Experiment 2

Deflection of nuclear radiation by electric and magnetic fields

Deflection in an electric field

Charged particles are affected by electric fields. An electric field is the area around a charged object.

If two parallel plates (one negative and one positive) form an electric field that particles from radioactive decay are made to travel through, the particles that are charged will accelerate towards the plate with opposite.

Alpha Particles in an electric field

Alpha particles are attracted to the negatively charged plate. This confirms that they must be positively charged. Alpha particles are helium nuclei; they contain 2 protons which gives them their positive charge.

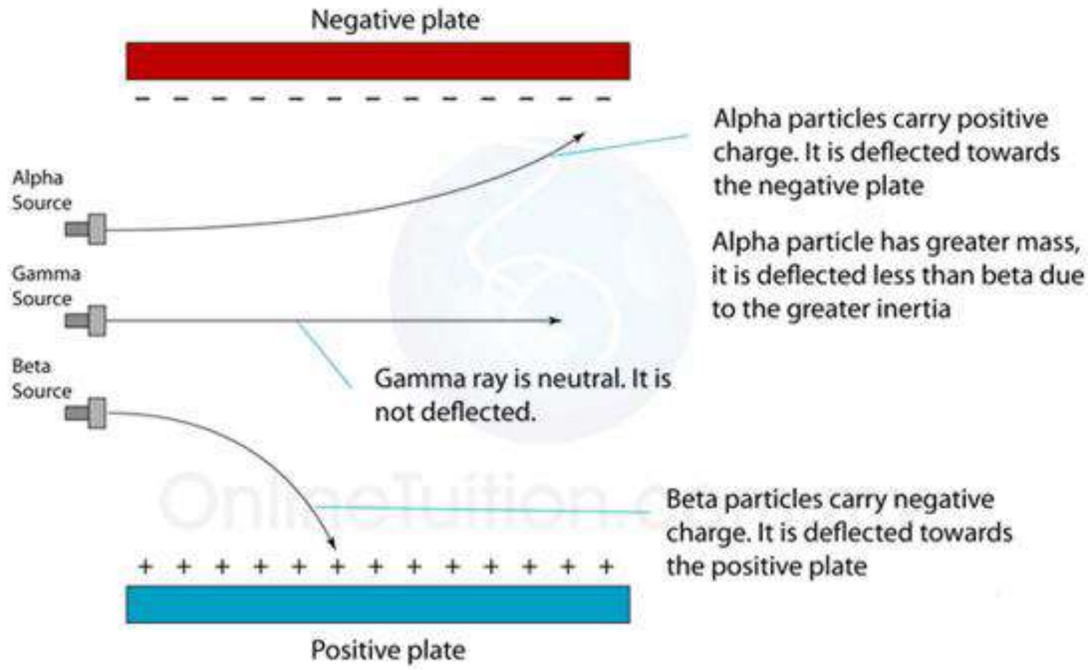
Beta Particles in an electric field

Beta particles are attracted to the positively charged plate. This confirms that they are negatively charged. Beta particles are fast moving electrons with low mass. They are deflected much more than the heavier alpha particles.

Gamma rays in an electric field

Gamma rays are unaffected by an electric field, and will just continue on its straight path. This shows gamma rays are uncharged. Gamma rays are highly energetic waves with no charge.

Note: beta- particle has much less mass than an alpha particle. The larger mass makes the alpha particle have more momentum than the beta particle. Therefore, an alpha particle is deflected less that a beta particle in a given electric field because of its higher momentum.



Deflection in a magnetic field

If a charged particle is moving in a magnetic field (B), then it experiences a force of magnitude: **$|F| = q\,|v \times B| = q\,v\,B\,\sin(\Theta)$** where q is the charge of the particle, v is its velocity, B is the magnetic field strength, and theta is the angle between v and B.

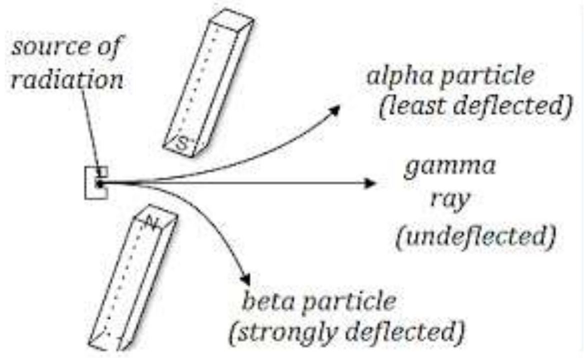
charged particles experience a force when they travel in a magnetic field. The force is applied at right angles to charged particles path - therefore they are forced into moving in a circular path.

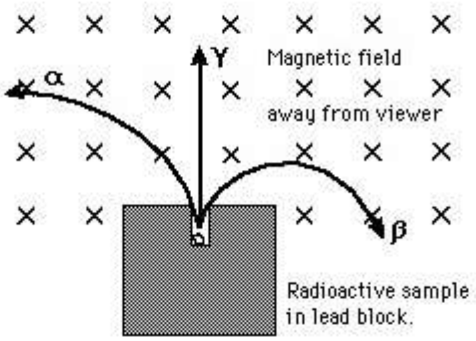
- Alpha particles are deflected by a magnetic field confirming that they must carry a charge.

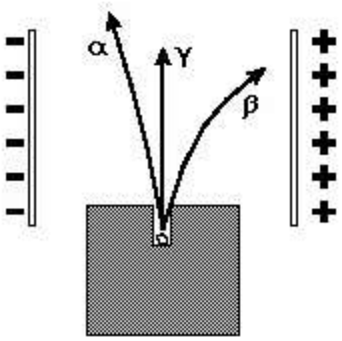
- Beta particles are deflected by a magnetic field in an opposite direction to alpha particles.

- Gamma rays are unaffected by a magnetic field. This shows gamma rays are uncharged as they do not experience a force when passing through the lines of a magnetic field. Gamma rays are highly energetic waves with no charge.

□ Due to higher momentum the alpha particle is less affected by the force of the field than the beta- particle.







Q1: Explain why alpha and beta particles are deflected in an electric or a magnetic field, but gamma rays are not deflected in such a field.

Solution: Alpha and beta radiations are charged particles. Alpha is positively charged and beta is negatively charged. Hence these are deflected in an electric or magnetic field whereas gamma radiations are uncharged particles and therefore cannot deflect in an electric or magnetic field.

Q2. Magnetic field does not cause deflection in

(a) α

(b) beta

(c) gamma rays

Q3. Alpha and beta particles are deflected in an electric or a magnetic field but gamma rays are not deflected in such a field because?

Q4. Is it possible to deflect γ - radiations in a way similar to α and β - particles, using the electric or magnetic field?

Q5. The three main kinds of radioactive decay particles are alpha, beta, and gamma. Which of the three particles would not be deflected by a magnetic field?

Q6. Why can't gamma rays be deflected by a magnetic field?

Q7. Which particle show more deflection in magnetic field?

Q8: What is deflection?

The deflection of something means making it change direction.

Q9. Which of the following cannot be deflected by a magnetic field?

(A) Alpha (B) Beta (C) Gamma rays (D) None of these.

Experiment 3

Photoelectric Absorption and Compton Scattering

INTRODUCTION

The gamma rays interact with detectors(atom) and absorbers by three major processes: photoelectric absorption, Compton scattering, and pair production.

Interactions of Photons with Matter

• Photons are electromagnetic radiation with zero mass, **zero charge**, and a velocity that is always c, the speed of light.

• Because they are electrically neutral, they **do not steadily lose energy** via interactions with atomic electrons, as do charged particles.

• Photons travel some considerable distance before undergoing a more **interaction** leading to **partial or total transfer** of the photon energy to **electron energy**.

• These electrons will ultimately deposit their energy in the medium.

• Photons are far **more penetrating** than charged particles of similar energy.

Energy Loss Mechanisms

- photoelectric effect
- Compton scattering
- pair production

1. Photoelectric Effect

What is Photoelectric Effect

The photoelectric effect is an effect where weakly bound electrons within metals are ejected from the material when electromagnetic radiation interacts with those electrons. The ejected electrons are known as the photoelectrons.

The photoelectric interaction is most likely to occur if the energy of the incident photon is **just greater than the binding energy** of the electron with which it interacts.

• In the photoelectric absorption process, a photon undergoes an interaction with an absorber atom in which the **photon completely disappears**.

• In its place, an energetic **photoelectron** is ejected from one of the bound shells of the atom.

• For gamma rays of sufficient energy, the most probable origin of the photoelectron is the most tightly bound or *K* shell of the atom.

• The photoelectron appears with an energy given by

$$E_{e-} = h\nu - E_b$$

(E_b represents the binding energy of the photoelectron in its original shell)

Thus, for gamma-ray energies of more than a few hundred keV, the photoelectron carries off the majority of the original photon energy.

Filling of the inner shell vacancy can produce **fluorescence radiation**, or x ray photon(s).

The probability of photoelectric absorption depends on the gamma-ray energy, the electron binding energy, and the atomic number of the atom

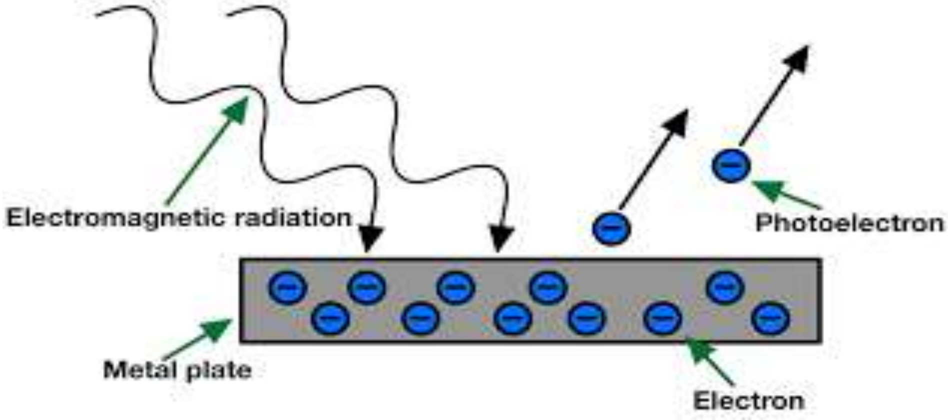


Fig: the photoelectric effect

The photoelectric process is the ***predominant mode of photon interaction*** at

o **relatively low photon energies**

o **high atomic number Z**

The probability of photoelectric absorption, symbolized τ (tau), is roughly proportional to

$$\tau \propto \frac{Z^n}{(h\nu)^3}$$

where the exponent n varies between 3 and 4 over the gamma-ray energy region of interest.

This severe dependence of the photoelectric absorption probability on the atomic number of the absorber is a primary reason for the preponderance of **high-Z materials (such as lead) in gamma-ray shields**.

2. Compton Scattering

The Compton effect, on the other hand, is a mid-energy phenomenon in which photons contact electrons and are scattered

• Compton scattering takes place between the incident gamma-ray photon and an electron in the absorbing material.

• It is most often the predominant interaction mechanism for gamma-ray energies typical of radioisotope sources.

• It is the **most dominant interaction mechanism in tissue**.

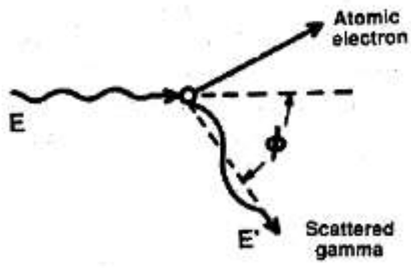


Fig. 2: ***representation of the Compton Scattering***

In Compton scattering, the incoming gamma-ray photon is **deflected** through an angle θ with respect to its original direction.

The photon transfers a portion of its energy to the electron (assumed to be initially at rest), which is then known as a *recoil electron,* or a ***Compton electron***.

• All angles of scattering are possible.

• The energy transferred to the electron can vary from zero to a large fraction of the gamma-ray energy.

• The Compton scattering probability is symbolized σ (sigma):

• almost ***independent of atomic number Z***;

• decreases as the photon energy increases;

• directly proportional to the number of electrons per gram.

The differences between photoelectric effect and the Compton effect are:

Photoelectric effect	Compton effect
1. Albert Einstein explained the photoelectric effect	1. Arthur Compton explained the Compton effect
2. The photon transfers all of its energy to a single electron.	2. A portion of the photon's energy is transferred to a single electron.
3. A low-energy phenomenon is the photoelectric effect.	3. The Compton effect is a phenomenon that occurs at a mid-energy level.
4. After the interaction, the photon vanishes.	4. The dispersed photon has a longer wavelength than the incident photon.

Pair Production

Pair production occurs only for gamma-rays of high energy. If a photon enters matter with an energy **in excess of 1.022 MeV**, it may interact by a process called ***pair production***.

The photon, passing near the nucleus of an atom, is subjected to strong field effects from the nucleus and may **disappear as a photon** and **reappear as a positive and negative electron pair**.

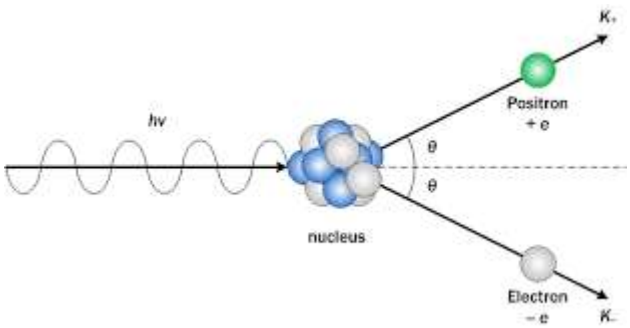


Fig: represent pair production

Note:

- Photoelectric effect: produces a scattered photon and an electron
- Compton effect: produces an electron
- Pair production: produces an electron and a positron