
# Unit 18: Quantum Physics

## 1 QUANTUM THEORY OF LIGHT - THE PHOTON

### 1.1 Max Planck's Quantum Theory

**Planck's Quantum Theory states that light is emitted and absorbed as particles or discrete packets of energy called photons.**

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

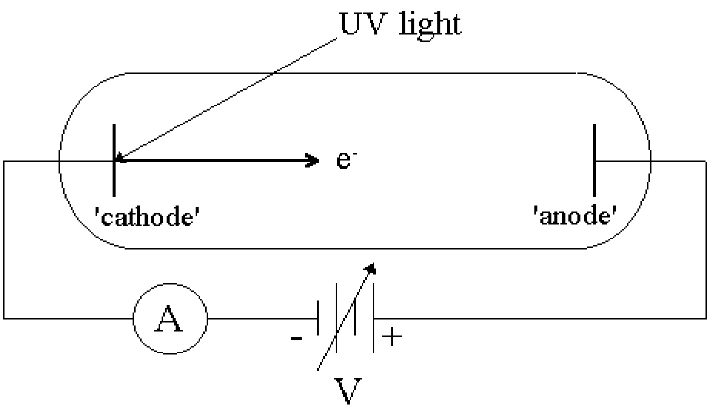
$$E_{\text{total}} = Nhf$$

The power of radiation is given by $P = \frac{E_{total}}{t} = \left(\frac{N}{t}\right) \times hf$

Hence $P$ = no. of photons emitted per unit time × energy of a photon

## 2 THE PHOTOELECTRIC EFFECT

**Photoelectric effect is the emission of electrons from the surface of a metal when electromagnetic radiation of sufficiently high frequency is shone on it.**




### 2.1 Experimental Observations of Photoelectric Effect

1. Electrons are emitted only when the frequency of light is above some minimum value $f_o$ called the **threshold frequency**. If the frequency is below $f_o$ , no electrons are emitted **regardless of how intense the light is**. The threshold frequency is characteristic of the metal irradiated. For zinc, the threshold frequency is in the ultraviolet region.

**Note:** The wavelength of radiation corresponding to the threshold frequency is called the **threshold wavelength**, $\lambda_0$. No emission of photoelectrons occurs for wavelengths greater than this.

2. Emission of photoelectrons is almost **instantaneous**. The time lag between turning on the light and the emission of the first electrons was negligible (~ $10^{-9}$ s) and unaffected by the intensity or brightness of the light, if the light is above the threshold frequency.

3. The **maximum kinetic energy** of the ejected electrons is **independent of the intensity** of the light, but **dependent** on the **frequency of the light** used.

4. The rate at which electrons were ejected and therefore the **photocurrent** produced was **proportional** to the **intensity** (brightness) of the light.

## 2.2 Failure of the Classical Wave Theory

**1. The existence of the threshold frequency**

Since energy of the wave is dependent on the square of its amplitude, the classical wave theory predicts that if sufficiently intense light is used, the electrons would absorb enough energy to escape. There should **not** be any threshold frequency.

**2. The almost immediate emission of photo-electrons**

Based on classical wave theory, electrons should absorb energy over a period of time before it gains enough energy to escape the metal. Accordingly, a dim light after some delay would transfer sufficient energy to the electron for ejection, whereas a very bright light would eject electrons after a short while. However, this did not happen in photoelectric effect.

**3. The frequency dependence of the maximum kinetic energy**

According to classical wave theory, by using light with higher intensity, the kinetic energy of an ejected electron can be increased. This is because the greater the intensity, the larger the energy of the light wave striking the metal surface, so electrons are ejected with greater kinetic energy. It cannot explain why the maximum kinetic energy is dependent on frequency and independent of intensity.

## 2.3 Einstein's Explanation of the Photoelectric Effect

1. A beam of light can be considered to be a **stream of particles** (called photons). Each photon has an energy given by:

$$E = hf$$

2. The intensity of the light beam $I$ is directly proportional to the number of photons passing through a unit cross-sectional area per unit time,

Intensity $$I = \frac{E_{total}}{tA} = \frac{Nhf}{tA} = nhf$$

where $n = \left(\frac{N}{tA}\right)$ is the number of photons passing a unit cross-sectional area per unit time.