WAVE MODEL/ VISIBLE LIGHT PARTICLES

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Outline

- Visible Light Particles
- Matter and energy
- Interactions of photon with matter
- Mechanism of Energy Loss (Photoelectric effect, Thomson scattering, Coherent (Rayleigh) scattering
- Compton scattering
- Stopping power

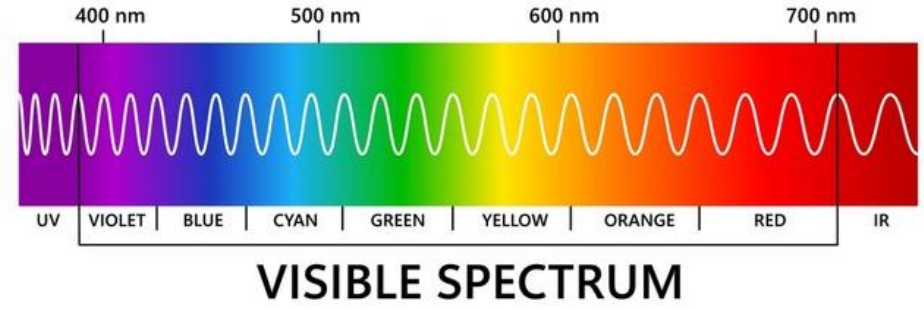
Objectives

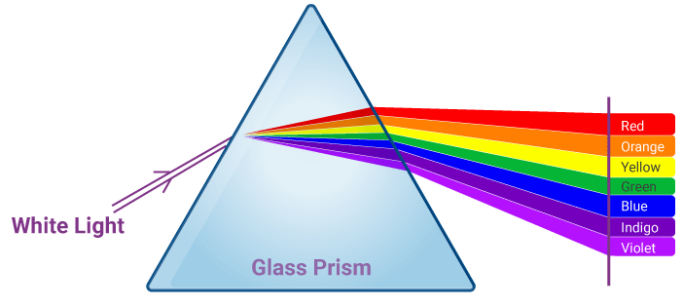
The student should be able to do the followings;

- Explain Visible Light Particles
- Differentiate between Matter and energy
- Mention the Interactions of photon with matter
- Explain the Mechanism of Energy Loss (Photoelectric effect, Thomson scattering, Coherent (Rayleigh) scattering, Compton scattering, Stopping power

Wave Model / visible light

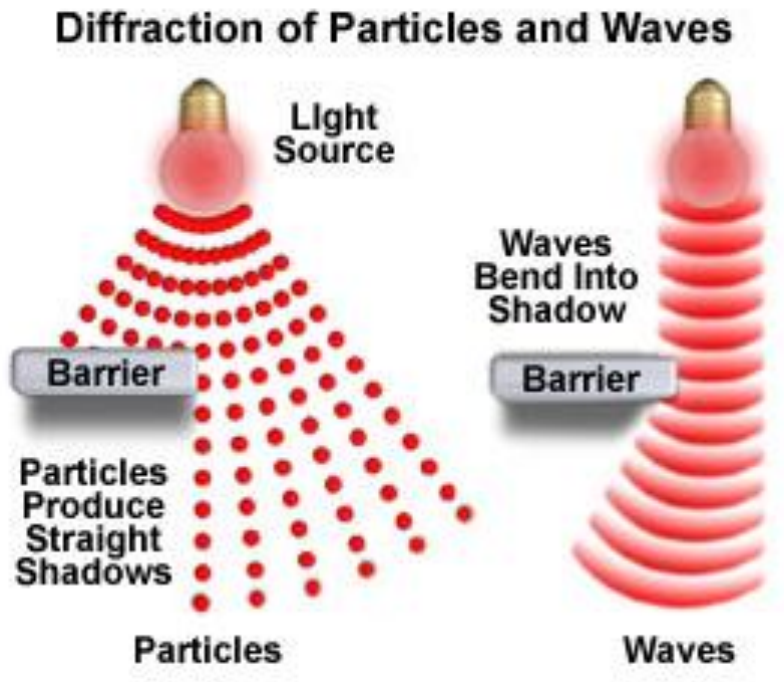
- The visible-light spectrum extends from short wavelength violet radiation through green and yellow to long-wavelength red radiation. On either side of the visible-light spectrum are ultraviolet light and infrared light.
- Visible light interacts with matter very differently from x-rays. When a photon of light strikes an object, it vibrates the molecules. The orbital electrons of some atoms are excited to an energy level that is higher than normal. This energy is immediately re-emitted as another photon of light (reflection).
- The atomic and molecular structures of any object determine which wavelengths of light are reflected.





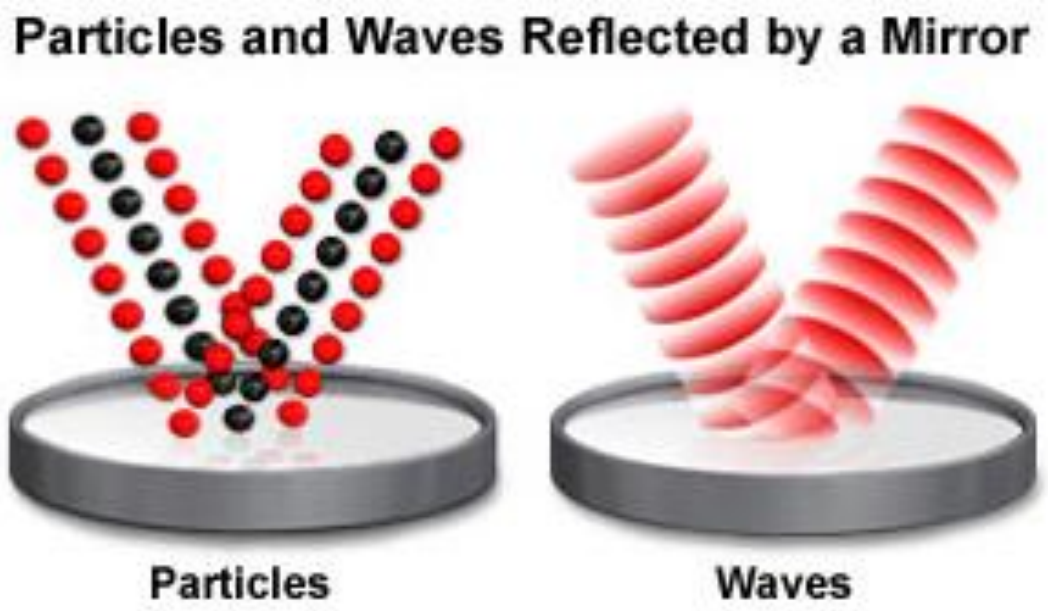
Wave Model / visible light particles

- A leaf in the sunlight appears green because nearly all the visible-light photons are absorbed by the leaf. Only photons with wavelengths in the green region are reflected. Similarly, a balloon may appear red by absorbing all visible light photons except long-wavelength red photons, which are reflected.



Wave Model / visible light particles

- Visible light particles are called photons, which are the smallest, fundamental particles of electromagnetic energy that carry light.
- These particles exhibit both wave-like and particle-like behaviors (wave-particle duality). Photons are emitted when electrons in atoms drop to lower energy levels.
- Visible light behaves like a wave.



Matter and Energy

- A simple relationship

$$\boldsymbol{E = m.c^2}$$

$E: the\ energy,$ $m: mass\ (kg),$ $c: speed\ of\ light\ (3 \times 10^8\ \frac{m}{s})$

allows the calculation of energy equivalence of mass and mass equivalence of energy. This equation is Einstein's theory of relativity.

Question: What is the energy equivalence of an electron (mass = 9.1×10^{-31} kg), as measured in joules and in electron volts?

$$\boldsymbol{E = m.c^2} = 9.1 \times 10^{-31} \times (3 \times \mathbf{10^8})^2 = 81.9 \times 10^{-15}\ \text{J}$$

$$= \frac{81.9 \times 10^{-15}}{\mathbf{1.6 \times 10^{-19}}} = 5.11 \times 10^5\ \text{keV}$$

Matter and Energy

Question: What is the energy equivalence of a proton (mass = 1.67×10^{-27} kg), as measured in joules and in electron volts?

$$E = m.c^2 = \quad \times \quad \times (3 \times 10^8)^2 = \quad \text{J}$$

$$= \frac{\times}{1.6 \times 10^{-19}} = \quad \text{keV}$$

Question: What is the energy equivalence of an object (mass = 1 kg), as measured in joules and in electron volts?

$$E = m.c^2 = \quad \times (3 \times 10^8)^2 = \quad \text{J}$$

$$= \frac{}{1.6 \times 10^{-19}} = \quad \text{keV}$$

Interactions of photon with matter

- Photon interactions with matter occur through three primary mechanisms:

1- Photoelectric effect

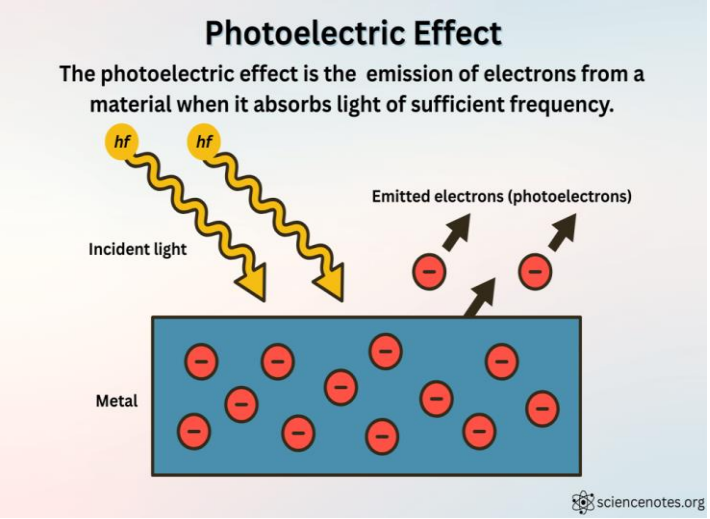
2- Compton scattering

3- Pair production

1- Photoelectric Effect (< 100 keV)

The photon is completely absorbed by an inner-shell electron, which is then ejected (photoelectron).

This effect dominates at <u>lower energies</u> and <u>higher (Z) materials</u>

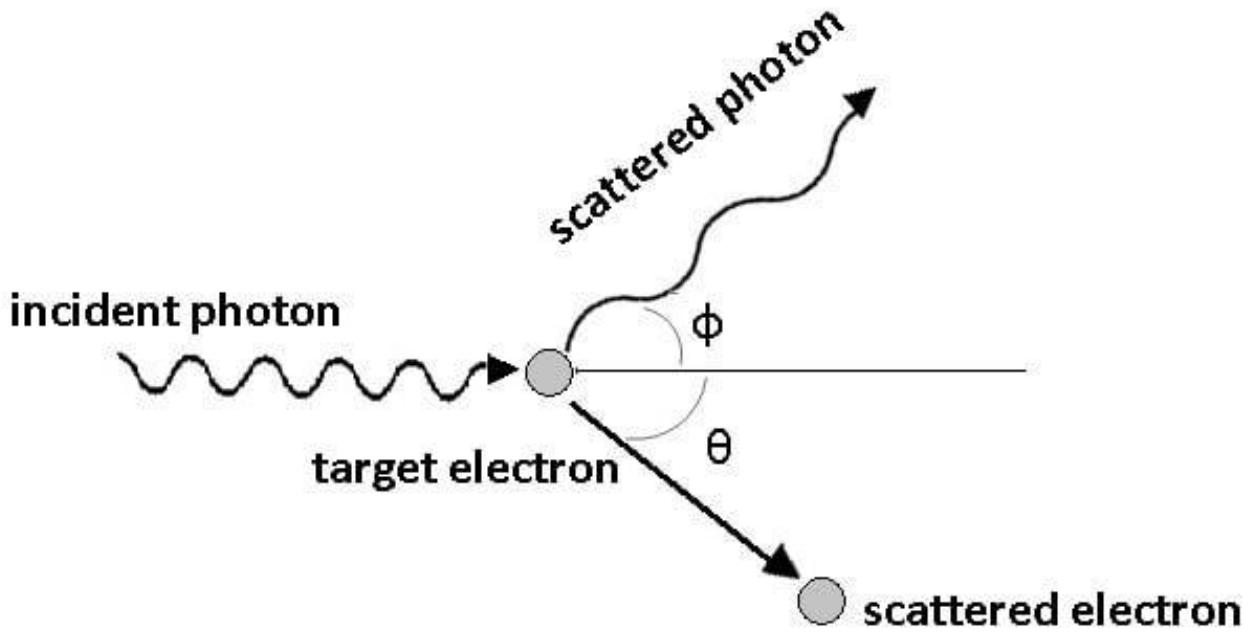


Interactions of photon with matter

2- Compton Scattering (100 keV - 10 MeV):

The incident photon interacts with an outer shell electron, transferring part of its energy and scattering at a lower energy level, while the electron is ejected.

resulting in a decrease in the photon's energy and an increase in its wavelength

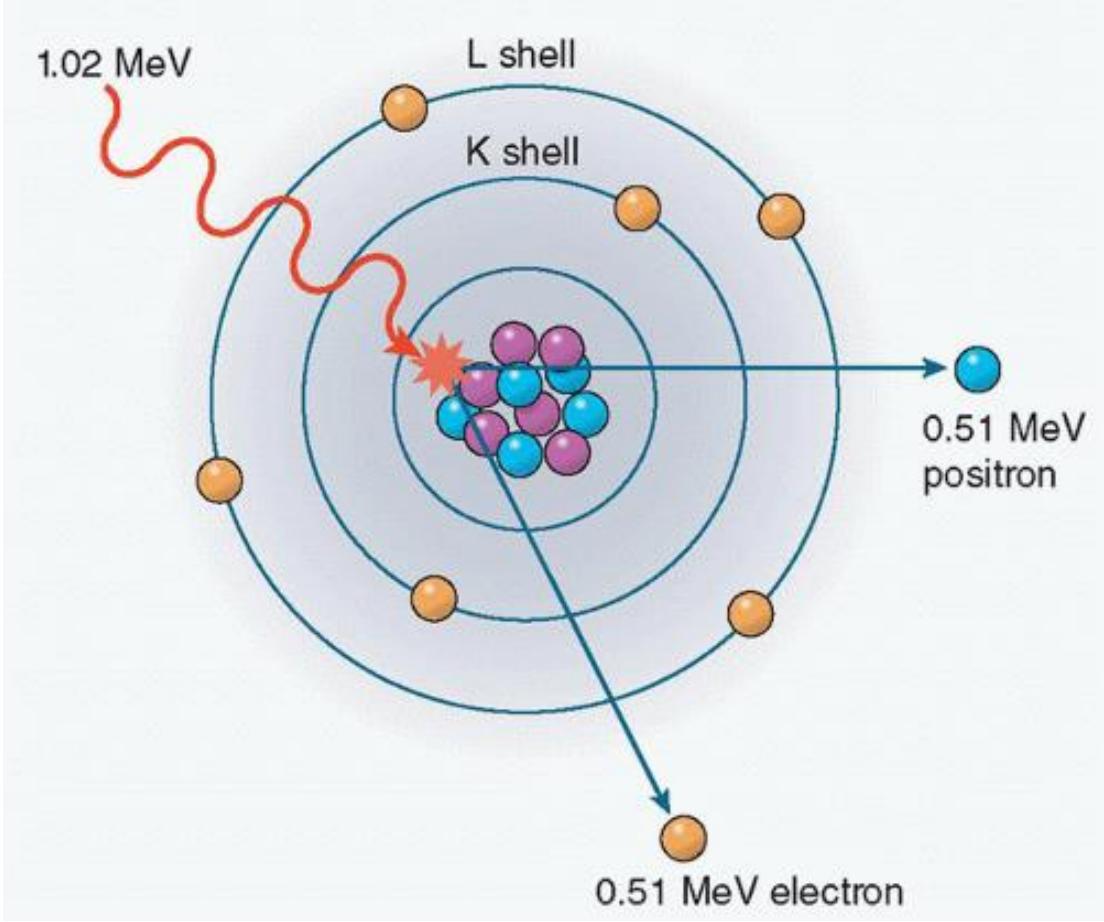


Interactions of photon with matter

3- Pair Production (> 1.02 MeV):

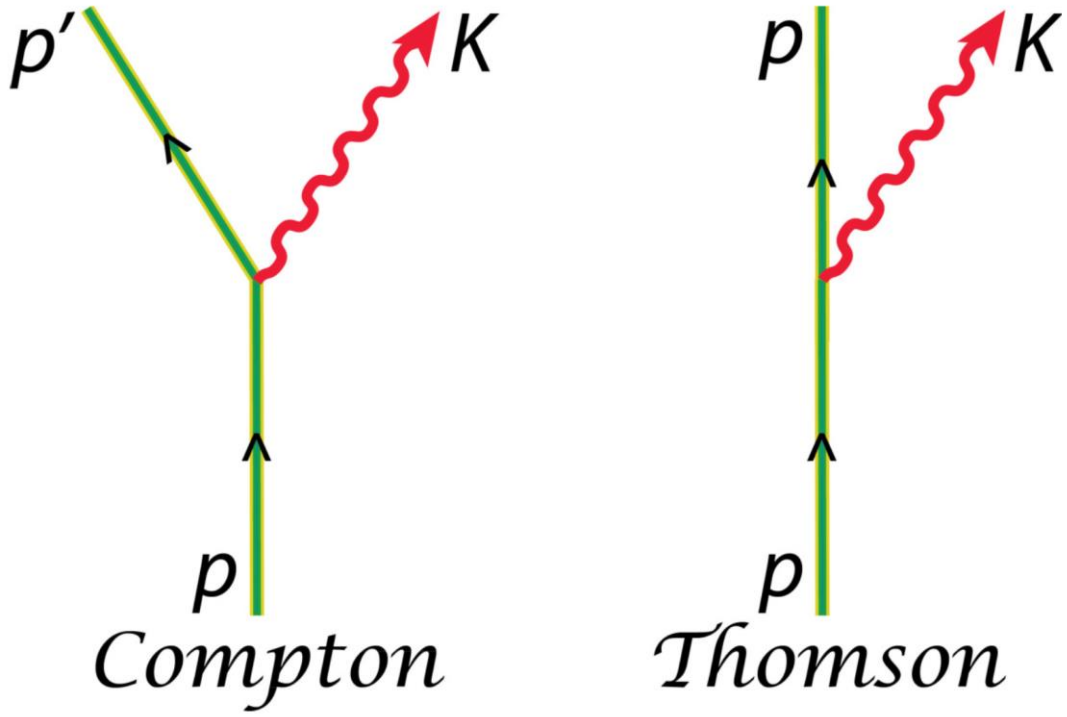
Pair production is the conversion of a high-energy photon (>1.02 MeV) into a particle and its antiparticle.

The photon interacts with the nucleus's electrostatic field, creating an electron and a positron, which then lose energy via ionization



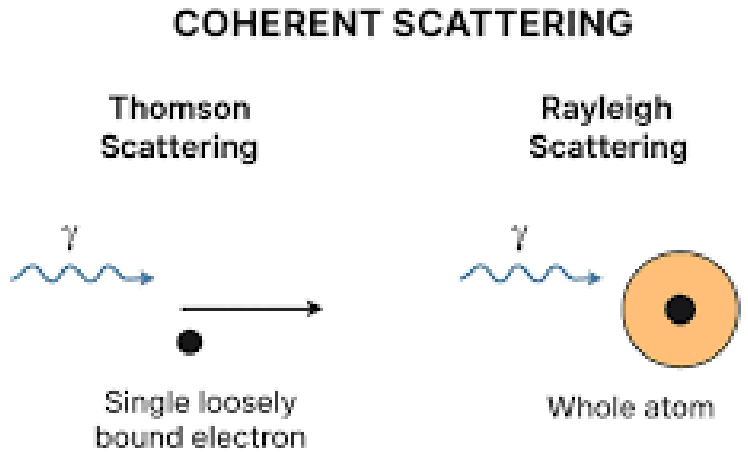
Thomson scattering, Coherent (Rayleigh) scattering

- **Thomson scattering** is the elastic scattering of low-energy electromagnetic radiation (photons) by free charged particles, (electrons).
- Thomson scattering is the low-energy approximation (elastic). Compton scattering occurs at higher energies, where the photon impacts the particle's kinetic energy, causing a frequency shift (inelastic).



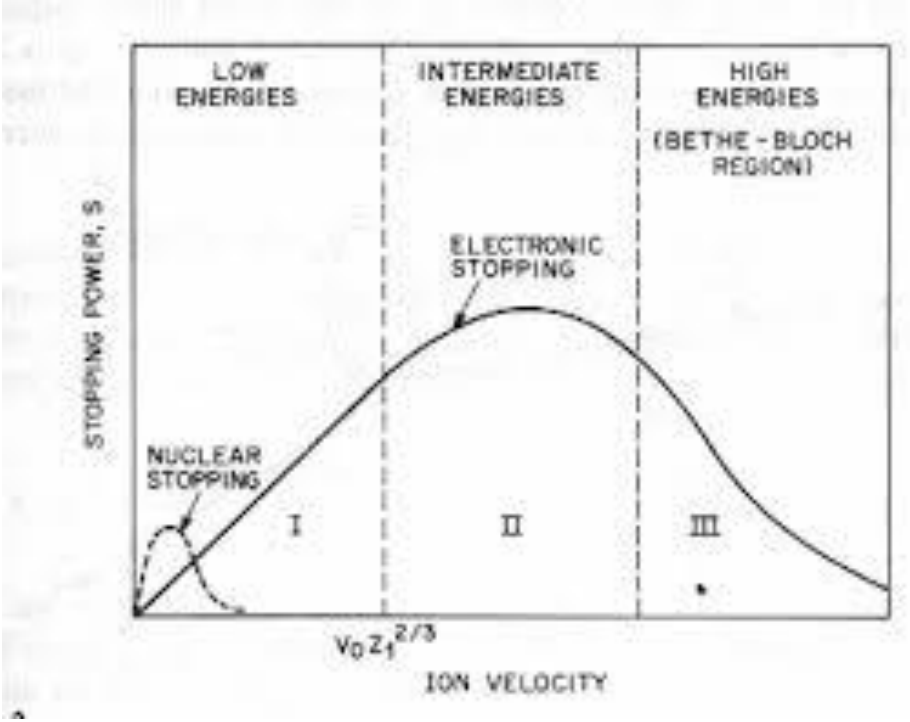
Thomson scattering, Coherent (Rayleigh) scattering

- **Coherent (Rayleigh) scattering** is a type of elastic, low-energy interaction where an incident photon interacts with an **entire atom's electron cloud**, changing direction without losing energy. It is characterized by zero energy deposition and is most common at lower energies (< 30 keV), such as in mammography
- Rayleigh scattering is the elastic scattering of a photon off an **entire atom**. Thomson scattering is the elastic scattering of a photon off a **single unbound electron**. Both are more likely to happen at lower energies.



Mechanism of Energy Loss: Stopping power

- **Stopping power** is the average rate at which energetic charged particles (like ions, protons, or electrons) lose kinetic energy per unit path length as they traverse a medium. It is primarily caused by Coulomb interactions, inelastic collisions with atomic electrons causing ionization/excitation, and elastic scattering with nuclei.
- Ionization is almost always the primary mechanism of energy loss. A charged particle (alpha or beta particle) exerts sufficient force of attraction or repulsion to completely remove one or more electrons from an atom



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