Quantum Mechanics-Section3

Dr. Jayanta Das

Department of Physics, Maharaja College, Ara, Bihar-802301

1 Wave *vs.* Particle

1.1 Photoelectric Effect: Quantization of Light

This topic has already been discussed briefly in the section- ‘Why do we need Quantum Mechanics?’. Here, the phenomena will be elaborated in details.

Phtoelectric effect was discovered earlier in 1887, when German physicist Heinrich Hertz was performing experiment with spark gap generator. He observed that he could change the sparking voltage between two metal plate electrodes by irradiating the plates with ultraviolet lights. But, no proper scientific explanation of the phenomena was available at that time. In 1897, J J Thomson discovered electron (e^-), the elementary charged particle inside atom. Studies by Thomson revealed that the observed modification in sparking voltage is the effect of light pushing electrons out of the electrode metals. The electromagnetic theory of light, on the other hand, was already well established by James Clerk Maxwell in 1865. It was known that electromagnetic waves transport energy from one place to other. It was therefore easy to imagine that electromagnetic energy is absorbed by atoms and as a result, the electrons are pushed out. These electrons, as they originate due to light, were called ‘photoelectrons’.

It was Philipp Lenard, an assistant of Hertz, who performed detailed studies on photoelectric effect later on. Putting the clean electrodes inside a vacuum tube, Lenard performed frequency and intensity dependent photoemission studies. These electrodes were connected to variable power supply and a micro-ammeter (μA) was used to measure electrical current through the circuit. In figure 1, a typical circuit diagram demonstrates the experimental arrangement for photoelectric effect. Ultraviolet light from external source falls on a photosensitive plate/cathode.

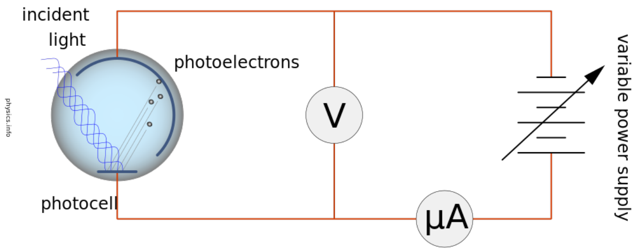

Figure 1: Photoelectric effect circuit

Photoelectrons emits out of one plate (emitter, cathode plate) and are collected on another plate (collector, anode plate). These electron flow through the closed loop while the photocurrent is measured by μ-Ammeter. This photocurrent (I) can be measured as a function of potential difference ‘V’ between the electrodes as well as function of frequency (ν) of the incident light. The voltage and frequency dependance of the current I will be discussed in different sections below.

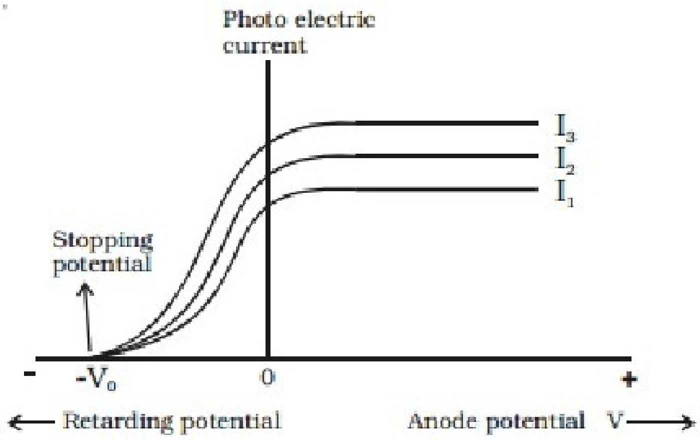

Figure 2: Variation of photocurrent I_{ph} with the potential difference V between the plates. The magnitude of photocurrent depends on incident light intensity, while the value of stopping potential V_S does not.

1.1.1 Potential difference (V) *vs.* photocurrent (I_{ph}): Light intensity (I) dependence

A typical I_{ph}-V characteristic is shown schematically in figure 2 for a fixed frequency ν and three different intensities (I_1,I_2,I_3) of the incident light. The notable point is that, even at zero potential difference between the electrodes, a finite current could be measured by μ-Ammeter. This means that the emitted photoelectrons have their intrinsic kinetic energy $\frac{1}{2}mv^2$ to reach the collecting plate even in absence of external electric field. At higher positive voltages, the plate current saturates. This happens when all the photoemitted electrons reach the collecting plate/anode, therefore the maximum current is reached. On the other hand, while the anode voltage is biased negatively with respect to the emitting plate, the current decreases gradually and eventually becomes zero. This occurs due to increasing repulsive force on the photoelectrons by the collecting plate. The corresponding negative voltage (-V_S) of the anode, for which the photocurrent just becomes zero, is called the *stopping potential.* $|-V_S|$ equals to the maximum kinetic energy of the emitted photoelectron $\frac{1}{2}mv_{max}^2$. It was observed later by Lenard (also we see in figure 2) that the intensity of the incident light has no effect on the magnitude of stopping potential. In figure 2, there are three characteristic curves corresponding to three incident light intensities I_1,I_2 and I_3. However, the stopping potential is same for all the cases. It is also interesting that the saturation photocurrent depends on the radiation intensity. As the radiation intensity increases, the saturation current also increases. Here, in the graph, $I_3>I_2>I_1$ and therefore the corresponding saturation current $I_{s3}^{ph}>I_{s2}^{ph}>I_{s1}^{ph}$.

References

[1] Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles, Authors: R. Eisberg, R. Resnick, Publisher: Wiley

[2] Quantum Physics, Author: Stephen Gasiorowicz, Publisher: John Wiley and Sons

[3] Quantum Mechanics: Theory and Applications, Authors: A. Ghatak, S. Lokanathan, Publisher: Trinity Press

[1]

---

[1] Figures are collected from online resources.