Lecture4

Heavy and Light particles

1. Interaction of Heavy Charged Particles with Matter

The interaction between **radiation** or **particles** and **atoms** of a matter is the only way to **transfer energy**. *Therefore*, an interaction is defined as the transfer of energy, in whole or partially, directly or indirectly to matter.

The **heavy charged particles** such as the **alpha** particle and the **protons interact** mainly through the **coulomb force** with the **orbiting electrons** of the atom as follow:

When the **particle** enters the material, it interacts with many orbital **electrons**, in every interaction, the particle **loses** its **energy** and this energy goes to the **electrons**, if this energy is sufficient to release the electron from the orbit, then the atom will be **ionized**, and if it is **not enough**, then the energy will transfer the electron from **one level** to **another** then the atom will be in **excitation state**.

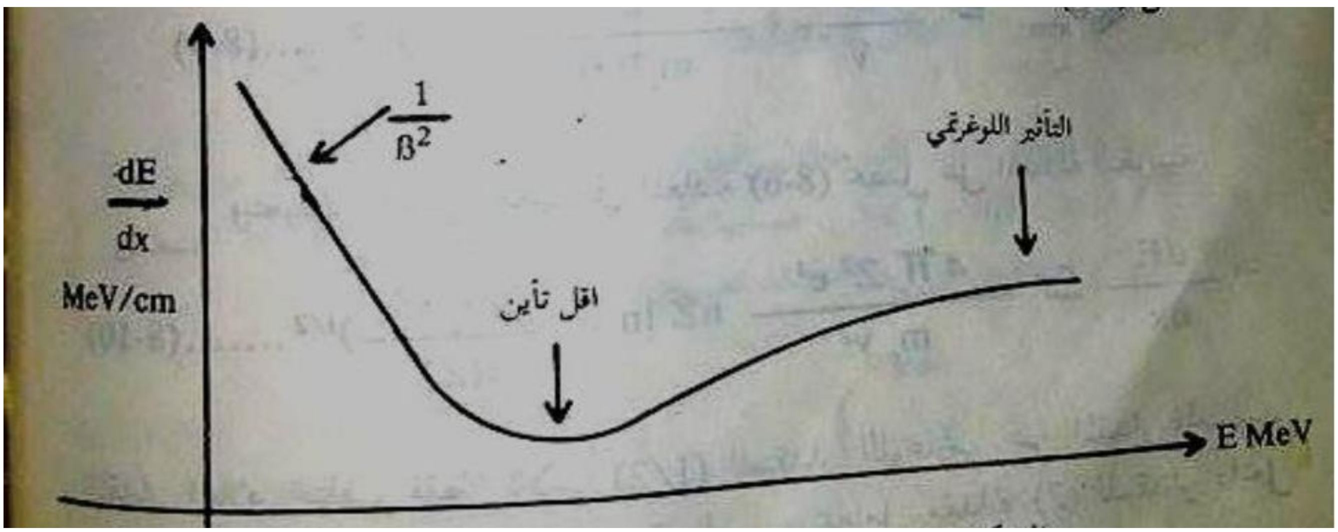
The **velocity** of the charged particle will gradually **decrease** due to **collisions** with many **electrons**, resulting in the particle **losing** all of **its energy** within the material. *Therefore*, it can be said that the energy lost per unit length of a single particle is known as the **stopping energy** (***S***).

Bethe scientist was the first to compute the energy lost in collisions between heavy charged particles and electrons. where an electron assumed a mass ***me*** distance ***b*** from the path of the charged particle, its charge ***Ze***, its mass ***M***, and its velocity ***V***. The stopping power equation can be derived and this equation is called the **Bethe equation**, as shown below:

$$S = -\frac{dE}{dX} = \frac{4\pi Z^2 e^4 NZ}{mv^2}\left[\ln\frac{2mv^2}{I} - \ln(1-\beta^2) - \beta^2\right]$$

Where: m and e = charge and mass of electron, E, Ze, V= kinetic energy, charge and velocity of particles. β = v/c, Z= atomic number, N= number of nucleus and I= ionization energy.

From the **above equation**, we note that the **stopping energy** for **heavy** particles does not depend on the **mass** of the **falling particle**, as well as it changes with the **energy** (***E***) as shown in the figure below.



We notice from the above figure that the **stopping energy decreases as the energy of the falling particle increases** (i.e., its velocity), so that the amount of

the drop is proportional to $\frac{1}{Q}$. ***But*** when the energy value (**E**) **increases** so that it

reaches the **velocity** of the particle, we notice that the drop **stops** at this point andthus the **ionization energy** reaches its **lowest value**.

As for the distance that the particle is able to travel inside matter from the sourceuntil its kinetic energy becomes zero, it is known as the **range**. The path of the particle inside the material takes a straight shape until it approaches its end. Therange can be calculated from the following equation:

$$R = \int_0^R dx = \int (-\frac{dE}{dx})^{-1} = \int_0^E \frac{dE}{S(E)}$$

2. Interaction of light charged particles with matter (Electrons)

The light charged particles such as the electrons and the positrons are similar in their interaction as the heavy charged particles in terms of the **coulometric effect**,**but** due to the convergence of their mass with the electron orbital, so their pathinside matter means a number of deviations. *Therefore*, the interaction of lightparticles with matter is classified into **two** types, namely, the **inelasticallyinteraction** and the **elastically interaction**.

❖ Inelastically interactions

It is the loss of energy by **inelastic collision** with the **orbiting electron**, and when the energy is transferred, either **ionization** or **excitation** occurs. The **stopping power** can be calculated from the equation developed by Mott in 1393 as in the equation below:

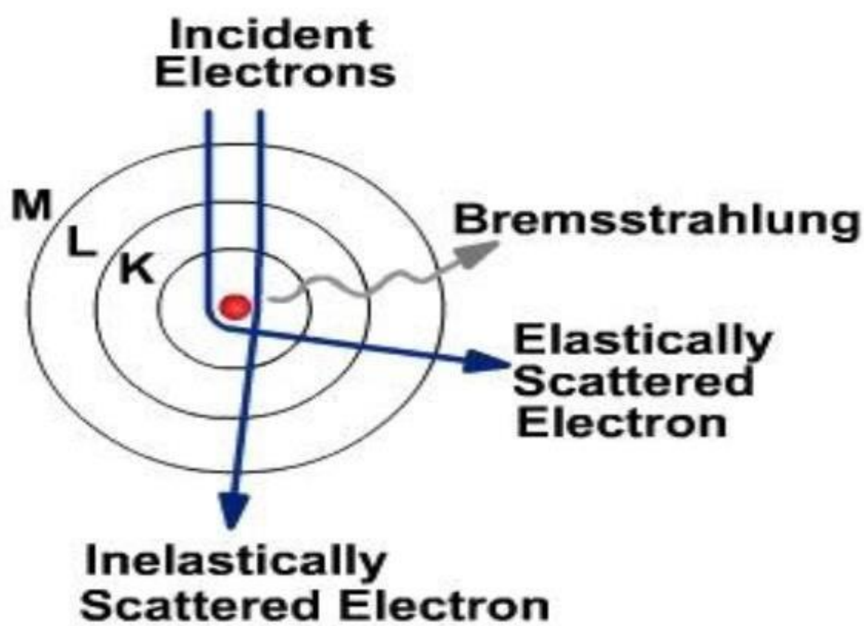
$$S = -\left(\frac{dE}{dX}\right)_c = \frac{4\pi e^2}{m_0 v^2} nZ \left[\ln\left(\frac{2m_0 v^0}{I(Z)}\right) - 1.2329 \right] erg.cm^{-1}$$

This type of interaction is what distinguishes light particles, and the energy is lost through radiation and is called **stopping rays**.

❖ Elastically interactions

The **high** energy electrons may reach a close distance from the inner orbit of the atom, as a result of the effect of the force of the coulometric attraction between the electron and the nucleus.

When the electron approaches a close distance to the nucleus, it **deviates** from its path, and this deflection leads to the emission of photons of its total energy part of the energy of the falling electron and these photons are called **Bremsstrahlung x-rays** as shown in the figure below.



The stopping energy can be calculated using the following equation:

$$S = \left(\frac{dE}{dx}\right)_r = \frac{NEZ(Z+1)e^4}{137 m_0 c^4}\left[4\ln\left(\frac{2E}{m_0 c^0}\right) - \frac{4}{3}\right]$$

The total stopping energy can be calculated by:

$$S = \left(\frac{dE}{dx}\right)_{total} = \left(\frac{dE}{dx}\right)_c + \left(\frac{dE}{dx}\right)_r$$

As for the distance that the particle is able to travel inside matter from the source until its kinetic energy becomes zero, it is known as the **range**, and can be calculated using the following equation:

$$\boldsymbol{R\left(\frac{gm}{cm^2}\right) = 412E^n\ (MeV)(for\ energy\ between\ 0.01 < E < 3\ MeV)}$$

Where: $\boldsymbol{n = 1.265 - 0.095\ln E}$

$$\boldsymbol{R\left(\frac{gm}{cm^2}\right) = 530E - 106\ (MeV)(for\ energy\ between\ 1 < E < 20\ MeV)}$$

As for the **interaction** of the **positron** with **matter**, it is analogous to what happens when the electron interacts with the substance, except that there is a difference in the end of the particle. At the end of the positron, that is, at its annihilation with an orbiting electron, it emits electromagnetic rays called **annihilation rays** and produces **photons** in the energy **0.511** MeV.

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