Chapter 3: Waves and Particles

3.1 Spectral energy density

Classical wave theory predicts that as light frequency increases, the spectral energy density increases without bound

$$\frac{dU}{df} = k_B T \times \frac{8\pi V}{c^3} f^2$$

Planck's Energy density formula

$$\frac{dU}{df} = \frac{hf}{e^{hf/k_B T} - 1} \times \frac{8\pi V}{c^3} f^2$$

3.2 Photoelectric Effect

Light of very small λ can hit a metal target and blast an electron off the surface. We can use this to measure Planck's constant h.

$$E = hf = h\frac{c}{\lambda}$$

energy of photon

$$KE_{max} = hf - \Phi$$

energy of ejected electron
or "Photoelectron"

where Φ is the amount of energy required to free the electron from the metal. It is also known as the "work function" of the metal, and is usually measured in eV.

3.3 Production of X-rays

X-rays are produced by very high energy electrons (25+ keV) smashing into a metal target. All of the electron's kinetic energy is transformed into an X-ray photon of wavelength λ = 0. 05 nm or smaller. In other words,

$$(\gamma_u - 1)m_e c^2 \quad = \quad hc/\lambda$$

energy of electron energy of photon

Where

$$u = speed\ of\ the\ electron$$
$$\gamma_u = \frac{1}{\sqrt{1 - \frac{u^2}{c^2}}}$$
$$m_e = 9.10938188 \times 10^{-31}\ kg$$

3.4 Compton Effect

Photons have no mass, but they do have momentum

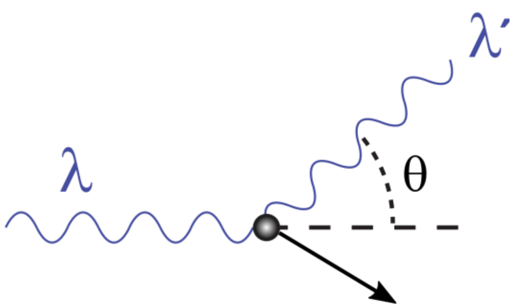
$$p = \frac{h}{\lambda}$$

We can think of X-ray (or gamma ray) photons hitting a surface as a collection of two-particle collisions. Incoming photons collide with the electrons, causing them to gain kinetic energy. To summarize the interaction,

(before collision)	(after collision)
Electron has only internal energy $E = m_e c^2$	Electron has kinetic energy
Photon has wavelength λ	Photon has longer wavelength λ'

The **Compton effect** describes the change in wavelength of the photon after the collision occurs. Compton's formula gives the relation between the change in λ and the angle of scattering

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



Min and max change in wavelength (λ′ – λ)

- The minimum change occurs when the scattering angle is 0° ($cos(0°) = 1$)
- The maximum change occurs when the scattering angle is 180° ($cos(180°) = -1$)

3.5 Pair Production

A pair of elementary particles with equal mass and opposite charge value can be produced when a photon is absorbed by a nearby atom. For pair production to occur, the energy (hf) must be at least equivalent to the mass of two electrons, meaning the photon must have 1.02 MeV or more.

3.6 Wave or Particle?

EM radiation can be described as a wave or particle.

Double-slit experiment

A Light source shines through two slits and is detected on a screen.

- At high intensity: continuous interference pattern is observed.
- At very low intensity: same interference pattern is observed, but made of discrete points.

If EM radiation is just waves, it makes sense – the waves interfere with each other. But if EM radiation is made of particles, what are the particles interfering with? As it turns out, the EM field measures the probability of finding a photon in a given spot too.