

PHYSICS PROJECT

**TOPIC-DUAL NATURE
OF RADIATION AND
MATTER**

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CLASS-I2 SECTION-D

INTRODUCTION

In the late 19th century, scientists made significant discoveries in understanding atomic structure and electricity. They found that light behaves like waves, which was supported by Maxwell's equations and Hertz's experiments. Experiments with electricity in low-pressure gas discharge tubes led to the discovery of cathode rays, fast-moving negatively charged particles.

J. J. Thomson confirmed that these rays were made up of electrons, fundamental particles found universally in matter. He determined their speed and specific charge. Interestingly, the specific charge remained constant, regardless of the material used or the gas present in the tubes.

Around the same time, scientists discovered that certain metals emitted negatively charged particles when exposed to ultraviolet light or high temperatures. These particles turned out to be electrons, having the same specific charge as the cathode rays.

For his work on electrons and electricity conduction, J. J. Thomson received the Nobel Prize in Physics in 1906. Later, R. A. Millikan's oil-drop experiment confirmed that electric charge is quantized, and from this, the mass of an electron could be determined.

These discoveries paved the way for modern physics and our understanding of the building blocks of matter.

ELECTRON EMISSION

Electron emission refers to the process by which electrons are released from a metal surface. Normally, metals contain free electrons that are responsible for their conductivity. However, these free electrons are bound to the metal's surface due to attractive forces from the metal ions. To escape, an electron must possess enough energy to overcome this attractive force. The minimum energy required for an electron to escape is called the work function (ϕ_0) and is measured in electron volts (eV).

The work function depends on the metal's properties and surface nature. Different metals have different work function values. For example, platinum has the highest work function ($\phi_0 = 5.65 \text{ eV}$), while caesium has the lowest ($\phi_0 = 2.14 \text{ eV}$).

Electron emission can occur through various processes:

A) Thermionic emission: By heating the metal, free electrons gain sufficient thermal energy to escape from the metal's surface.

B) Field emission: Applying a very strong electric field (of the order of 10^8 V/m) to a metal allows electrons to be pulled out, as in a spark plug.

C) Photoelectric emission: When light of suitable frequency shines on a metal surface, electrons are emitted from the metal. These photo-generated electrons are called photoelectrons.

These processes are essential in understanding electron behavior and have significant applications in atomic and nuclear physics.

PHOTOELECTRIC EFFECT

HERTZ'S OBSERVATION-

The photoelectric effect, first observed by Heinrich Hertz in 1887, is a phenomenon related to the emission of electrons when a material is exposed to light. During Hertz's experiments on electromagnetic waves, he noticed that illuminating a metal surface with ultraviolet light from an arc lamp enhanced the high voltage sparks across the detector loop.

When light shines on a metal surface, certain electrons near the surface absorb energy from the incident radiation. This absorbed energy allows these electrons to overcome the attractive forces of the positive ions within the material. Once these electrons gain enough energy from the incident light, they are able to escape from the surface of the metal and enter the surrounding space. These free electrons are what we now commonly refer to as photoelectrons.

HALLWACH'S AND LENARD'S OBSERVATIONS

During the late 19th and early 20th centuries, Wilhelm Hallwachs and Philipp Lenard conducted detailed investigations on the photoelectric emission phenomenon.

Lenard's experiments involved an evacuated glass tube with two metal plates (electrodes). When ultraviolet radiations were allowed to fall on one of the metal plates (the emitter plate), a current flowed in the circuit. As soon as the ultraviolet radiations were stopped, the current flow also stopped. This showed that ultraviolet light caused electrons to be ejected from the emitter plate, attracted towards the positively charged collector plate, and resulted in the current flow.

In 1888, Hallwachs connected a negatively charged zinc plate to an electroscope and observed that when illuminated by ultraviolet light, the zinc

plate lost its charge and even became positively charged. These observations led him to conclude that negatively charged particles (electrons) were emitted from the zinc plate under the influence of ultraviolet light.

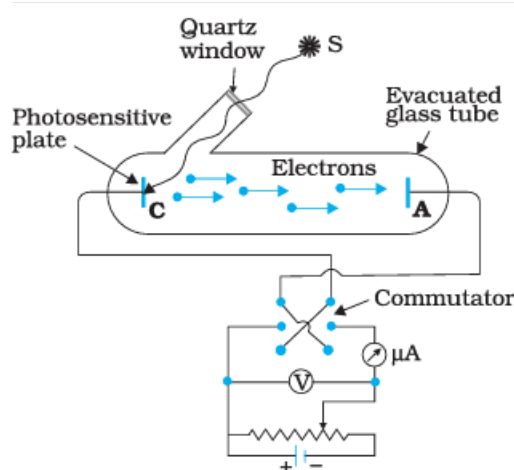
With the discovery of electrons in 1897, it became clear that incident light causes the emission of electrons from the emitter plate. These emitted electrons are attracted towards the collector plate due to their negative charge.

Hallwachs and Lenard also observed that the emission of electrons depended on the frequency of the incident light. When the frequency of the incident light was lower than a certain minimum value, known as the threshold frequency, no electrons were emitted. The threshold frequency varied with the material of the emitter plate.

They found that certain metals like zinc, cadmium, and magnesium responded only to ultraviolet light for electron emission, whereas alkali metals like lithium, sodium, potassium, caesium, and rubidium were sensitive even to visible light. All these photosensitive substances emit electrons when illuminated by light. These emitted electrons came to be known as photoelectrons, and the phenomenon was termed the photoelectric effect.

EXPERIMENTAL STUDY OF PHOTOELECTRIC EFFECT

The experimental study of the photoelectric effect involves a setup shown in Figure. It consists of an evacuated glass or quartz tube with two metal plates: the photosensitive plate C (emitter) and the collector plate A. Monochromatic light of short wavelength is emitted from a source S and passes through a window W to



fall on the photosensitive plate C. The transparent quartz window allows ultraviolet radiation to reach the photosensitive plate.

When light falls on the photosensitive plate, electrons are emitted from it. These emitted electrons are collected by the collector plate A, which is maintained at a desired positive or negative potential relative to the emitter plate C using a battery and a commutator. The potential difference between the emitter and collector plates can be varied. The emitted electrons cause an electric current to flow in the circuit, which is measured by a microammeter (μA), while the potential difference is measured by a voltmeter (V).

Using this setup, various aspects of the photoelectric effect can be studied:

- (a) Variation of photocurrent with intensity of radiation,
- (b) Variation of photocurrent with the frequency of incident radiation,
- (c) The effect of the potential difference between the collector and emitter plates,
- (d) The influence of the material used for the emitter plate C.

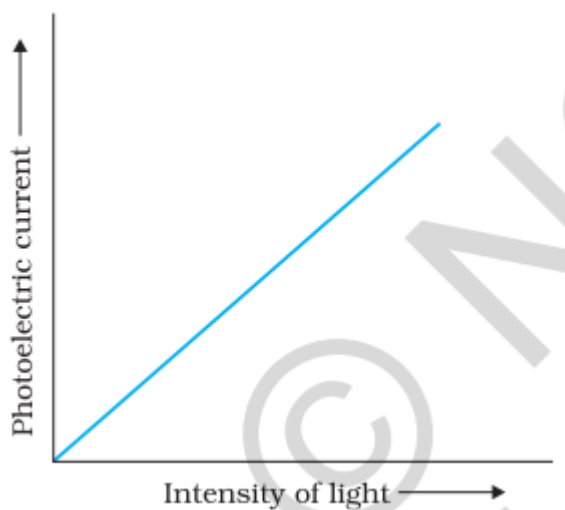
To study different frequencies of light, colored filters or glass can be placed in the path of light falling on the emitter C. The intensity of light can be adjusted by changing the distance of the light source from the emitter. By performing these experiments and observing the resulting photocurrent, researchers can gain insights into the behavior and characteristics of the photoelectric effect.

EFFECT OF INTENSITY OF LIGHT ON PHOTOCURRENT

In the experimental setup, the collector plate A is maintained at a positive potential with respect to the emitter plate C. This arrangement ensures that electrons ejected from the emitter plate C are attracted towards the collector plate A due to the electric field created by the potential difference.

To study the effect of the intensity of incident light on the photoelectric effect, the frequency of the incident radiation and the accelerating potential are kept fixed. However, the intensity of light is varied, and the resulting photoelectric current is measured each time. The observations show that the photocurrent increases linearly with the intensity of the incident light, as depicted in Fig. 11.2.

The graph in Fig. 11.2 illustrates that the photocurrent is directly proportional to the number of photoelectrons emitted per second. In other words, as the intensity of incident light increases, more photoelectrons are emitted per unit of time. This implies that the number of photoelectrons emitted per second is directly proportional to the intensity of incident radiation. Thus, brighter light (higher intensity) leads to a greater number of photoelectrons being emitted, while dimmer light (lower intensity) results in a lower number of photoelectrons emitted.



EFFECT OF POTENTIAL ON PHOTOELECTRIC CURRENT

