UNIT 3

PHOTOELECTRICITY

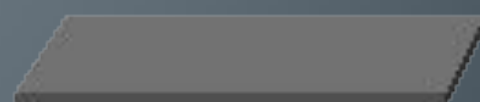
OBJECTIVES

After studying this topic YOU will be able to

- State Planck's hypothesis and properties of photons.
- Draw circuit diagram and explain the process of photoelectric emission.
- Define: Threshold frequency, threshold wavelength, stopping potential and work function.
- State characteristics of photoelectric effect.
- Derive Einstein's photoelectric equation.
- Solve numerical on photo electricity.
- Explain the principle, construction, working and application of LDR.
- Explain the principle, construction, working and application of photoelectric cell.

PHOTOELECTRIC EFFECT

"The phenomenon that when light is incident on a metal surface such as magnesium, zinc, lithium; electrons are emitted"



"Light Energy (photon) gets converted into Electrical Energy (electrons)"

PLANCK'S HYPOTHESES

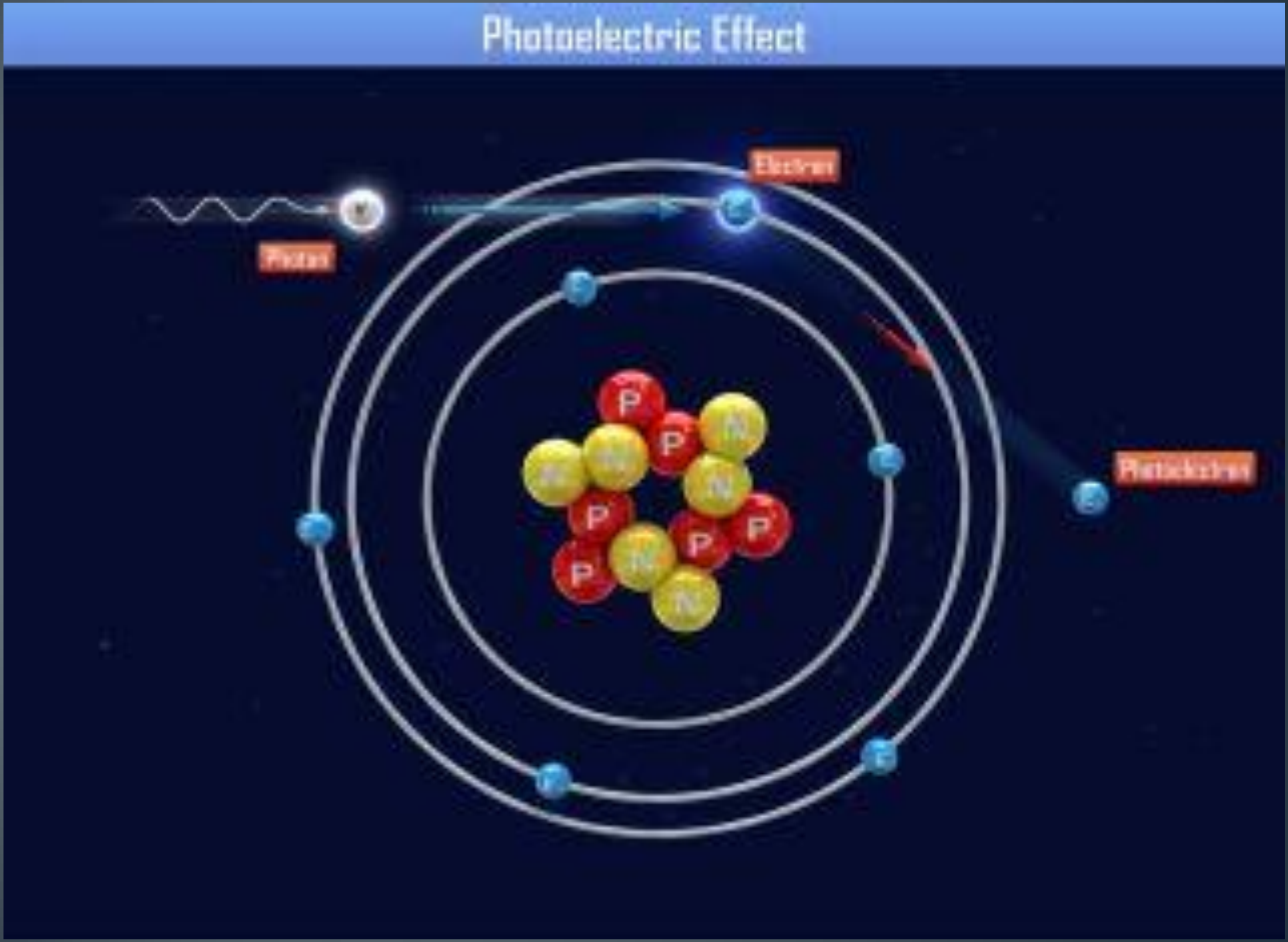
- **Planck's quantum theory** proposed that energy is not emitted or absorbed continuously, but in **discrete units or packets**.
- These packets are called **photons or quanta**.
- According to Planck's theory **$E = h\upsilon$**

  where h = Planck's constant = 6.62×10^{-34} Js

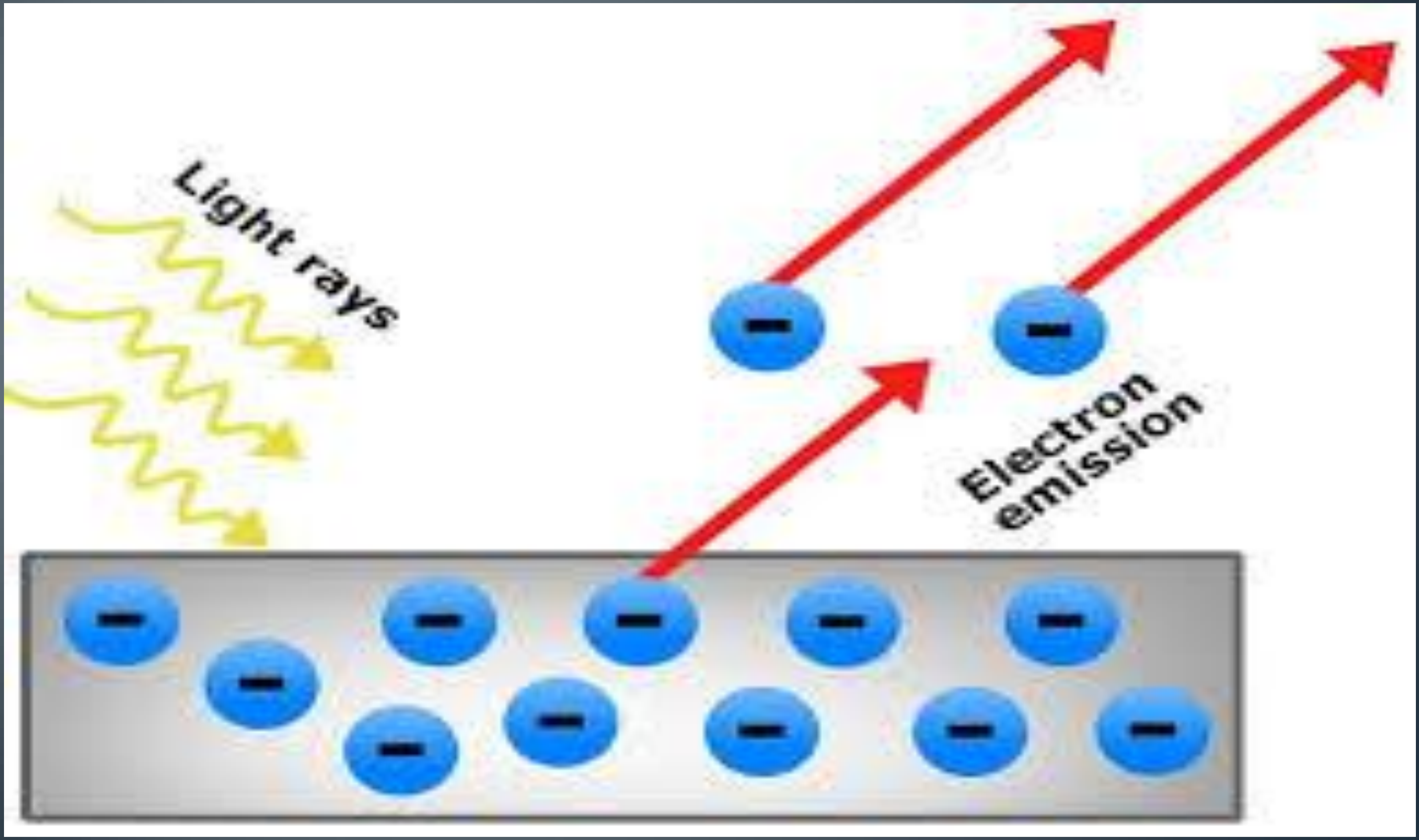
  υ = frequency of radiation
- According to this theory, energy is always emitted or absorbed in integral multiple of $h\upsilon$ and not in fraction of $h\upsilon$, i.e., **$E = nh\upsilon$**

  where n = integral multiple

CONCEPT OF PHOTONS



PHOTOELECTRIC EFFECT



PROPERTIES OF PHOTONS

- Photon are electrically neutral
- Photons cannot be deflected by electric field or magnetic field.
- Photons cannot be ionized.
- Photon is a indivisible entity.
- Photons travels with velocity of light.
- The energy of each photon is $\mathbf{E = h\upsilon = hc/\lambda}$
- The mass of photon is given by $\mathbf{m = E/c^2 = h\upsilon/c^2 = h/c\lambda}$
- The momentum of photon is given by $\mathbf{p = mc = h\upsilon/c = h/\lambda}$

Ex. 3.1 The energy of photon is 5.28×10^{-19} J. Calculate frequency and wavelength.

Given: $E = 5.28 \times 10^{-19}$ J, $c = 3 \times 10^{8}$ m/s and $h = 6.63 \times 10^{-34}$ Js

Find: υ and λ

Formula: $E = h\upsilon$ and $\lambda = c/\upsilon$

Solution: We know $E = h\upsilon$

Frequency is calculated as $\boldsymbol{\upsilon = E/h}$

$\therefore \upsilon = (5.28 \times 10^{-19})/(6.63 \times 10^{-34})$

$\therefore \boldsymbol{\upsilon = 0.79 \times 10^{15}}$ **Hz**

We know wavelength is $\boldsymbol{\lambda = c/\upsilon}$

$\therefore \lambda = (3 \times 10^{8})/(0.79 \times 10^{15})$

$\therefore \boldsymbol{\lambda = 3797 \times 10^{10}}$ **m = 3797 A°**

Ans: Thus, the frequency and wavelength are **0.79×10^{15} Hz** and **3797 A°** respectively.

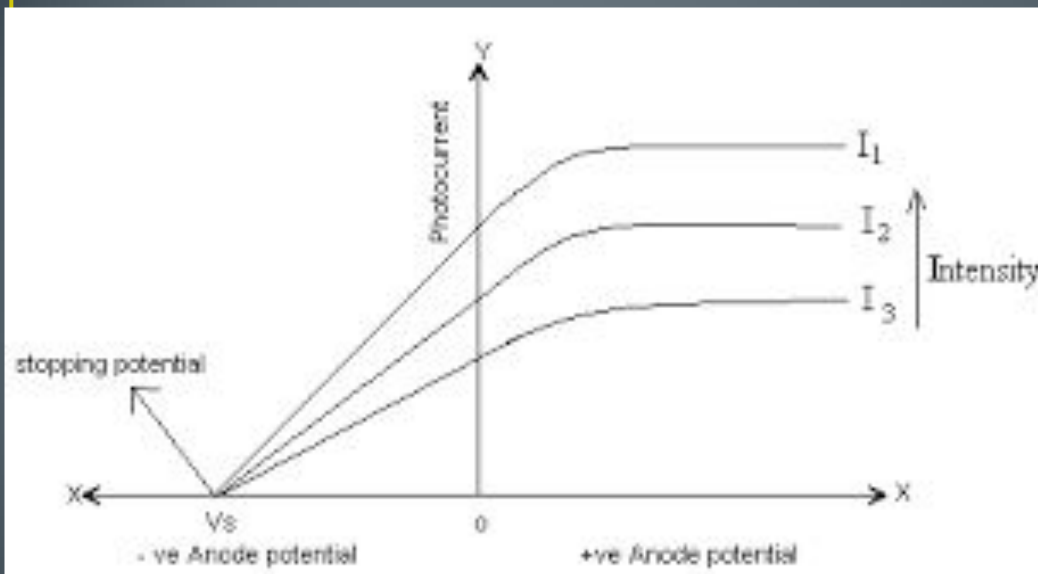
DEFINITIONS

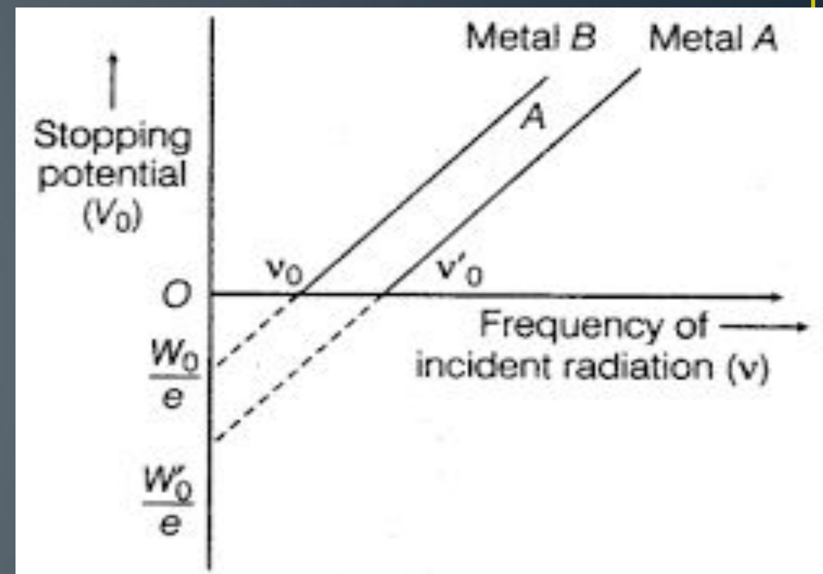
- **Threshold frequency (υ_o):** It is the minimum frequency (υ_o) of the incident light at which emission of electron just begins.
- **Threshold wavelength (λ_o):** It is the maximum wavelength (λ_o) of the incident light at which emission of electron just begins.
- **Photoelectric Work function (W_o):** It is the minimum energy require to detach the electron from metal surface.
- **Stopping Potential (V_o):** It is negative voltage at which photoelectric current becomes zero.

CHARACTERISTICS OF PHOTOELECTRIC EFFECT

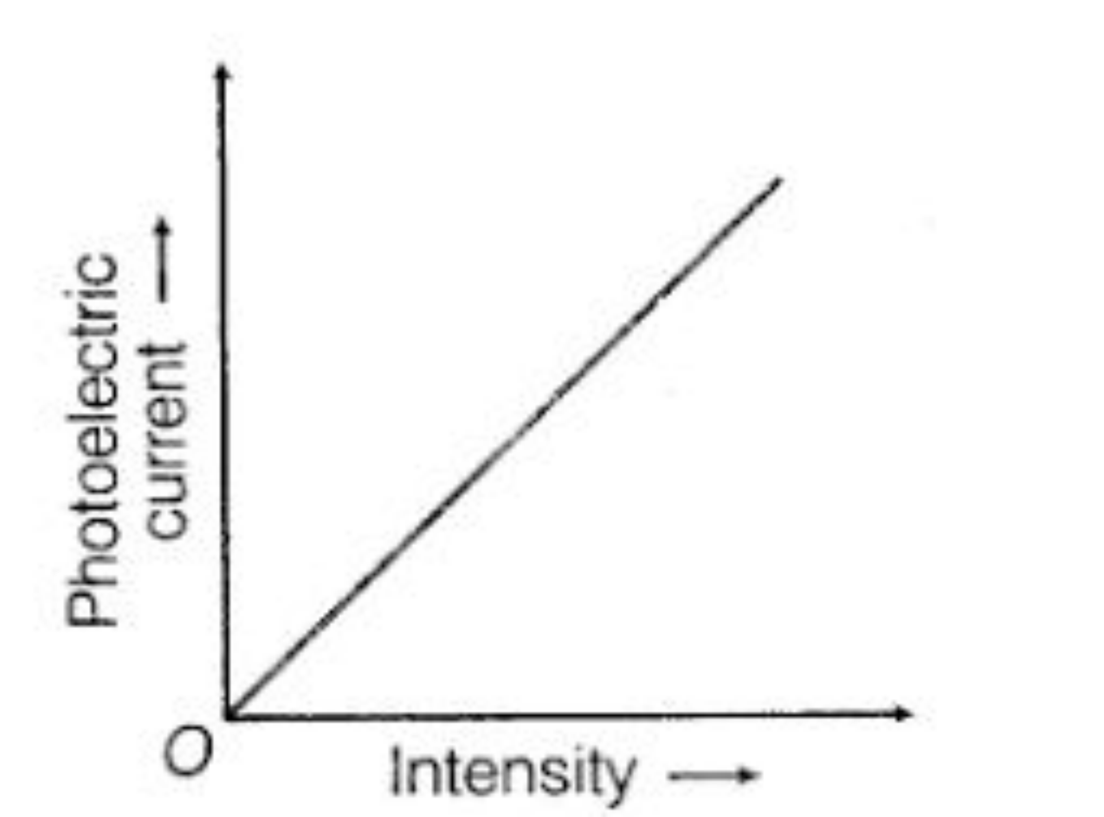
- A metal emits electrons only when the frequency of incident light is greater than threshold frequency (υ_o)
- Photoelectric current is directly proportional to intensity of light and independent of frequency.
- The velocity of photoelectron is directly proportional to frequency of light and independent of intensity of light.
- Stopping potential is directly proportional to frequency of light.
- It is an instantaneous process.

Effect of Potential and Frequency





Effect of Intensity



EINSTEIN"S PHOTELECTRIC EQN

- Energy of photon absorbed by the atom ($h\upsilon$) is

(i) used to detach the electron (W_o) &

(ii) given to electron in form of kinetic energy (K.E).

- Thus, $h\upsilon = W_o + K.E$

$$h\upsilon = W_o + \frac{1}{2}mv^2$$

Photoelectric work function $W_o = h\upsilon_o$

$$\frac{1}{2}mv^2 = h\upsilon - h\upsilon_o$$

$$\frac{1}{2}mv^2 = h(\upsilon - \upsilon_o)$$

EINSTEIN"S PHOTELECTRIC EQN

- Thus $$\frac{1}{2}mv^2 = h(\upsilon - \upsilon_o)$$

is Einstein's Photoelectric equation

REMARKS

Case (i) : If $\upsilon < \upsilon_o$ ………………… No emission.

Case (ii) : If $\upsilon = \upsilon_o$ ………………… Emission just begins.

Case (iii): If $\upsilon > \upsilon_o$ ………………… Emission takes place.

Ex. 3.2 When light of wavelength 3800 A^0 is incident on a metal plate, electrons are emitted with zero velocity. Calculate threshold frequency and work function of the metal.

Given: $\lambda_o = 3800\ A^0 = 3800 \times 10^{-10}$ m, v = 0 (electrons are emitted at threshold wavelength), $c = 3 \times 10^8$ m /s and $h = 6.63 \times 10^{-34}$ Js

Find: υ_o and W_o

Formula: $\upsilon_o = c/\lambda_o$ and $W_o = h\upsilon_o$

Solution: We know $\upsilon_o = c/\lambda_o$

Threshold frequency is calculated as $\boldsymbol{\upsilon_o = c/\lambda_o}$

$\therefore \upsilon_o = (3 \times 10^8)/(3800 \times 10^{-10})$

$\therefore \boldsymbol{\upsilon_o = 0.789 \times 10^{15}}$ **Hz**

We know work function is $\boldsymbol{W_o = h\upsilon_o}$

$\therefore W_o = (6.63 \times 10^{-34}) \times (0.789 \times 10^{15})$

$\therefore \boldsymbol{W_o = 5.23 \times 10^{-19}}$ **J**

Ans: Thus, the threshold frequency is **0.789×10^{15} Hz** and work function **5.23×10^{-19} J** respectively.

Ex 3.3 The work function of substance is 4eV,Find the longest wavelength of light that can cause photoelectric emission

$W_o = h\upsilon_o$

$= hc/\lambda_o$

or

$\lambda_o = hc/W_o$ **where** W_o **is in** eV

$= hc/eW_o$

substituting values of h,c,e

$\lambda_o = 12400/W_o$ in A^o

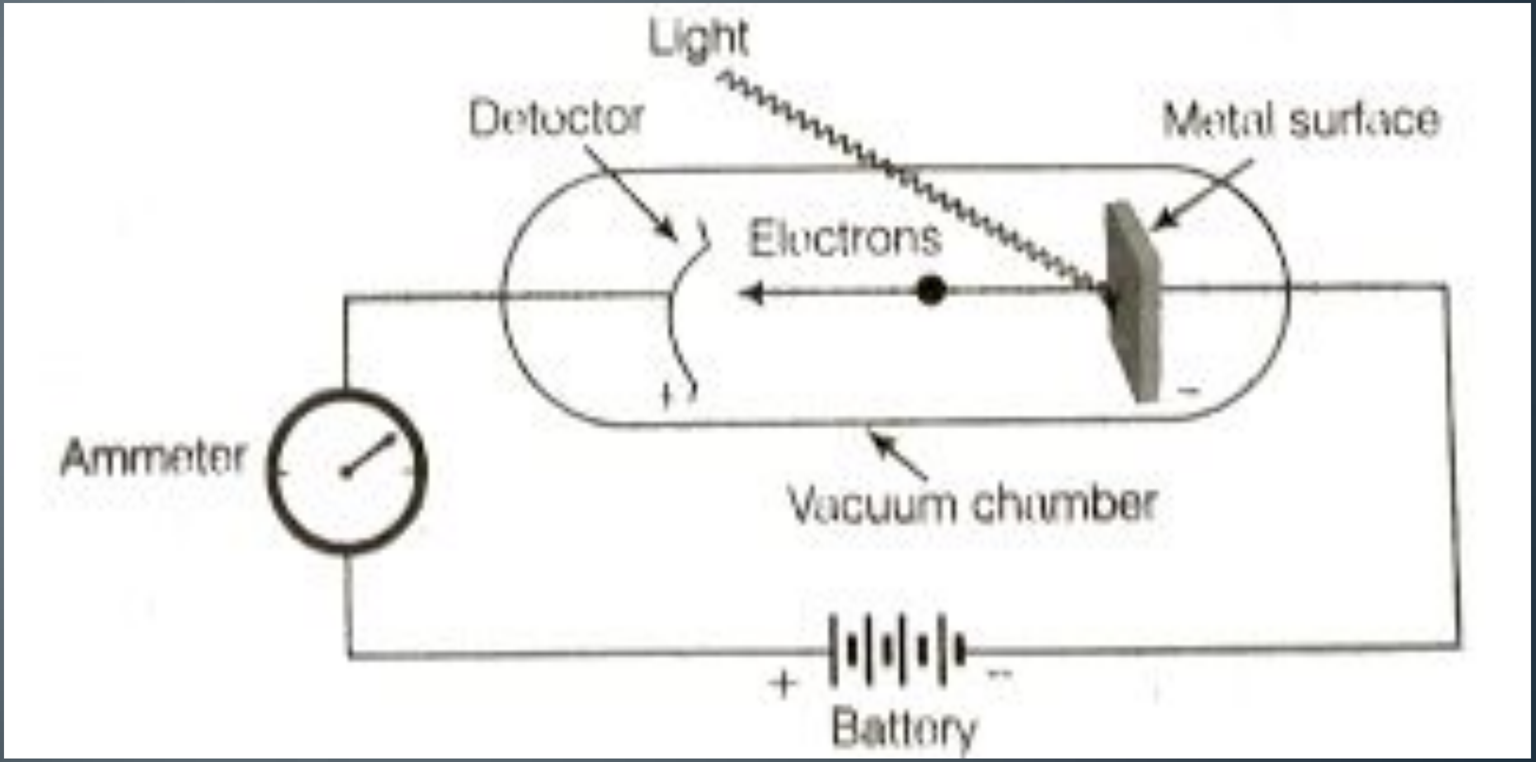
$=12400/4eV$

$=3100 A^o$

PHOTOELECTRIC CELL

- Light energy is converted into electrical energy.
- Photoelectric cell consists of Cathode (K) & Anode (A), enclosed in an evacuated glass bulb.
- The cathode is coated by photosensitive materials from inner side.
- Cathode is connected to – ve terminal and anode is connected to + ve terminal of battery through mA.
- When light falls on cathode, it emits photoelectrons. These photoelectrons are attracted by anode.

CIRCUIT DIAGRAM



APPLICATIONS

- Lux meter for measurement of intensity of light.
- Automatic control of traffic lights.
- Switch On and Off the street lights automatically.
- Recording and Reproduction of sound during shooting of films.
- Detecting flaws in metals
- Burglar Alarms and Fire Alarms.
- Exposure meter.

TYPES OF PHOTO CELL

- Photoelectric cell are of following types:
  - Photovoltaic cell
  - Photoconductive cell
  - Photoemissive cell

Photoconductive Cell

- The oldest photoelectric device is the photoconductive cell. It is also known as a photoresistor.
- The photoconductive cells are used in many applications such as automatic On and Off of street lights, as counting devices, in various alarm systems, and scanning codes in supermarkets.
- The free electrons from the semiconductor materials are emitted when a light is incident on photovoltaic cell, which decreases the resistivity and increases the conductivity.
- The photoconductive materials used are lead sulfide (PbS), lead selenide (PbSe), and lead telluride (PbTe) which are sensitive to infrared radiation, whereas cadmium sulfide (CdS) has sensitivity to light in the visual

Photoemissive cell

- The photoemissive cell, known also as phototube, they are used in astronomy, in the form of photo-multiplier tubes, to measure electromagnetic radiation from celestial objects.
- A photoemissive cell is constructed with an anode and a semi-cylindrical cathode with layers of cesium, potassium, or rubidium, sealed in an evacuated or gas-filled bulb.
- The photons strike the cathode, and some electrons are emitted. These emitted electrons are attracted to the positive anode as a photocurrent of microampere order.

Photovoltaic Cell

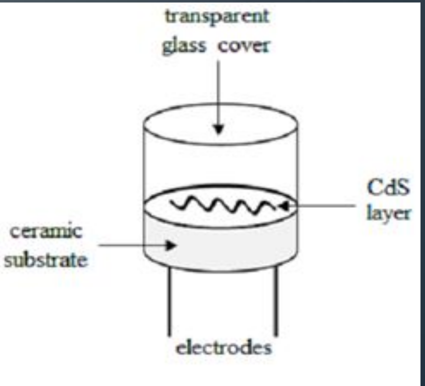
- The first photovoltaic cells appeared shortly after the photoemissive cell.
- They are now used in a wide range of electronic systems, an example is modulated-light systems such as fibre optics communications.
- Semiconductor, of such material that light flux falling in it displaces electrons from some of the atoms, is the sensitive element in a photovoltaic cell.
- The most suitable semiconductors for photovoltaic cells are selenium and cuprous oxide.

PHOTORESISTOR (LDR)

- Photo resistor or light dependent resistor (LDR) is a nonlinear resistor, whose resistance value change with the change in incident light energy.

- **Principle:** The conductivity of the semiconductor material varies directly with the amount of intensity of light. Thus the increase in conductivity or decrease in resistivity of semiconductor material depends upon the increase in intensity of light incident on it.

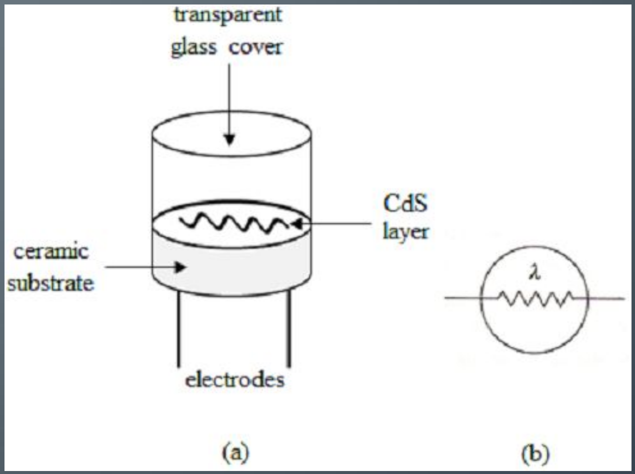
- **Construction:** The photo resistors or LDR are manufactured from photo conductive semiconductor materials such as cadmium sulphide (CdS), cadmium selenide (CdSe), lead sulphide (PbS) and thalmium sulphide (TmS).



(a)

PHOTORESISTOR (LDR)

- It has a ceramic substrate, over which a layer cadmium sulphide (CdS) is deposited in zig-zag form to increase the length.
- This substrate is encapsulated hermetically with a transparent glass cover.
- The electrodes are extended in the interleaved form to increase the contact are with the sensitive material (CdS). Fig. below shows the structure and symbol of LDR.



PHOTORESISTOR (LDR)

- **Working:** When the light is incident on cadmium sulphide (CdS) layer deposited on ceramic substrate of LDR, electron hole pairs are generated.
- Hence resistance of the semiconductor material (CdS) decreases and conductivity increases.
- Thus the resistance of LDR varies inversely with the amount of illumination of light.
- **Applications:** Automatic contrast and brightness control in TV receivers, Optical coding, proximity switch, Light activated control, circuits, photo electric counter circuit and burglar alarm.