Physics of atom

Lecture One / Practical

Compton Scattering: Revealing the Particle Nature of Light

First stage

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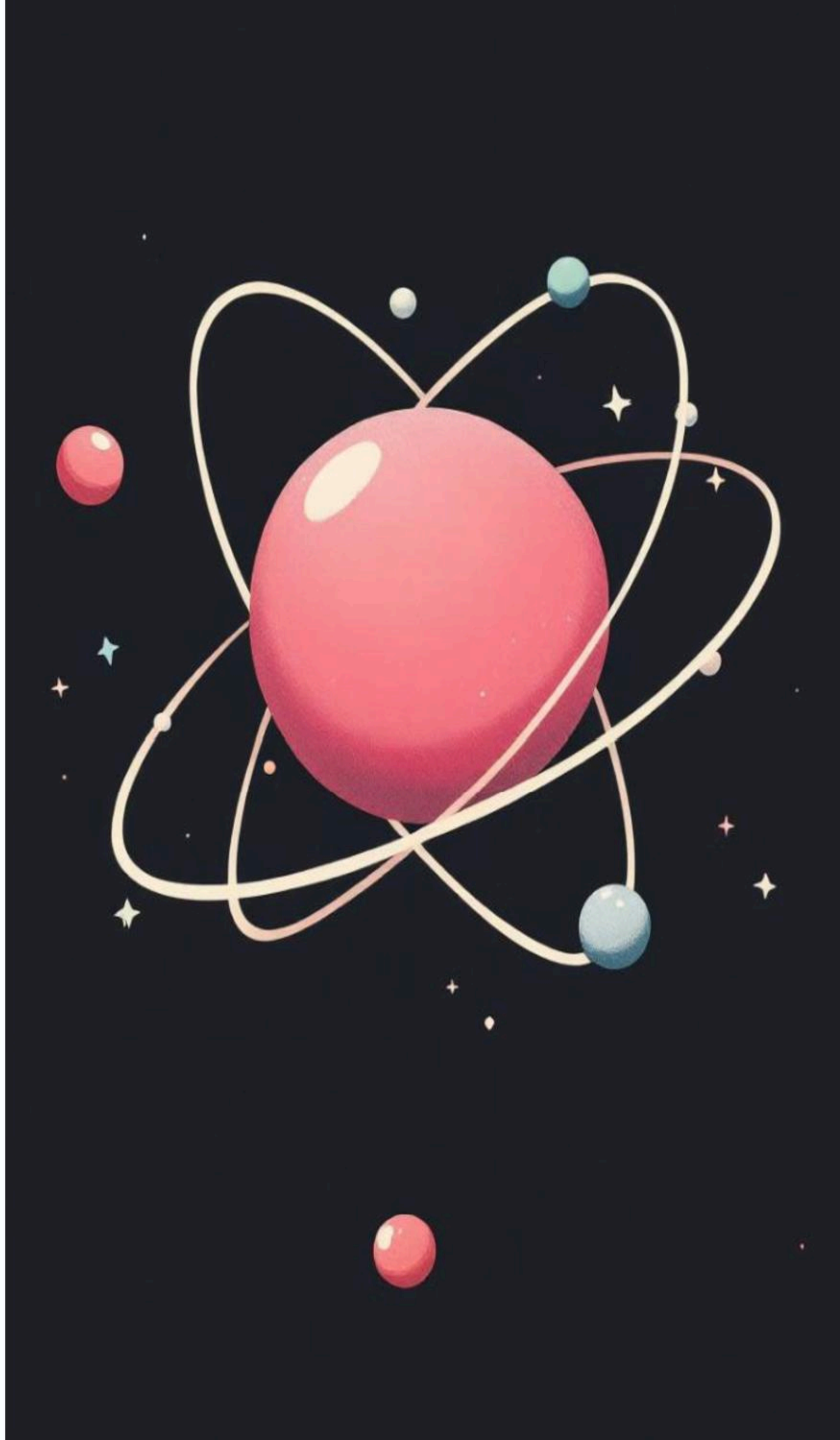
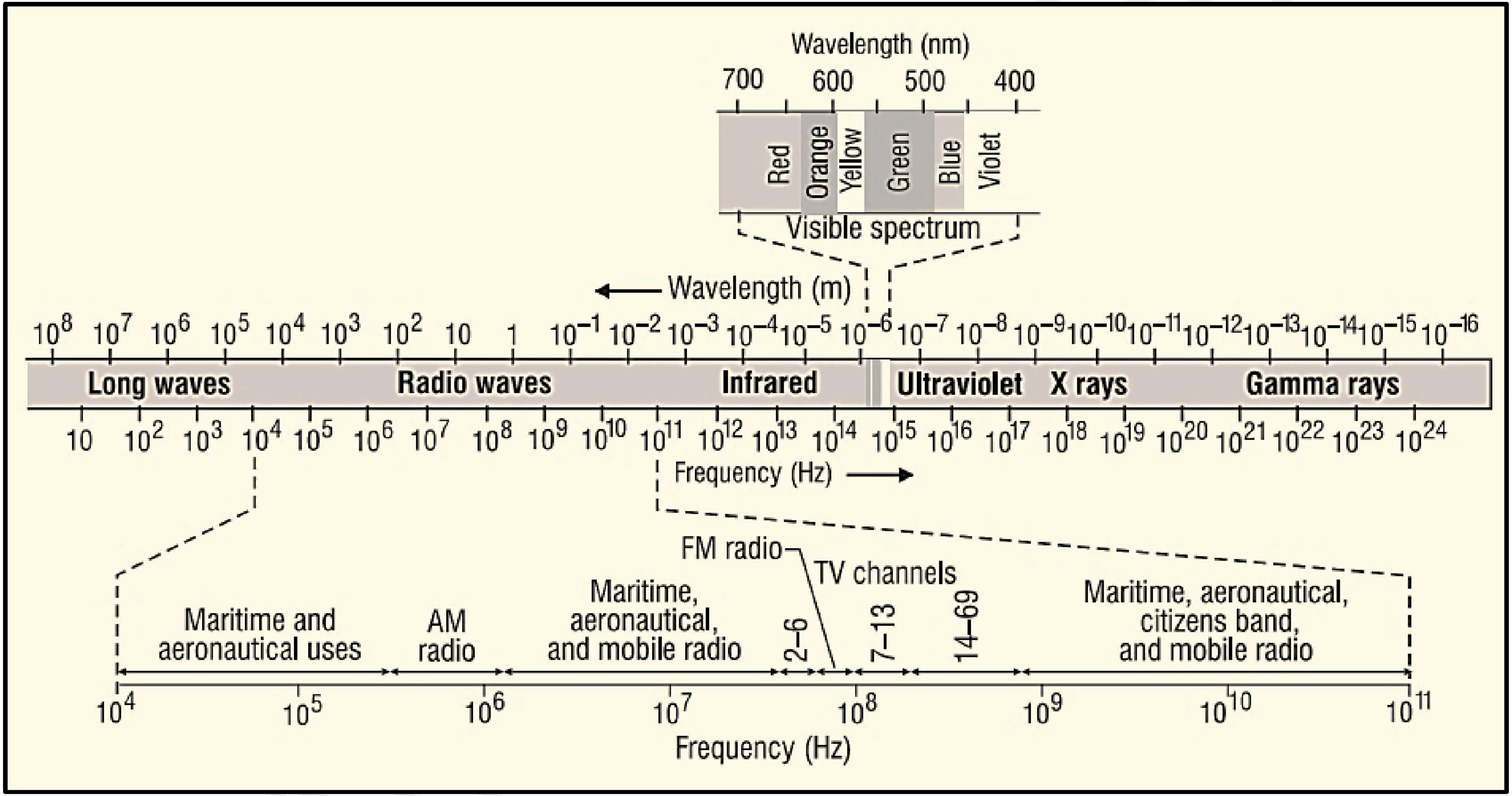




Electromagnetic Radiation Spectrum

Introduction

In his **1924 Ph.D**. thesis, **Louis de Broglie** claimed that **(electrons were also waves,** and gave a **formula for their wavelength)**.

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

where λ is the wavelength,

h is the Planck constant, ($6.626070\ 15 \times 10^{-34}$ J.s) ,,,, ($4.135667\ 696 \times 10^{-15}$ ev.s).

P is the momentum

m is the mass;

v is the velocity

Electron mass = 9.1×10^{-31} kg

Compton scattering is a fundamental phenomenon in physics that demonstrates the **particle nature of electromagnetic radiation (light).** Conducted by **Arthur H. Compton in 1923**, this experiment provided strong evidence for the **quantum theory** of light, showing that **photons behave like particles with momentum and energy**.

Photon

A photon is the quantum (smallest discrete unit) of **electromagnetic radiation**. It is an **elementary particle (a boson with integer spin).**

That serves as the force carrier for the electromagnetic force. Photons have **zero rest mass (massless)**, travel at the speed of light in a vacuum **(speed of light in vacuum): 3 ×10^{8} m /s), Charge Neutral (no electric charge)** and exhibit both **wave-like and particle-like properties**.

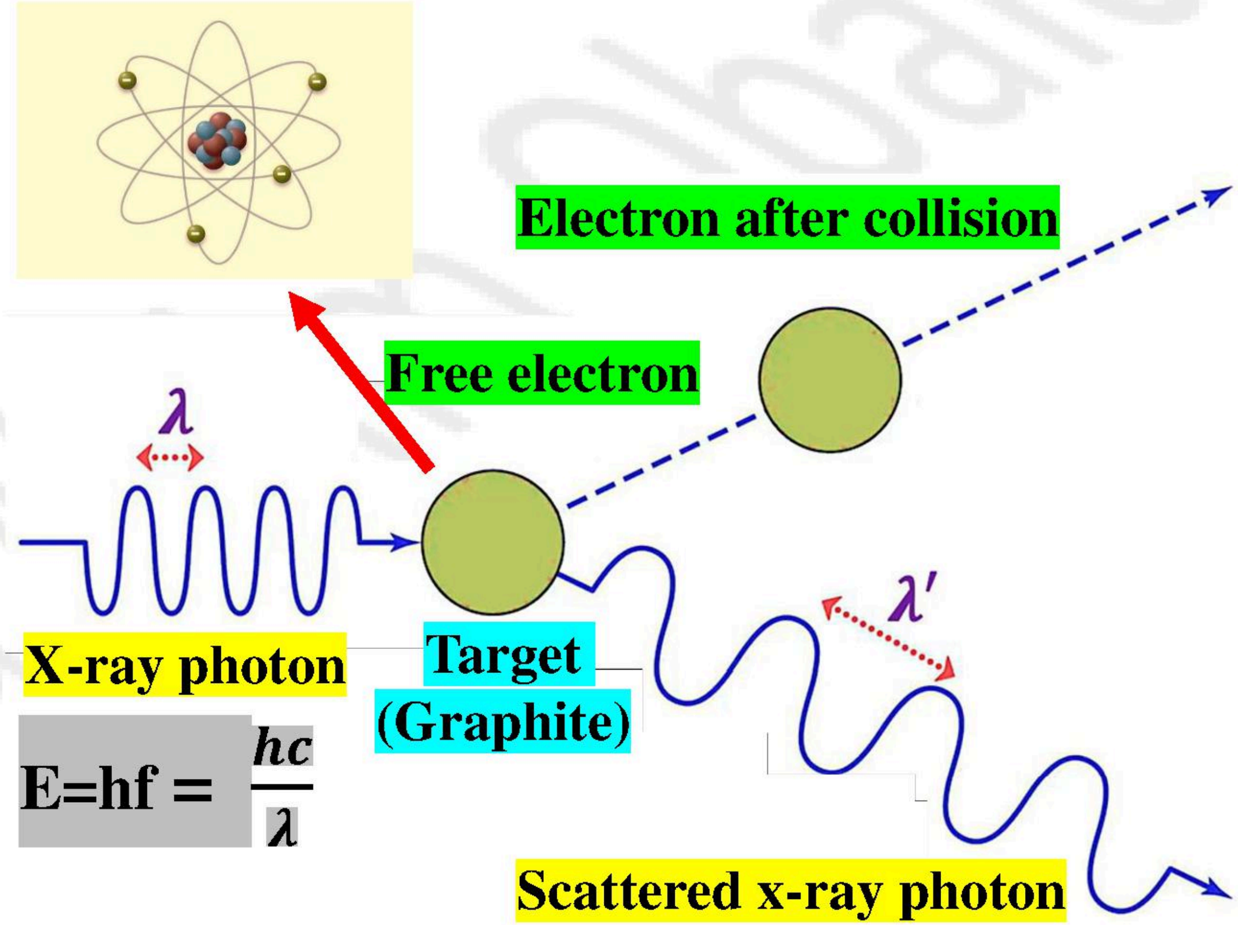
Experimental Setup

1. **X-ray Source:** A monochromatic X-ray beam (**refers to an X-ray beam that consists of photons with a single, well-defined wavelength (or energy)),** was directed at a target containing free electrons (e.g., graphite).

2. **Detector:** A Bragg spectrometer was used to measure the intensity and wavelength of the scattered X-rays at different angles (θ).

3. **Observations:** At each angle, two peaks were observed:

- **Unshifted Peak:** Corresponds to X-rays scattered without interaction with free electrons.
- **Shifted Peak:** Corresponds to X-rays scattered by free electrons, **with an increased wavelength**.



$$E = hf = \frac{hc}{\lambda}$$

(Compton Shift): The wavelength of the scattered photon increases compared to the incident photon due to the transfer of energy and momentum to the electron

Compton scattering formula

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta)$$

$$\Delta\lambda = \lambda_c(1 - \cos\theta)$$

$\Delta\lambda$ change in wavelength of the photon after scattering.

λ is the wavelength of the incident photon (before scattering).

λ' is the wavelength of the scattered photon (after scattering).

λ_c This is the **Compton wavelength** of the electron Numerically, $\lambda_c = 2.43 \times 10^{-12}$ **m**

$\cos\theta$ is the **scattering angle**.

- **When θ=0°** (forward scattering), (1−cosθ)=0, so there is no change in wavelength (Δλ = 0).
- **When θ=90°** (perpendicular scattering), (1−cosθ)=1, so the wavelength increases by exactly λ_c .
- **When θ=180°** (backscattering), (1−cosθ)=2, so the wavelength increases by $2\ \lambda_c$.**(Maximum wavelength shift)**
- **The compton scattering depends on the scattering angle θ .**

Problem 1: **An X-ray photon with a wavelength of 0.02nm is scattered at an angle of 90° . Calculate the wavelength of the scattered photon.**

Sol/

$$\Delta\lambda = \lambda_c(1 - cos\theta)$$

$$\Delta\lambda = (2.43\times10^{-12})\,(1-0) = \mathbf{2.43\times10^{-12}m}$$

Wavelength of scattered photon (λ′)

$$\lambda' = \lambda + \Delta\lambda$$

Substituting $\lambda = 0.02$ nm = 2×10^{-11}m:

$$\lambda' = (2\times10^{-11}) + (2.43\times10^{-12}) = \mathbf{2.243\times10^{-11}m}$$

Problem 2: **What is the maximum possible wavelength shift for a photon undergoing Compton scattering?**

Sol/

Maximum wavelength shift occurs at θ=180°:

$$\Delta\lambda_{max} = \lambda_c(1 - \cos 180^0)$$

$$\Delta\lambda_{max} = 2\,\lambda_c$$

$$\Delta\lambda_{max} = 2\,(2.43 \times 10^{-12}\,m)$$

$$\Delta\lambda_{max} = 4.86 \times 10^{-12}\,\text{m}$$

Problem 3: **A photon with a wavelength of 0.03nm undergoes Compton scattering, and the scattered photon has a wavelength of 0.03243nm. Calculate the scattering angle?**

Sol/

$$\Delta\lambda = \lambda' - \lambda$$

Substituting $\lambda' = 0.03243\text{nm} = 3.243\times10^{-11}\text{m}$ and $\lambda = 0.03\text{nm} = 3\times10^{-11}\text{m}$

$$\Delta\lambda = (3.243\times10^{-11}) - (3\times10^{-11}) = \mathbf{2.43\times10^{-12}m}$$

Compton formula

$$\Delta\lambda = \lambda_c\,(1-\cos\theta)$$

$$1-\cos\theta = \frac{\Delta\lambda}{\lambda_c}$$

$$1-\cos\theta = \frac{2.43\times10^{-12}\,m}{2.43\times10^{-12}\,m}$$

$$1-\cos\theta = 1$$

$$\cos\theta = 1\text{-}1$$

$$\cos\theta = 0$$

$$\theta = \cos^{-1}(0) = 90^{0}$$

$$\theta = 90^{0}$$