)$$

where $F_{\alpha} = R_2(E_2) - m_{\alpha} G_{\alpha} E_2^{1.84} Z^{-0.145 \log E_2}$

Here G_{α} is equal to the factor inside the first bracket of equation (4.3.2) and F_{α} is the correction term obtained from equation (4.3.2). $R_2(E_2)$ must be the known range of α - particles at $0.7Mev/amu$ or $(0.75Mev/amu)$. At the cost of a little accuracy equation (4.3.3) may be used directly for calculating particle ranges between $1Mev/amu$ to $12Mev/amu$, otherwise above $4Mev$ the range can be obtained using equation for range of proton that is,

$$R(p) = m_p G_p E^{1.85} Z^{-0.145 \log E} + F_p \quad (4.3.4)$$

where $G_p = \left[\frac{A}{915 \times 1.85 \times Z^{0.635} \left(1 - \frac{0.145 \log Z}{1.85}\right)} \right]$
 $F_p = R_1(E_1) - m_p G_p E_1^{1.85} Z^{-0.145 \log E_1}$

and the range of other heavier particles of energy $E_1(Mev)$ greater than β_i where $\beta_i = 0.04z_i^{2/3}$ can be calculated from the proton ranges; that is,

$$R_i(E_i, z_i, m_i) = R_i(E_{ci}, z_i, m_i) + \frac{m_i/m_p}{z_i^2} \times \left[R_p\left(\frac{E_i m_p}{m_i}\right) - R_p\left(\frac{E_{ci} m_p}{m_i}\right) \right] \quad (4.3.5)$$

Now putting equation (4.3.4) in to equation (4.3.5) we get

$$R_\alpha = \frac{G_p m_\alpha}{z^2} \times \left[E^{1.85} Z^{-0.145 \log E} - E_2^{1.85} Z^{-0.145 \log E_2} \right] + R_2(E_2) \quad (4.3.6)$$

letting

$$F_{\alpha\alpha} = R_2(E_2) - \frac{G_p m_\alpha}{z^2} E_2^{1.85} Z^{-0.145 \log E_2} \quad (4.3.7)$$

we get

$$R_\alpha = \frac{G_p m_\alpha}{z^2} E^{1.85} Z^{-0.145 \log E} + F_{\alpha\alpha} \quad (4.3.8)$$

4.4 Present Empirical relation for range

Present Empirical relation for range of alpha particle is given by

$$R_\alpha = \frac{G_p m_\alpha}{z^2} E^{1.82} Z^{-0.145 \log E} + F_{\alpha\alpha} \quad (4.4.1)$$

Where

$$G_p = \left[\frac{A}{918 \times 1.82 \times Z^{0.635} \left(1 - \frac{0.145 \log Z}{1.82} \right)} \right]$$

$$F_{\alpha\alpha} = R_2(E_2) - \frac{G_p m_\alpha}{z^2} E_2^{1.82} Z^{-0.145 \log E_2}$$

4.5 Stopping Power For Compound Targets

The stopping power of a compound medium can be obtained by additivity theorem [17].

$$\left(\frac{-dE}{\rho dx}\right)_{compound} = \frac{1}{M} \sum_i^n N_i A_i \left(\frac{-dE}{\rho dx}\right) \quad (4.5.1)$$

Here M is the molecular weight of the compound medium consisting N_i atoms of atomic weight A_i . For example for CdT_e the stopping power can be given as

$$\begin{aligned} \frac{-dE}{\rho dx} &= \frac{1}{M} \left[N_{Cd} A_{Cd} \left(\frac{-dE}{\rho dx}\right)_{Cd} + N_{Te} A_{Te} \left(\frac{-dE}{\rho dx}\right)_{Te} \right] \\ &= \frac{1}{240.02} \times \left[112.41 \left(\frac{-dE}{\rho dx}\right)_{Cd} + 127.61 \left(\frac{-dE}{\rho dx}\right)_{Te} \right] \end{aligned} \quad (4.5.2)$$

4.6 Range For Compound Targets

While studying energy losses in nuclear research emulsions, gave the following formula for the range in n-component materials [17].

$$\frac{1}{R} = \sum_i^n \frac{f_i}{R_i} \quad (4.6.1)$$

where R_i is the calculated range in the i - *th* component and f_i is the fraction by weight of that constituent of the stopping medium.

Equation (4.6.1) can be written for CdT_e as

$$R_{CdTe} = \frac{R_{Cd} R_{Te}}{0.4684 R_{Te} + 0.5316 R_{Cd}} \quad (4.6.2)$$

Chapter 5

RESULTS AND DISCUSSION

The organization of this chapter is as follows: In the first section we calculate stopping power and range of Al, Cu, Ge, Au, Ag, Cd, Te and CdTe using Present empirical formula and discuss the results of the present empirical formula and SRIM-2000 and compare the results obtained from present empirical formula with the values obtained from SRIM-2000 tables.

5.1 Stopping Power Calculation

The stopping powers of the elements *Al, Cu, Ge, Ag* and *Au* and for a compound *CdTe* are calculated from energy range *4Mev* to *15Mev* for α - particle energy using the empirical relation given in equation (4.2.1) and (4.5.1) respectively and their results are tabulated in table 5.1 and 5.2 and plotted in fig 5.1 to 5.8 along with Srim-2000 tabulated values.

Energy (Mev)	Aluminum		Copper		Germanium	
	Empirical	SRIM -2000	Empirical	SRIM -2000	Empirical	SRIM-2000
4	694.1	693.7	490.5	480.5	456.8	457.9
4.5	642.3	651.7	456.6	449.7	425.6	429.9
5	599.2	609	428.3	423.9	399.4	405.6
5.5	562.8	572	404.2	401.5	377.2	384.4
6	531.4	539.8	383.3	381.9	357.9	365.7
6.5	504.1	511.5	365.1	364.5	341.1	349.1
7	480.1	486.4	349	349	326.2	334.1
8	439.7	443.7	321.8	322.1	301	308.4
9	406.9	408.7	299.6	299.7	280.4	286.9
10	379.6	379.5	281	280.6	263.2	268.7
11	356.5	354.6	265.2	264.2	248.5	252.9
12	336.7	333.2	251.5	249.8	235.8	239.2
13	319.4	314.5	239.6	237.2	224.8	227.1
14	304.2	298.1	229	225.9	215	216.3
15	290.7	283.4	219.6	215.8	206.2	206.7

Table 5.1: Stopping Power in $Mev - cm^2/g$ of Al, cu and Ge for α - particle energy from $4Mev - 15Mev$

Energy (Mev)	Silver		Gold	
	Empirical	SRIM -2000	Empirical	SRIM -2000
4	392.6	378.7	299	258.5
4.5	366.8	352.9	280.4	242.6
5	345.1	333.8	264.8	232.8
5.5	326.7	317.2	251.4	223.6
6	310.6	302.5	239.7	215
6.5	296.6	289.5	229.5	207.1
7	284.2	277.8	220.4	199.9
8	263.1	257.7	205	187
9	245.8	240.8	192.2	176
10	231.3	226.4	181.5	166.4
11	218.9	213.9	172.3	158.1
12	208.2	203	164.3	150.7
13	198.8	193.3	157.3	144.1
14	190.4	184.7	151.1	138.1
15	183	176.9	145.5	132.8

Table 5.2: Stopping Power in $Mev - cm^2/g$ of Ag and Au for α - particle energy from $4Mev - 15Mev$

Energy (Mev)	Cadmium		Tellurium		CdTe
	Empirical	SRIM -2000	Empirical	SRIM -2000	Empirical
4	381.8	378	353.9	355.9	367
4.5	356.8	349.9	330.9	325.4	343
5	335.8	332	311.6	308.6	322.9
5.5	317.8	316	295.1	293.8	305.7
6	302.3	301.8	280.8	280.5	290.9
6.5	288.6	289	268.2	268.6	277.8
7	276.6	277.4	257.1	257.8	266.2
8	256.1	257.4	238.2	239.1	246.6
9	239.3	240.6	222.7	223.5	230.5
10	225.2	226.3	209.7	210.1	217
11	213.2	213.9	198.6	198.5	205.4
12	202.7	203	189	188.4	195.4
13	193.6	193.3	180.5	179.4	186.6
14	185.5	184.7	173	171.4	178.9
15	178.3	177	166.3	164.2	171.9

Table 5.3: Stopping Power in $Mev - cm^2/g$ of Cd,Te and CdTe for α - particle energy from $4Mev - 15Mev$

5.1.1 Plot Of Stopping Power versus energy

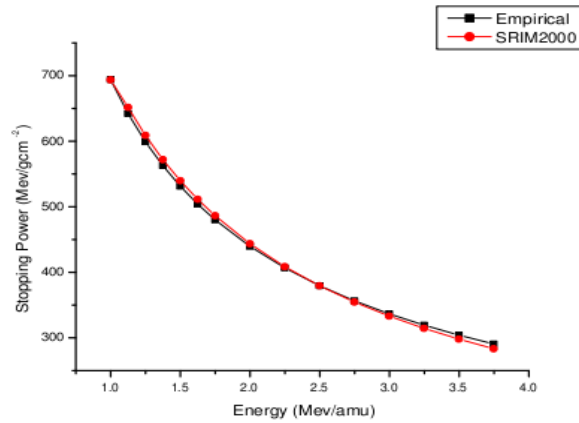


Figure 5.1: Present Empirical Values for Stopping Power of alpha particles versus energy in Al along with other workers value

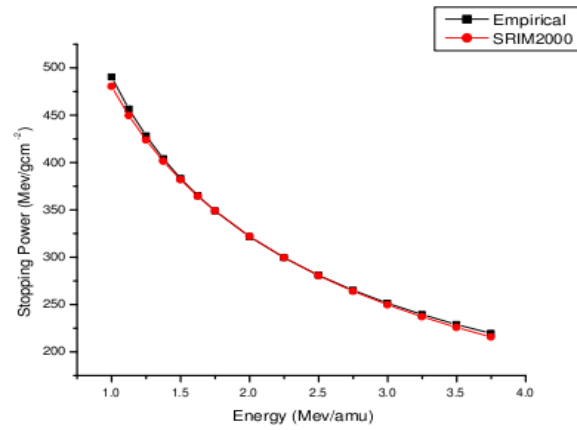


Figure 5.2: Present Empirical Values for Stopping Power of alpha particles versus energy in Cu along with other workers value

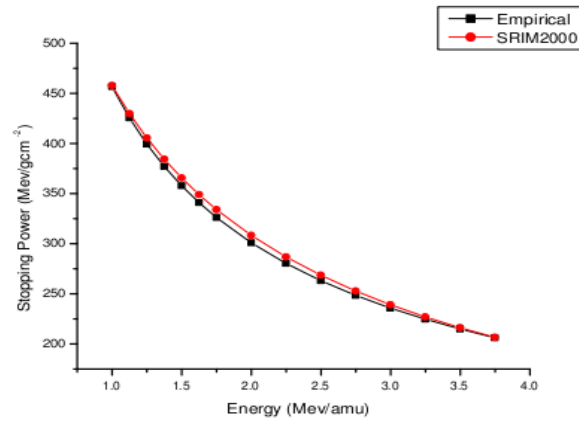


Figure 5.3: Present Empirical Values for Stopping Power of alpha particles versus energy in Ge along with other workers value

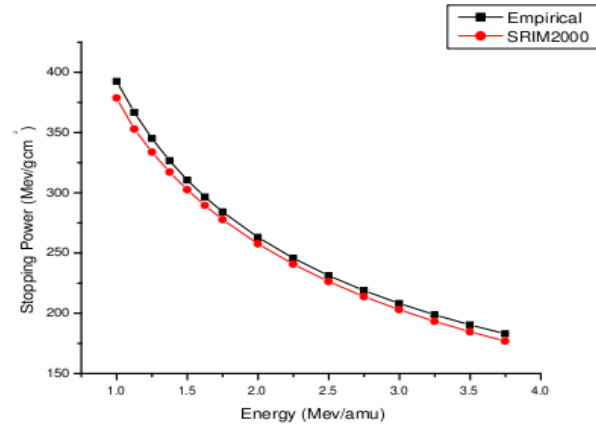


Figure 5.4: Present Empirical Values for Stopping Power of alpha particles versus energy in Ag along with other workers value

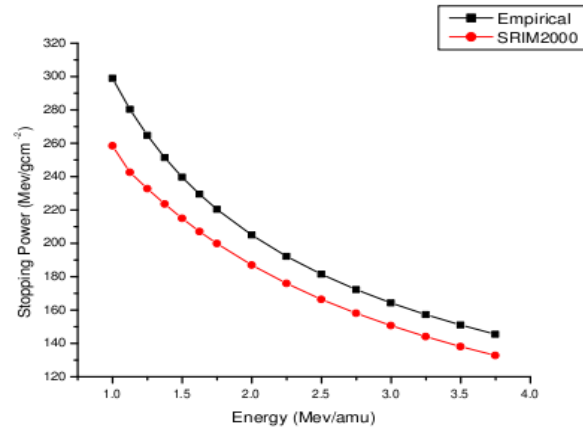


Figure 5.5: Present Empirical Values for Stopping Power of alpha particles versus energy in Au along with other workers value

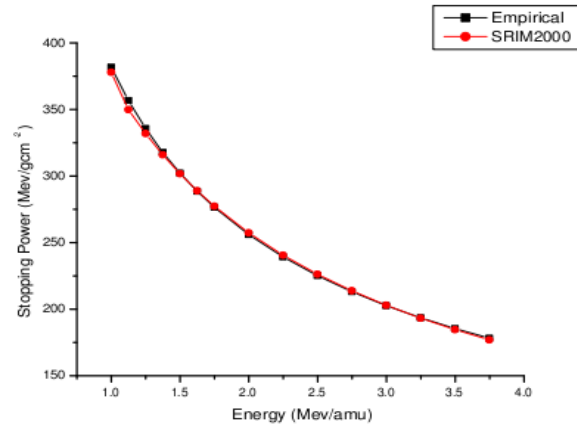


Figure 5.6: Present Empirical Values for Stopping Power of alpha particles versus energy in Cd along with other workers value

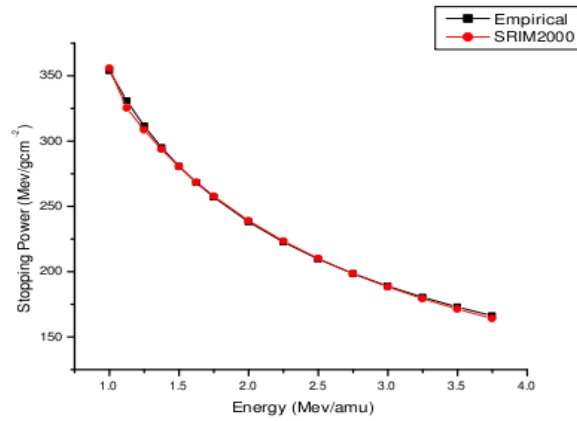


Figure 5.7: Present Empirical Values for Stopping Power of alpha particles versus energy in Te along with other workers value

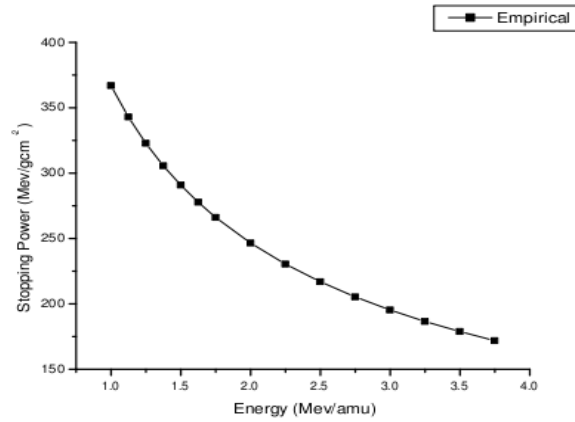


Figure 5.8: Present Empirical Values for Stopping Power of alpha particles versus energy in CdTe along with other workers value

5.2 Description of the Plots Of Stopping Power versus energy

The Figures 5.1 - 5.4 and figures 5.6- 5.8 are plots of the stopping power versus the incident alpha particle energy from $4\text{MeV} - 15\text{MeV}$ for the elements Al, Cu, Ge, Ag, Cd, Te and compound CdTe respectively. The squares represents the calculated results using present empirical formula and comparison with the values of SRIM-2000 tables which is shown by circle. We found that our results have a satisfactory agreement with the values of SRIM-2000 tables for the given energies. But for the compound CdTe we could not get available SRIM-2000 results to compare.

The compound CdTe is a gamma detector it works at room temperature. Figure 5.5 is the plot of the stopping power versus the incident alpha particle energy from $4\text{MeV} - 15\text{MeV}$ for the element Au. As the figure shows clearly the present empirical values are not in good agreement with SRIM-2000 with in the given range of energies.

5.3 Range Calculation

Using the empirical relation given in equations (4.4.1) and (4.6.2) the range of the elements Al,Cu,Ge,Ag and Au and the compound CdTe respectively are calculated and their values are tabulated below.

In these calculations values of starting ranges are taken from the literature and these are also tabulated as follows.

Elements	Al	Cu	Ge	Ag	Au	Cd	Te
Range R ₂ (E ₂)	2.745	5.100	4.782	5.622	9.687	6.420	6.830

Table 5.4: Range of $0.7\text{Mev } \alpha - \text{particle}(He)$ in mg/cm^2

The values of G_p and $F\alpha\alpha$ for a given substance are given in table 5.4 below

Element	$F\alpha\alpha$	G_p
Al	0.819	3.477
Cu	1.903	5.074
Ge	1.691	5.469
Ag	1.939	6.461
Au	4.690	8.663
Cd	2.628	6.649
Te	2.718	7.196

Table 5.5: The values of G_p and $F\alpha\alpha$ for a given substance

The empirical results calculated by the range formulas are tabulated in the table 5.5 and 5.6 and plotted in figures 5.9 to 5.16 below.

Energy (Mev)	Aluminum		Copper		Germanium	
	Empirical	SRIM -2000	Empirical	SRIM -2000	Empirical	SRIM-2000
4	4.29	4.28	6.97	6.78	7.16	6.98
4.5	5.04	5	8.03	7.85	8.29	8.1
5	5.85	5.79	9.16	8.99	9.51	9.29
5.5	6.71	6.64	10.37	10.2	10.79	10.55
6	7.63	7.54	11.64	11.46	12.16	11.87
6.5	8.6	8.49	12.97	12.8	13.59	13.27
7	9.61	9.49	14.38	14.19	15.09	14.72
8	11.79	11.63	17.36	17.16	18.28	17.82
9	14.16	13.97	20.61	20.37	21.73	21.17
10	16.7	16.51	24.03	23.81	25.41	24.75
11	19.42	19.24	27.7	27.46	29.32	28.58
12	22.31	22.15	31.57	31.34	33.46	32.62
13	25.36	25.23	35.65	35.43	37.8	36.9
14	28.75	28.49	39.92	39.74	42.35	41.39
15	31.94	31.93	44.38	44.25	47.1	46.11

Table 5.6: Range in g/cm^2 of the elements Al,Cu and Ge for α – *particle* energy from $4Mev - 15Mev$

Energy (Mev)	Silver		Gold	
	Empirical	SRIM -2000	Empirical	SRIM -2000
4	8.4	8.12	13.35	12,28
4.5	9.72	9.47	15.08	14.25
5	11.12	10.91	16.91	16.32
5.5	12.61	12.44	18.85	18.46
6	14.18	14.04	20.89	20.7
6.5	15.83	15.72	23.02	23.04
7	17.55	17.46	25.25	25.45
8	21.21	21.18	29.96	30.55
9	25.18	25.16	35	35.98
10	29.35	29.41	40.35	41.73
11	33.8	33.93	46	47.81
12	38.48	38.7	51.96	54.22
13	43.4	43.71	58.18	60.93
14	48.54	48.97	64.67	67.94
15	53.9	54.47	71.41	75.24

Table 5.7: Range in g/cm^2 of the elements Ag and Au for α – particles energy from $4Mev$ – $15Mev$

Energy (Mev)	Cadmium		Tellurium		CdTe
	Empirical	SRIM -2000	Empirical	SRIM -2000	Empirical
4	9.27	8.06	9.91	8.46	9.6
4.5	10.63	9.42	11.37	9.91	11.01
5	12.07	10.87	12.93	11.48	12.51
5.5	12.61	12.4	14.58	13.12	13.59
6	15.22	14.01	16.32	14.85	15.79
6.5	16.91	15.69	18.14	16.65	17.54
7	18.68	17.44	20.05	18.54	19.38
8	22.45	21.16	24.09	22.53	23.29
9	26.49	25.15	28.44	26.82	27.49
10	30.8	29.4	33.07	31.41	31.97
11	35.37	33.92	37.97	36.27	36.71
12	40.18	38.68	43.13	41.41	41.7
13	45.23	43.7	48.55	46.81	46.94
14	50.51	48.96	54.21	52.48	52.41
15	56.01	54.46	60.1	58.39	58.11

Table 5.8: Range in g/cm^2 of the elements Cd,Te and $CdTe$ for α – particles energy from $4Mev$ – $15Mev$

5.3.1 Plots of Range versus energy

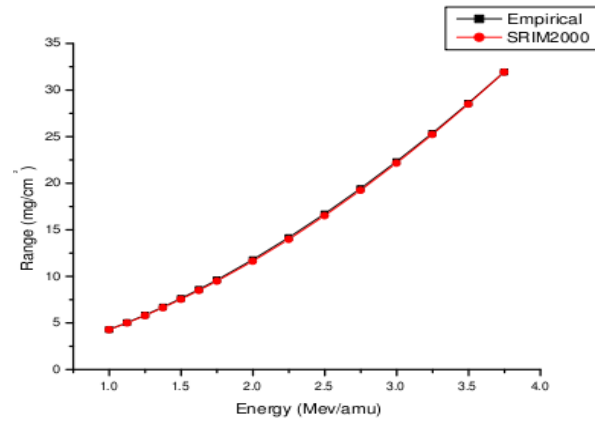


Figure 5.9: Present Empirical Values for Range of alpha particles versus energy in Al along with other workers value

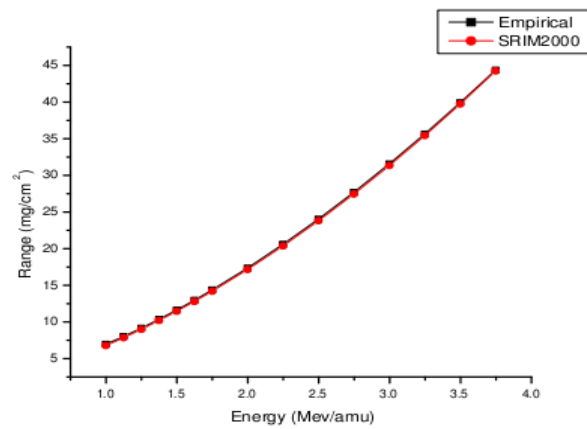


Figure 5.10: Present Empirical Values for Range of alpha particles versus energy in Cu along with other workers value

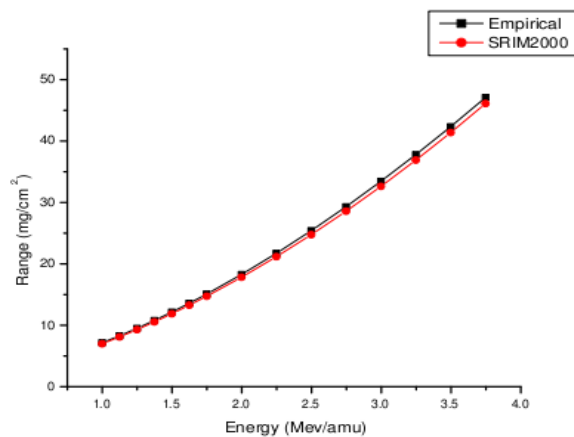


Figure 5.11: Present Empirical Values for Range of alpha particles versus energy in Ge along with other workers value

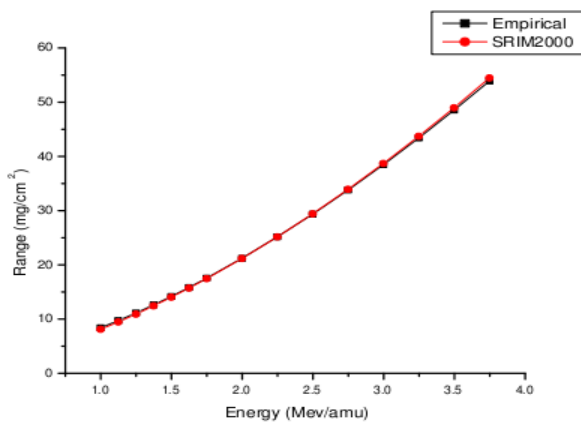


Figure 5.12: Present Empirical Values for Range of alpha particles versus energy in Ag along with other workers value

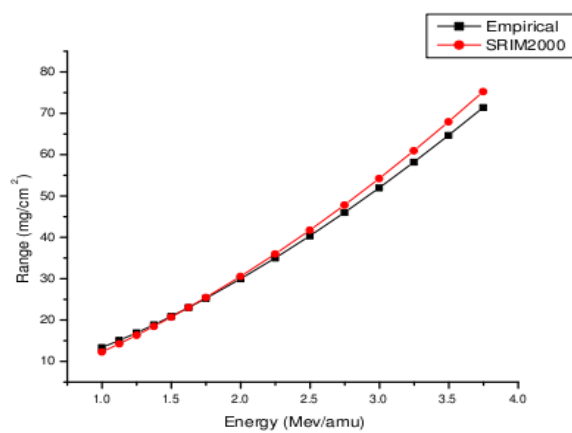


Figure 5.13: Present Empirical Values for Range of alpha particles versus energy in Au along with other workers value

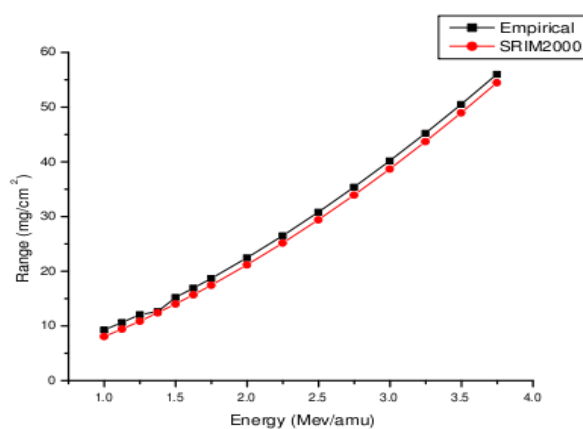


Figure 5.14: Present Empirical Values for Range of alpha particles versus energy in Cd along with other workers value

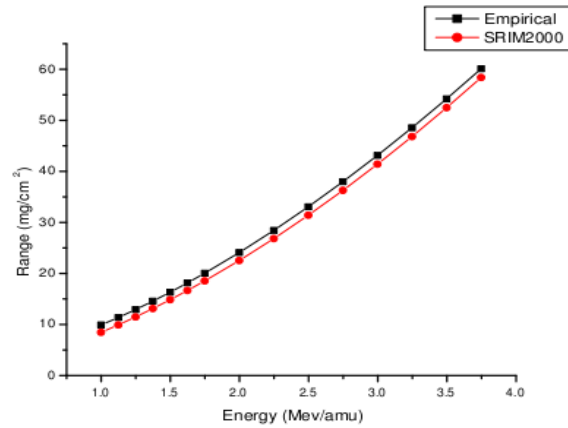


Figure 5.15: Present Empirical Values for Range of alpha particles versus energy in Te along with other workers value

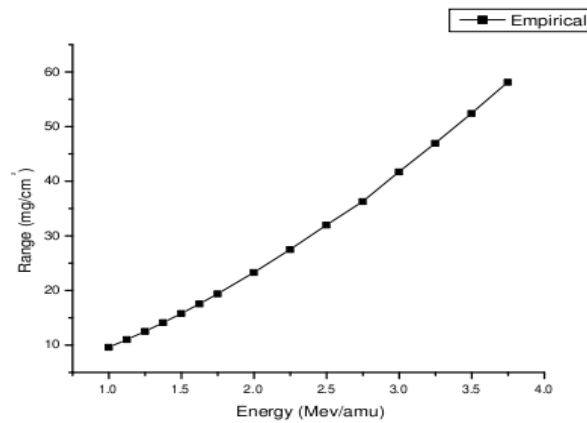


Figure 5.16: Present Empirical Values for Range of alpha particles versus energy in CdTe along with Previous Empirical values

5.4 Description of the Plots Of Range versus energy

As it is shown in the Figures 5.9 - 5.12 and figures 5.14- 5.16 are plots of the range versus the incident alpha particle energy from $4\text{Mev} - 15\text{Mev}$ for the elements Al, Cu, Ge, Ag, Cd, Te and compound CdTe respectively. The squares represents the calculated results using present empirical formula and comparison with the values of SRIM-2000 tables which is shown by circle. We found that our results have a very good agreement with the

values of SRIM-2000 tables for the given energies. But for the compound CdTe we could not get available SRIM-2000 results to compare.

It is noted that there is no good agreement between the present empirical results and SRIM-2000 table for figure 5.13 which is the plot of the range versus the incident alpha particle energy from $4\text{Mev} - 15\text{Mev}$ for the elements Au.

Fig 5.16 shows present empirical values for range of alpha particles versus energy in CdTe. This can not be compared with other results since other results are not available.

5.5 Percentage difference of empirical stopping power values from SRIM Values

The percentage difference between the stopping power calculated from equation (4.2.1) and the corresponding values obtained from SRIM table and plotted in figure (5.17) for the elements Al,Cu,Ge,Ag and Au.

Energy (Mev)	4.00	4.50	5.00	5.50	6.00	6.50	7.00	8.00	9.00	10.00
Al	-0.06	1.44	1.61	1.61	1.56	1.45	1.30	0.90	0.44	-0.03
Cu	-2.08	-1.53	-1.04	-0.67	-0.37	-0.16	0.00	0.09	0.03	-0.14
Ge	0.24	1.00	1.53	1.87	2.13	2.29	2.36	2.40	2.27	2.05
Ag	-3.67	-3.94	-3.39	-2.99	-2.68	-2.45	-2.30	-2.10	-2.08	-2.16
Au	-15.67	-15.58	-13.75	-12.43	-11.49	-10.82	-10.25	-9.62	-9.20	-9.07

Table 5.9: percentage difference of empirical stopping power values from SRIM values for energy from 4Mev-10Mev

Energy (Mev)	11.00	12.00	13.00	14.00	15.00
Al	-0.54	-1.05	-1.56	-2.05	-2.58
Cu	-0.38	-0.68	-1.01	-1.37	-1.76
Ge	1.74	1.42	1.01	0.59	0.24
Ag	-2.34	-2.56	-2.84	-3.09	-3.45
Au	-8.98	-9.02	-9.16	-9.41	-9.56

Table 5.10: percentage difference of empirical stopping power values from SRIM values for energy from 11Mev-15Mev

5.6 Percentage difference of empirical Range values from SRIM-2000 Values

The percentage difference between the range calculated from equation (4.4.1) and the corresponding values obtain from SRIM-2000 tables are tabulated in the table 5.8 and plotted in figure for the elements Al,Cu,Ge,Ag and Au.

Energy (Mev)	4.00	4.50	5.00	5.50	6.00	6.50	7.00	8.00	9.00	10.00
Al	-0.23	-0.80	-1.04	-1.05	-1.19	-1.30	-1.26	-1.38	-1.36	-1.15
Cu	-2.80	-2.29	-1.89	-1.67	-1.57	-1.33	-1.34	-1.17	-1.18	-0.92
Ge	-2.58	-2.35	-2.37	-2.27	-2.44	-2.41	-2.51	-2.58	-2.65	-2.67
Ag	-3.44	-2.64	-1.92	-1.37	-1.00	-0.70	-0.52	-0.14	-0.08	0.20
Au	-8.71	-5.82	-3.61	-2.11	-0.92	0.09	0.79	1.93	2.72	3.31

Table 5.11: percentage difference of empirical range values from SRIM values for energy from 4Mev-10Mev

Energy (Mev)	11.00	12.00	13.00	14.00	15.00
Al	-0.94	-0.72	-0.13	-0.28	-0.03
Cu	-0.87	-0.73	-0.62	-0.45	-0.29
Ge	-2.59	-2.58	-2.44	-2.32	-2.15
Ag	0.38	0.57	0.71	0.88	1.05
Au	3.79	4.17	4.51	4.81	5.09

Table 5.12: percentage difference of empirical range values from SRIM values for energy from 11Mev-15Mev

5.6.1 Plots of Percentage difference of Stopping power versus energy

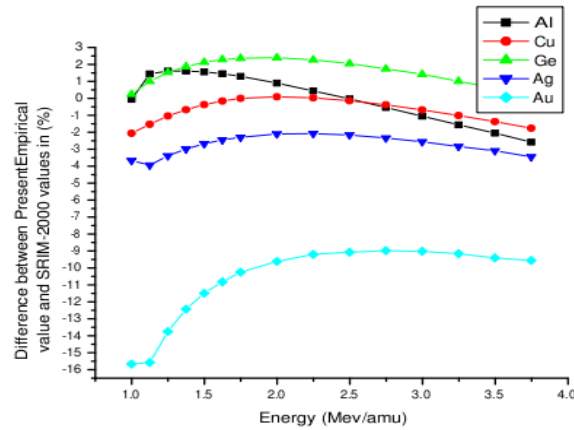


Figure 5.17: percentage difference between Present Empirical values and SRIM-2000 of the stopping Powers versus energy of alpha particles for Al,Cu,Ge,Ag and Au.

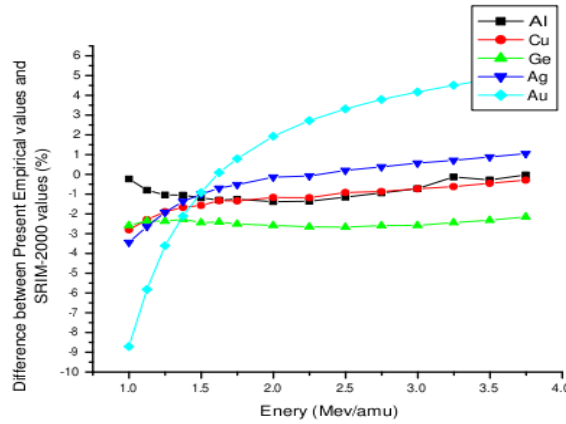


Figure 5.18: Percentage difference between Present Empirical values and SRIM-2000 of the Range versus energy of alpha particles for Al,Cu,Ge,Ag and Au.

5.7 Comparison with previous empirical result and SRIM-2000 values

5.7.1 Alpha particle Stopping Power

In the figure 5.17 it is clearly shown that the percentage difference between the stopping power calculated from equation (4.2.1) and the corresponding values obtained from SRIM-2000 tables for the elements Al,Cu,Ge,Ag and Au. It is evident from the figure that the present empirical values for Al,Cu,Ge and Ag are in good agreement with SRIM-2000 values. Al,Cu,Ge and Ag has a maximum difference of 2.6% ,2.1%,2.4% and 3.9% with SRIM-2000 values respectively.

For Au the present empirical values do not agree well with SRIM-2000 values and the maximum difference 15.7%. From this one can say that the percentage difference shows a systematic behavior with the energy as well as with atomic number. That is for energy of alpha particle the percentage deviation from SRIM-2000 values increases as energy of alpha particles increases. Moreover, for larger atomic numbers like Au the present empirical formula is not in good agreement with SRIM result.

5.7.2 Alpha particle Range

The range of alpha particles calculated from equations (4.4.1) is presented in figures 5.9-5.13 with the values of SRIM-2000 tables. The percentage difference between the range calculated from equation (4.4.1) and the corresponding values obtained from SRIM-2000 tables for the elements Al,Cu,Ge,Ag and Au is shown in the figure 5.18. It can be inferred that the results for Al,Cu, Ge and Ag are in good agreement to the SRIM-2000 tables. The agreement has a maximum percentage difference of 1.4% for Al, 2.8% for Cu, 2.7% for Ge 3.4% for Ag and 8.71% for Au.

In the case of Au the present values are not in good agreement with the values of SRIM-2000 tables. This shows the present empirical results do not have good agreement with the values of SRIM-2000 tables for elements having large atomic number.

5.8 Conclusion

This paper introduces a modified empirical formula to calculate the stopping power of various elements and their corresponding range for alpha particles energy from $4\text{Mev} - 15\text{Mev}$. The modified empirical formula is obtained by changing the constants a and b of the previous empirical formula, so that the errors are minimized.

This is checked by comparing with available tabulated data obtained from literature. From the result one can notice that the error obtained from calculated values by present empirical formula is smaller than error obtained from calculated values by previous empirical formula. It is also noted that the error increases with increasing alpha particles energy and atomic number of the stopping element. For higher atomic number such as Au the error is large.

Equations (4.2.1) and (4.4.1) give good result for Al, Cu, Ge, Ag, Cd, and Te from alpha particle energies $4\text{Mev} - 15\text{Mev}$. But for Au not give good result so above these energies and for higher atomic numbers the values of the constant a, b, c and d should be changed or another parameter is required to minimize the error.

To sum up, this paper leads other researchers for further investigation of empirical formula for stopping power and range of $\alpha - particles$ for large energy and elements having large atomic number.

References

- [1]. J.E. Turner, Atoms, Radiation, and Radiation Protection, Wiley, New York, 1995,
- [2]. [Rutherford, 1911] E. Rutherford (1911). Philos. Mag. 21, 669.
- [3]. [Bohr, 1913] N. Bohr (1913). Philos. Mag. 25, 10.
- [4]. [Bohr, 1941] N. Bohr (1941). Phys. Rev. 59, 270.
- [5]. [Bohr, 1948] N. Bohr (1948). K. Danske Vidensk. Selskab. Mat.-Fys. Medd. 18,1
- [6]. [Bohr et al., 1940] N. Bohr, J. K. Boggild, K. J. Brostrom, and T. Lauritsen (1940). Phys. Rev. 58, 839.
- [7]. [Bethe, 1930] H. Bethe (1930). Ann. Physik 5, 325.
- [8]. [Bethe, 1932] H. Bethe (1932). Z. Phys. 76, 293.
- [9]. [Bloch, 1933] F. Bloch (1933). Ann. Physik 16, 285.
- [10]. [Thomson, 1906] J. Thomson (1906). Conduction of electricity through gases , pp. 370382. Cambridge University Press 2nd rev. edition.
- [11]. www.gsi.de/forschung/pp/pub/thesis/korostiy2006. Date 31/03/2011
- [12]. ocw.mit.edu/courses/...radiation-interactions.../energy_depos_hcp. Date 31/03/2011
- [13]. en.wikipedia.org/wiki/Stopping_power Date 02/04/2011
- [14]. Beiser concepts of modern physics, fourth edition, McGraw Hillin New York 1987.
- [15]. Kenneth S. Krane Introductory nuclear physics, United States of America, 1988.
- [16]. A.K. Chaubey and H.V. Gupta New empirical relations for stopping power and range of charged particles, Aligarh Muslim, 1977.
- [17]. Glenn. F. Knoll, Radiation, detection and measurement third edition, Wiley India Pvt Ltd January 2000.
- [18]. John David Jackson, Classical electrodynamics third edition, University of California, Berkeley, 1925.

Declaration

This thesis is my original work, has not been presented for a degree in any other University and that all the sources of material used for the thesis have been dully acknowledged.

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This thesis has been submitted for examination with my approval as University advisor.

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