Quadrant II – Notes

Programme: Bachelor of Science (Third Year)

Subject: Physics

Paper Code: PYD101

Paper Title: Quantum Mechanics

Unit 1: Waves and particles

Module Name: The concept of particle nature of radiation (Photoelectric Effect)

Module No: 02

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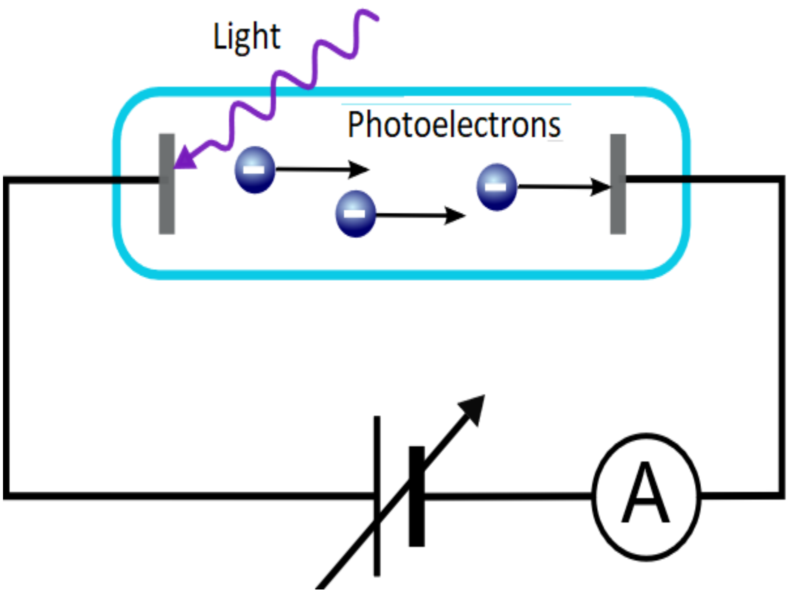
The Photoelectric Effect

In 1887, Hertz discovered that when the light of short wavelength is incident on a metal surface, it emits electrons. The electrons ejected out of the metal under the action of light are known as photoelectrons and this phenomenon is known as the photoelectric effect.



The Photoelectric Experiment

A retarding potential, V, is applied between the cathode and anode. When the Ultraviolet rays are incident on the metal plate, anode, photoelectrons are emitted from the surface. Some emitted photoelectrons have enough energy to reach the cathode, in spite of the retarding potential, and constitute a current. The number of emitted electrons decreases (or the current decreases) with increasing retarding potential. When V exceeds a certain value Vo, current ceases as the electrons do not have enough energy to strike the cathode.

Observations of the Photoelectric Effect

- The energy distribution in the emitted electrons is independent of the intensity. i.e. a strong light beam yields more photoelectrons than a weak beam but the average energy of the photoelectrons does not change.
- There is no time lag between the arrival of light at the metal and the emission of the electrons.
- The energy of the photoelectron depends on the frequency of the light incident on the metal. No electrons were emitted at frequencies below a certain critical frequency (Threshold frequency), which depends on the characteristic of the material. Above this frequency, the energy of the electrons increases linearly with the frequency.
- The strength of the photoelectric current is directly proportional to the intensity of the incident light, provided the frequency is greater than the threshold frequency.

The Failure of the Electromagnetic Theory

- According to calculations, if ultraviolet light is incident on sodium, it would require about 500 days to knock off an electron from it. Experimentally, no time lag was observed between the incident light and the emitted photoelectron.
- According to the classical theory, the light of greater intensity should impart greater K.E to the ejected electron. But this was not observed.
- Also, the velocity of the ejected electron should not depend on the frequency of light, but according to the experiment it does.

Einstein's Photoelectric Equation

Einstein proposed that electromagnetic radiation is quantized into quanta of energy $h\nu$, where h is Plank's constant. When a photon of light is incident on the metal, the energy of the photon is completely transferred to the electron. A part of the energy of the photon is required to dislodge the electron from the metal and the rest of the energy is transferred into the kinetic energy of the photoelectron. The minimum energy required by the electron in order to escape from a metal surface is called its Work Function. Einstein's photoelectric effect equation is given by

$$hv = \frac{1}{2}mv^2 + hv_0$$

Where hv_0 is the work function and v is the velocity of the electron.

Success of the quantum theory

The quantum theory of light is successful in explaining the photoelectric effect. It predicts correctly that the maximum photoelectron energy depends on the frequency of the incident light. It is also able to explain why even the feeblest light can lead to immediate emission of the photoelectrons. Also, it gave an explanation as to why no photoelectrons were observed, below the threshold frequency, even if high-intensity beam was used.