Photoelectric Effect

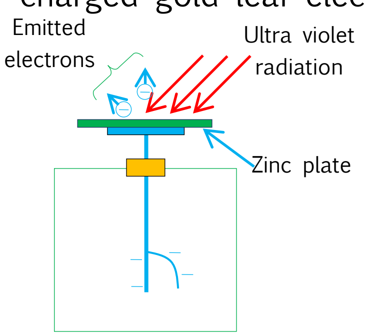
Metals emit electrons when supplied with sufficient energy. Thermionic emission involves supplying the required energy by heating the metal. Another way of supplying the energy is by illuminating the metal surface with light of high enough frequency such as the ultra violet light, as discovered by Heinrich Hertz in 1887. The emitted electrons are now called photoelectrons.

In terms of their behavior and their properties, photoelectrons are not different from other electrons. The prefix **photo** simply tells us that the electrons have been ejected from a metal surface by incident light.

Surfaces that are able to undergo photoelectric emission are said to be photo emissive and have lower values for work function e.g. potassium, sodium, calcium, zinc etc. generally group (1) elements

A simple experiment to demonstrate Photoelectric effect

Ultra radiations are directed onto clean zinc plate placed onto the cap of a negatively charged gold leaf electroscope.



- The leaf of the electroscope is observed to gradually fall or collapse.
- The leaf falls because the electroscope loses charge
- Free electrons in the zinc plate gain sufficient energy from the ultra violet radiation to leave the plate. Hence photoelectric effect.

When a glass plate is placed in the path of the ultra violet radiation, the divergence of the leaf remains constant. This is because glass absorbs ultra violet light.

If instead the electroscope was made positive in the first experiment, the leaf divergence remains constant. This is because any emitted electrons are immediately attracted back by the positive charges on the cap of the electroscope hence restoring the charges.

Radiations of lower frequency than ultra violet, such as infrared, radio waves etc. do not carry sufficient energy to eject an electron from metal surface and thus do not cause photoelectric effect.

Plank's Quantum theory

States that the energy of a body is emitted or absorbed in discrete packets called **quanta.**

Accordingly the energy E contained in a quantum of radiation is proportional to the frequency f of the radiation

$$E \propto f \quad \therefore E = hf$$

Where $h = 6.626 \times 10^{-34}\ Js$; *Planks constant*

For an electromagnetic radiation of wavelength λ, $E = \dfrac{hc}{\lambda}$

Thus $E \propto f$ and $E \propto \dfrac{1}{\lambda}$

Dimensions of h

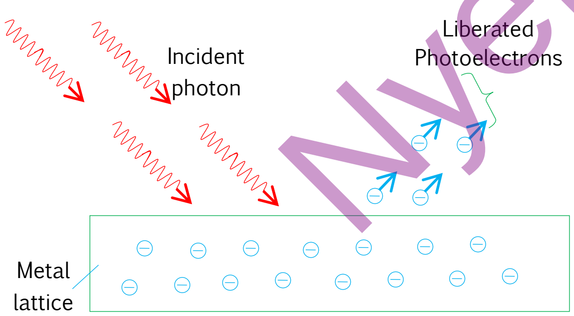
$$h = \frac{Energy}{frequency} = \frac{force \times distance}{frequency}$$

$$\Rightarrow [\mathrm{h}] = \frac{[force] \times [distance]}{[frequency]} = \frac{\mathrm{MLT^{-2} \times L}}{\mathrm{T^{-1}}}$$

$$\therefore \quad [\mathrm{h}] = \mathrm{ML^2T^{-1}}$$

Einstein's theory of photoelectric effect

Einstein extended planks theory to explain photoelectric effect by considering light as a particle. He considered a beam of light as consisting of several streams particles called **photons.** Like the bullets fired from a machine gun rather than water from horse pipe



Each light particle or photon carries or delivers a **packet** of energy or **quanta** given by $E = hf$. Where f is the frequency of the light or radiation. It is the photon that knocks off electrons by giving it all its energy to that single electron without sharing with other electrons from the metal surface. The energy is used to overcome the **work function** of the metal by the electron so as to escape from the metal surface. The emitted electrons are now called **photoelectrons.**

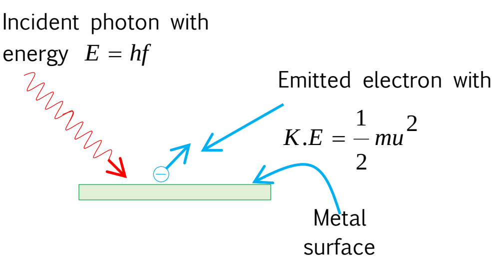
A **photon** is thus a tiny packet of electromagnetic energy emitted by an atom

Work function (w_0) is the minimum amount of energy required to liberate or eject an electron from a metal surface.

Work function is characteristic of the metal and therefore different metals have different values for work function

Einstein's photoelectric equation

To liberate or eject an electron from a particular metal surface, a quantity of energy called work function w_0 has to be supplied to the electron by the incident radiation



If the energy $E = hf$ of the incident photon is greater than the work function w_0 of the metal, the excess energy $(hf - w_0)$ appears as the kinetic energy of the emitted electron.

$$(hf - w_0) = K.E_{max}$$

$$hf = w_0 + \frac{1}{2}mu_{max}^2 \quad . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

This is Einstein's photoelectric equation

The emitted electron escapes with a velocity having any value up to a maximum. The value of maximum velocity depends on:

i) The work function w_0 of the metal and

ii) The frequency f of the incident radiation

It's important to note that the electrons are involved in collisions on their way out of the surface and therefore emerge with energy which is less than the maximum kinetic energy

If the incident photon has **just** enough energy to liberate the electron, the emitted electron gains no K.E and therefore floats on the surface of the metal.

Since the work function w_0 is constant for a particular metal, there exists a minimum frequency called threshold frequency f_0 given by $w_o = hf_o$

Equation (2) can also be written as

$$(hf - hf_o) = K.E_{max}$$

- **Threshold frequency** f_0 is defined as the minimum frequency below which no electrons are emitted from the metal surface. Also known as **cut-off** frequency

- Also **threshold frequency** is the minimum frequency that a photon can have to cause photoemission from a metal
- **Threshold wavelength** λ_0 is the maximum or largest wavelength above which no electrons can be emitted from the metals surface

  From wave motion $c = \lambda_o f_o$ where c is the speed of light. Such that: $w_o = \frac{hc}{\lambda_o}$
- If an electron of charge e is accelerated by a potential difference V, it gains kinetic energy given by $K.E = eV$.

  Hence from above $(hf - w_0) = eV$
- **An electron volt** (eV) is the kinetic energy gained by an electron which has been accelerated through a p.d of one volt

$$1eV = 1.6 \times 10^{-19} J$$

Worked example:

1. The work function for tungsten metal is $4.52eV$

(a) What is the threshold wavelength for tungsten?

(b) What is the maximum kinetic energy of the electrons when radiation of wavelength 198 nm is used?

(c) What is the stopping potential in this case?

Solution

(a)

$$w_0 = \frac{hc}{\lambda_0} \qquad \Rightarrow \lambda_0 = \frac{hc}{w_0} = \frac{6.6\times10^{-34}3\times10^{8}}{4.52\times1.6\times10^{-19}}$$

$$\therefore \lambda_0 = 2.74\times10^{-7}\,m$$

(b)

$$K.E_{max} = \frac{hc}{\lambda} - w_0$$

$$= \frac{6.6\times10^{-34}3\times10^{8}}{1.98\times10^{-7}} - 4.52\times1.6\times10^{-19}$$

$$= 2.768\times10^{-19}\,J$$

(c) Let V_s be the stopping potential

$$K.E_{max} = eV_s \quad \Rightarrow V_s = \frac{K.E_{max}}{e} = \frac{2.768\times10^{-19}}{1.6\times10^{-19}}$$

$$\therefore V_s = 1.73V$$

2. The threshold frequency of sodium metal is $5.6\times10^{14}\,Hz$. Calculate the velocity of photoelectrons emitted when sodium is illuminated by light of wavelength $5.0\times10^{-7}\,m$ (electron mass $=9.11\times10^{-31}\,kg$).

Solution

$$K.E_{max} = hf - w_0 \equiv \frac{hc}{\lambda} - hf_0$$

$$= \left(\frac{6.6\times10^{-34}3\times10^{8}}{5.0\times10^{-7}}\right) - 6.6\times10^{-34}\times5.6\times10^{14}$$

$$= 2.64\times10^{-20}\,J$$

$$K.E_{max} = \frac{1}{2}mu^2 \Leftrightarrow u = \sqrt{\left(\frac{2\times K.E_{max}}{m}\right)}$$

$$u = \sqrt{\left(\frac{2\times2.64\times10^{-19}}{9.11\times10^{-31}}\right)} = 2.4\times10^{5}\,ms^{-1}$$

3. Light of wavelength 435nm is incident on a metal surface, and it is observed that electrons leave the surface with a maximum kinetic energy of $1.16eV$.

(a) What is the work function of this metal?

(b) What is the maximum kinetic energy of the electrons if light of wavelength 560nm is used?

(c) What is the longest wavelength of light that will cause electrons to be emitted from this surface?

Solution

(a)

$$w_0 = \frac{hc}{\lambda} - K.E_{max}$$

$$w_0 = \left(\frac{6.6\times10^{-34}3\times10^{8}}{4.35\times10^{-7}}\right) - 1.16\times1.6\times10^{-19}$$

$$\therefore w_0 = 2.696\times10^{-19}\,J \equiv 1.68eV$$

(b)

$$K.E_{max} = \frac{hc}{\lambda} - w_0$$

$$w_0 = \left(\frac{6.6\times10^{-34}3\times10^{8}}{5.60\times10^{-7}}\right) - 2.696\times10^{-19}$$

$$\therefore w_0 = 8.397\times10^{-20}\,J \equiv 0.52eV$$

(c) Longest wave length is the threshold wavelength (λ_0)

$$w_0 = \frac{hc}{\lambda_0} \qquad \Leftrightarrow \lambda_0 = \left(\frac{6.6\times10^{-34}3\times10^{8}}{2.696\times10^{-19}}\right)$$

$$\therefore \lambda_0 = 7.34\times10^{-7}\,m \equiv 734nm$$

4. In an experiment on photoelectric effect using radiations of wavelength $4.00\times10^{-7}\,m$, maximum K.E was observed to be $1.40\times10^{-19}\,J$. With radiations of wavelength $3.00\times10^{-7}\,m$, the maximum K.E was $3.06\times10^{-19}J$ .Derive the value of planks Constant

Solution

$$\lambda_1 = 4.00\times10^{-7}m \ and \ K.E_1 = 1.40\times10^{-19}J$$
$$\lambda_2 = 3.06\times10^{-7}m \ and \ K.E_2 = 3.06\times10^{-19}J$$

From Einstein's $w_0 = \frac{hc}{\lambda} - K.E_{max}$

$$w_0 = \frac{hc}{\lambda_1} - K.E_1 \quad and \quad w_0 = \frac{hc}{\lambda_2} - K.E_2$$

$$\Rightarrow \frac{hc}{\lambda_1} - K.E_1 = \frac{hc}{\lambda_2} - K.E_2$$

$$hc\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right) = K.E_1 - K.E_2 \quad \Rightarrow h = \frac{K.E_1 - K.E_2}{c\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)}$$

$$h = \frac{1.40\times10^{-19} - 3.06\times10^{-19}}{3.0\times10^8\times\left(\frac{1}{4.00\times10^{-7}} - \frac{1}{3.00\times10^{-7}}\right)}$$

$$\therefore h = 6.64\times10^{-34}Js$$

5. Light of wavelength 0.5μm incident on a metal surface ejects electrons with kinetic energies up to a maximum value of $2\times10^{-19}J$. What energy is required to remove an electron from the metal?

$$w_0 = \frac{hc}{\lambda} - K.E_{max}$$

$$= \left(\frac{6.6\times10^{-34}3\times10^8}{5.0\times10^{-7}}\right) - 2\times10^{-19}$$

$$= 1.96\times10^{-19}J \equiv 1.23eV$$

Trial questions

1. Light from a source with a variable wavelength is incident on a metal. It is observed that electrons are emitted from the surface of the metal for all wavelengths less than 525 nm but never for wavelengths above 525 nm.

(a) What is the minimum energy necessary to remove an electron from the surface of the metal?

(b) After leaving the surface, electrons must cross through a potential difference V in order to contribute to the current in an external circuit. When the wavelength of the light is changed to 345nm, what potential difference is necessary to prevent the most energetic electrons from completing the circuit?

Ans: (a) 2.36eV (b) 1.23V

2. Ultraviolet radiation of wavelength 176nm is incident on the surface of a metal. Electrons are released from the metal with a maximum kinetic energy of 4.52eV.

(a) What is the maximum wavelength of the incident radiation that could cause electrons to be released from the metal?

(b) If the wavelength of the incident radiation were changed to 288 nm, what would be the maximum kinetic energy of the emitted electrons?

Ans: (a) 491nm (b) 1.78eV

3. The stopping potential for a certain surface is 1.25V when it is illuminated with light of wavelength 471nm. When the wavelength is changed to a new value, the stopping potential becomes 1.68V.

(a) What is this new wavelength?

(b) What is the work function of this surface?

Ans: (a) 405nm (b) 1.38eV

4. An ultraviolet lamp of adjustable wavelength is shining on a metal surface. It is observed that electrons begin to emerge from the surface when the wavelength is 255nm.

(a) What is the minimum energy necessary to remove an electron from the surface of this metal?

(b) If the wavelength is reduced to 215nm, what is the energy of the electrons that leave the surface?

Ans: (a) 4.86eV (b) 0.91eV

5. A metal surface is illuminated with light of different wavelengths. It is observed that electrons are emitted from the metal for wavelengths of light up to 525 nm but for no wavelengths above 525nm. When light of 420nm is used, what is the maximum kinetic energy of the electrons?

Ans: 0.59eV

6. A metal surface is illuminated with ultraviolet light of adjustable wavelength. It is observed that electrons are emitted from the surface when the wavelength of the ultraviolet light is below 325nm but never when the wavelength is above 325nm. What is the kinetic energy of the emitted electrons when light of wavelength 243nm is used? Ans: 1.29eV

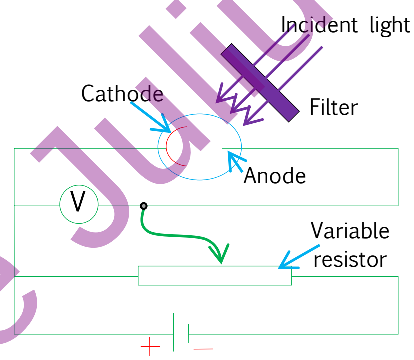
7. The largest wavelength of light that will cause emission of photoelectrons from a certain surface is 486nm.

(a) What is the work function of the surface?

(b) When light of wavelength 325nm is used, what is the stopping potential?

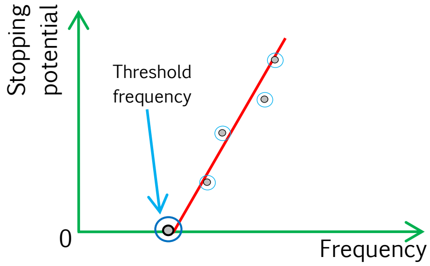
Ans: (a) 2.55eV (b) 1.27V

Experiment to verify Einstein's photoelectric equation



- The anode of the photocell is made negative with respect to the cathode
- A monochromatic light of frequency f is allowed to fall on the cathode of a photocell, causing emission of electrons
- These electrons travel to the anode causing current to flow, which is detected at E
- The p.d between the anode and cathode is slowly increased until E reads zero
- The value of this p.d V_s is noted
- Different filters are used to vary the frequency of the incident light
- Results tabulated

- A graph of V_s against f is plotted



- The linear nature of the graph verifies Einstein's equation $V_S = \left(\frac{h}{e}\right) f - \left(\frac{h}{e}\right) f_0$

Stopping potential the minimum potential that prevents the most energetic electrons from reaching the negative anode.

Since this potential stops the flow of current in a photocell, it can also be defined as **stopping potential** the minimum potential which reduces the photocurrent to zero

Determination of Planks constant h from the above graph

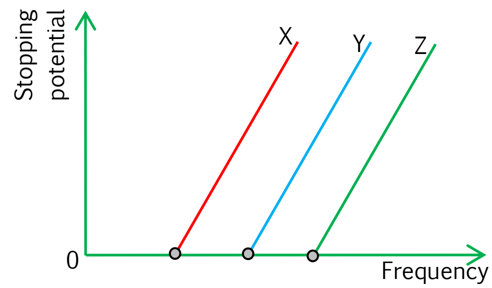
From Einstein's equation $V_S = \left(\frac{h}{e}\right) f - \left(\frac{h}{e}\right) f_0$

which is the equation of straight line of general form $y = mx + c$

When the slop S of the graph is obtained, will be equivalent to $\left(\frac{h}{e}\right)$

Thus $S = \left(\frac{h}{e}\right)$ $\therefore h = S \times e$

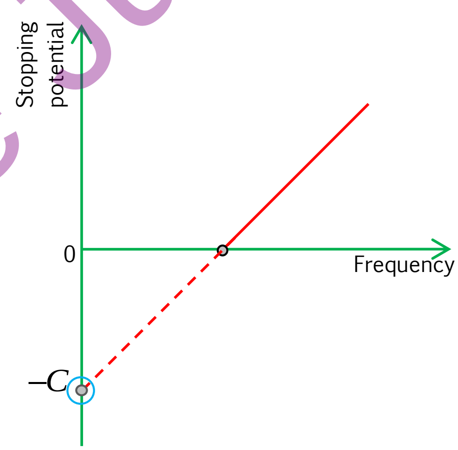
It is important to note that the ratio $\left(\frac{h}{e}\right)$ is constant irrespective of the element of the cathode used. A plot of V_s against f for different metals will have the same slope



Thus metal Z has highest threshold frequency as well as work function

Obtaining work function w_0 from the graph

When the graph is extra plotted, it will meet the vertical axis at point $-C$



From Einstein's equation $V_S = \left(\frac{h}{e}\right) f - \frac{w_0}{e}$

which is the equation of straight line of general form $y = mx + c$

When the vertical intercept $-C$ of the graph is obtained, will be equivalent to $\left(\frac{-w_0}{e}\right)$

Thus $\left(\frac{-w_0}{e}\right) = -C$ $\therefore w_0 = C \times e$

1. The following results were obtained from an experiment on photoelectric effect of a particular metal surface.

Wavelength (nm)	405	436	492	546	579	607
stopping potential (V)	1.13	0.93	0.62	0.36	0.24	0.15

(a) Plot a suitable graph and use the graph to determine;

(i) Planks constant

(ii) The work function of the metal

(iii) The threshold frequency of the metal surface

Laws of photoelectric emission

This is a summary of experimental results of photoelectric effect. They represent the features or characteristics of photoelectric effect.

1. The time lag between irradiation of the metal surface and emission of the electrons by the metal surface is negligible. I.e. photoelectric effect is **instantaneous**
2. For a given metal, surface there is a minimum value of frequency of radiation called **threshold frequency** below which no photo electrons are emitted from the metal however intense the incident radiation may be.
3. The velocity and K.E of the emitted photoelectrons increase with increase in the frequency of the incident radiation and is independent of the intensity of light.
4. the number of photoelectrons emitted from the surface per second is directly proportional to the intensity of incident radiation for a fixed frequency of light

The classical theory of the Photoelectric effect

The classical wave theory was the first to attempt to offer explanation about the properties or observations of photoelectric effect

1. **The maximum kinetic energy of the electrons should be proportional to the intensity of the radiation.** As the brightness of the light source is increased, more energy is delivered to the surface and the electrons should be released with greater kinetic energies.

2. **The photoelectric effect should occur for light of any frequency or wavelength.** According to the wave theory, as long as the light is intense enough to release electrons, the photoelectric effect should occur no matter what the frequency or wavelength.

3. **The first electrons should be emitted in a time interval of the order of seconds after the radiation begins to strike the surface.** In the wave theory, the energy of the wave is uniformly distributed over the wave front. If the electron absorbs energy directly from the wave, it would

continuously absorb energy from the light until it has accumulated enough to escape from the metal surface and thereby causing remarkable time lag.

Failures of the wave or classical theory to account for the photoelectric emission

1. Existence of threshold frequency

According to the classical theory, the energy of the incident radiation depends on its intensity; the greater the intensity of illumination, the greater the supply of energy. This would imply that radiations of high enough intensity should cause emission even when the frequency is below the minimum value

However as long as the incident radiation is below the threshold frequency, no photoelectrons are emitted however intense the incident radiation is

2. Instantaneous emission of photoelectrons

Classical theory suggests that the energy of the incident radiation would be continuously absorbed by the electron. Implying that the electron would take some time to accumulate sufficient energy that would enable them escape from the metal surface. By this theory, emission of photoelectrons would not be instant

3. Variation of K.E of the emitted photoelectrons

According to the classical theory, increasing the intensity of the incident radiation would mean more incident energy and a greater maximum K.E of the emitted photoelectrons

But instead the maximum K.E of the photoelectrons emitted depend on the frequency of the incident radiation.

4. Variation of photoelectric current with intensity

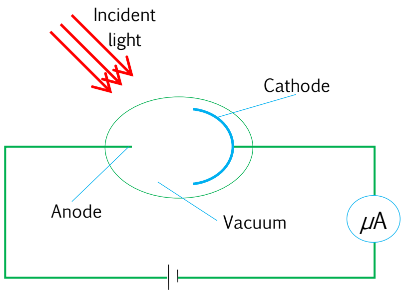
When the intensity of illumination is increased, the number of photons incident on the metal surface also increases. Hence more free electrons in the metal receive sufficient energy to escape. The rate of emission increases and therefore a large current flows.

Thus the size of the photocurrent depends on the intensity of the incident radiation.

However, According to classical theory, increase in the intensity would increase the K.E of the emitted electron and they would escape with greater speed instead, which is false.

Photocell

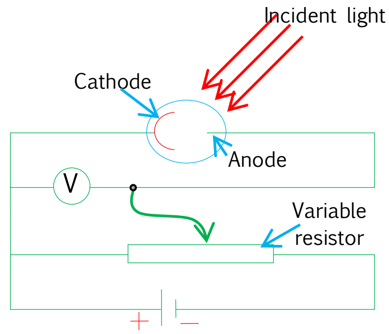
- Photocells change radiation into electric current.
- In their construction, the anode is made thin so that it does not obstruct the incident radiation
- It's placed in vacuum because the metals are reactive



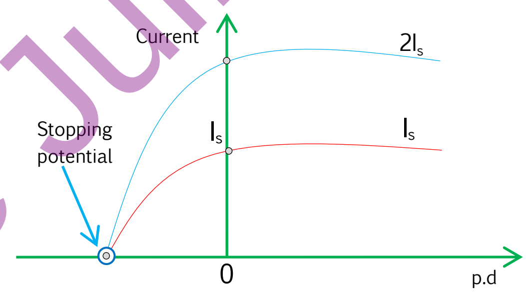
- When radiation of frequency greater than threshold frequency of the photo emissive cathode is incident on the cathode, electrons are emitted, they move to the anode and current flows in the external circuit.
- The size of the current increases with the intensity of the incident radiation.
- If the light beam is interrupted, the current stops flowing.
- When the device is connected to a suitable relay circuit, it can be used to open doors, act as a burglar alarm or as switching device.

Variation of p.d V with current I

The circuit below is used to investigate the relationship between photocurrent (resulting from emitted electrons) and voltage across the electrodes



- A monochromatic light i.e. constant frequency is used.
- The photocurrent I is measured for increasing values of V up to the stopping potential value
- A graph of photocurrent I against the p.d V is plotted.



- When the intensity of the light is double by moving the light source closer to the photocell, the saturation currents (I_s) also doubles.
- The stopping potential remains constant in both cases because, the energy if the photoelectrons are dependent on frequency of incident light (which has been kept constant) and not intensity
- The photocurrent is not zero even when the p.d is zero. This is because electrons are emitted with varying velocities (K.E), some of which are sufficient to overcome the repulsive electric field and reach the anode

Example

A photocell is connected in the circuit as shown in fig (i). The cathode is illuminated with monochromatic light of wavelength

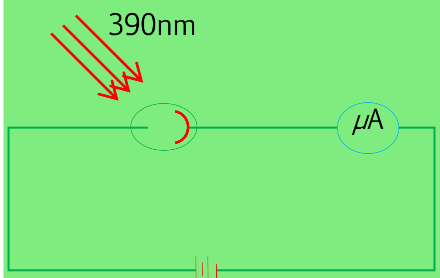
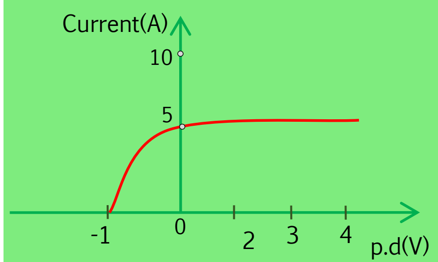


fig (i)



fig(ii)

390nm and the current I in the circuit recorded for different p.d V applied between the anode and the cathode. The graph fig (ii) shows the results obtained.

(a) Find the maximum K.E of the photoelectrons

(b) What is the work function of the cathode in eV?

(c) If the experiment is repeated using monochromatic light of wavelength 310nm, where would the new graph cut the V-axis?

Solution:

(a) $\text{from the graph } V_s = -1.0V$

$K.E_{\max} = eV_s \equiv 1.0\times1.6\times10^{-19}\,J$

(b) From

$$w_0 = \frac{hc}{\lambda} - K.E_{max} \Rightarrow W_0 = 2.19eV$$

$$= \frac{6.6\times10^{-34}\times3\times10^{8}}{3.9\times10^{-7}} - 1.6\times10^{-19}$$

$$= 3.48\times10^{-19} \equiv 2.18eV$$

(c) When $\lambda_2 = 310nm = 3.1\times10^{-7}m$

$$K.E_{max} = \frac{hc}{\lambda} - W_0$$

$$K.E_{max} = \frac{6.6\times10^{-34}\times3\times10^{8}}{3.1\times10^{-7}} - 3.48\times10^{-19}$$

$$K.E_{max} = 2.91\times10^{-19}\,J$$

$$V_s = \frac{2.91\times10^{-19}}{1.6\times10^{-19}} = 1.82V$$

The graph would cut the horizontal axis at $-1.82V$

Applications of Photocells (Photoelectric Emission)

(i) A photocell can make doors open automatically in buildings when a light beam is interrupted by somebody/obstacle.

(ii) Intruder alarm systems. The intruder intercepts the infrared beam falling on a photocell, hence cutting off of current. This interruption therefore sets the alarm on.

(iii) Photovoltaic cells are used in solar panels, calculators and for powering electronic watches.

(iv) Used as automatic devices for switching on light at night when it tries to darken or when the frequency of the light reduces.

(v) Automatic counting machines in industries.
(vi) Used in reproduction of sound from a film
(vii) Lighting sensors such as the ones used in smartphones enable automatic adjustment of screen brightness according to the lighting. This is because the amount of current generated via the photoelectric effect is dependent on the intensity of light hitting the sensor.
(viii) Digital cameras can detect and record light because they have photoelectric sensors that respond to different colors of light
(ix) Used to generate electricity in Solar Panels. These panels contain metal combinations that allow electricity generation from a wide range of wavelengths.

Worked example

1. A $100mW$ beam of light of wave length $4.0\times10^{-7}m$ falls on a caesium surface of a photocell.

(i) How many photons strike the caesium surface per second?

(ii) If 80% of the photons emit photoelectrons. Find the resulting photocurrent.

(iii) Calculate the kinetic energy of each photoelectron if the work function of caesium is $2.15eV$.

Solution:

(i)

$Power = 100mW = 100mJs^{-1} = 0.1Js^{-1}$

$\lambda = 4.0\times10^{-7}m$

$Energy\ of\ each\ photon\ (one\ photon)\ E = hf$

$$E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{4.0\times10^{-7}} = 4.97\times10^{-19}J$$

$$Number\ of\ photons\ n = \frac{Total\ energy}{Energy\ of\ one\ photon}$$

$$n = \frac{100\times10^{-3}}{4.97\times19^{-19}} = 2.02\times10^{17}s^{-1}$$

(ii) If 80% of the photons emit electrons, then the number of electrons emitted is given by $n = 2.02\times10^{17}\times0.8 = 1.616\times10^{17}s^{-1}$

$Photo\ current\ I = ne$

$I = 1.616\times10^{17}\times1.6\times10^{-19} = 2.57\times10^{-2}A$

(iii)

$$K.E_{max} = hf - W_0$$

$$= \frac{hc}{\lambda} - W_0$$

$$= \frac{6.63\times10^{-34}\times3\times10^{8}}{4.0\times10^{-7}} - \left(2.15\times1.6\times10^{-19}\right)$$

$$= 4.9725\times10^{-19} - 3.44\times10^{-19}$$

$$= 1.53\times10^{-19}J$$

$$= 0.944eV$$

Experimental evidence for quantum theory

(i) Photoelectric effect:

To liberate an electron from a metal surface, a quantum or packet of energy called the work function which is characteristic of the metal surface has to be supplied i.e. $hf - W_0 = \frac{1}{2}mv^2$ where w_0 is the work function.

(ii) Optical spectra:

A line in the optical emission spectrum indicates the presence of a particular frequency f of light and is considered to arise from loss of energy which occurs in an excited atom when an electron jumps directly or in steps from a higher energy level E_2 to lower energy level E_1. The frequency of the packet of energy emitted is given by $hf = E_2 - E_1$.

(iii) X-ray line spectra:

Electron transition from one shell to another leads to liberation of energy in packets characteristic of the target atom.

Differences between X-ray production and photoelectric effect:

Photoelectric Effect	X-rays
• Electromagnetic radiation falls on metal surface and electrons are emitted.	• Fast moving electrons hit the metal target and x-rays (electromagnetic radiation) is produced.
• Little heat is generated	• A lot of heat is generated

Differences between classical theory and quantum theory:

Classical or wave Theory	Quantum theory
• It allows continuous absorption and accumulation of energy.	• No continuous absorption allowed. The energy is either absorbed or rejected.
• Energy of radiation is evenly distributed over the wave front.	• Energy is radiated, propagated and absorbed in packets (quanta or photons).
• What matters is total energy of the incident radiation (beam).	• What matters is the energy of individual photon.

TASK

1. State the conditions under which photoelectric emission occurs
2. Explain how the photoelectric effect provides evidence for the quantum theory of light.
3. Explain why light whose frequency is less than the threshold frequency cannot cause photoelectric emission.
4. Explain why the classical theory (wave theory) of light fails to account for the photoelectric effect (emission).

End of chapter questions

Where necessary assume the constants:
Plank's constant $h = 6.64 \times 10^{-34}\,Js$
Speed of light in vacuum $c = 3.0 \times 10^{8}\,ms^{-1}$
Electronic charge $e = 1.6 \times 10^{-19}\,C$
Electronic mass $m_e = 9.11 \times 10^{-31}\,kg$
Electronvolt $1eV = 1.6 \times 10^{-19}\,J$

1. Calculate the stopping potential of platinum surface irradiated with U.v

light of wavelength 1.2 x 10^{-7}m if the total work function of platinum is 6.3eV (Ans: 4.0V).

2 When light of wavelength 5.9×10^{-7}m is incident on a sodium metal, electrons of maximum K.E of 1.71×10^{-20}J are emitted. Calculate the maximum K.E of the electrons that will be emitted by sodium metal illuminated by light of wavelength 4.5×10^{-7}m. (Ans: 1.21×10^{-19}J).

3. Monochromatic radiation of frequency 1.0 x 10^{15} Hz is incident on a clean magnesium surface for which the work function is 0.59 x 10^{-18}J. calculate

(i) the maximum kinetic energy of the emitted electrons

(ii) the potential to which the magnesium surface must be raised to prevent the escape of electrons

(iii) The cut-off wavelength.

Ans: 7.4×10^{-20}J, 0.46V, 3.37×10^{-7}m

4. Gold has a work function of 4.9eV.

(a) Calculate the maximum K.E in joules of the electrons emitted when Gold is illuminated with U.v of frequency 1.7 x 10^{15}Hz

(b) What is the energy expressed in eV.

(c) What is the stopping potential of the electrons?

(Ans: (b) 2.1eV (c) 2.1eV)

5. A metal of work function 2.5eV is irradiated with light of unknown frequency. The maximum velocity of the photoelectrons emitted is 1.14×10^{6}m/s. Calculate the maximum wavelength of the incident radiation (Ans: 2.7×10^{-7}m)

6. A metal of work function 3.50eV is irradiated with light of unknown frequency. The maximum velocity of the photoelectrons is 4.71×10^{6}m/s. Calculate the maximum wavelength of the incident radiation (Ans: 1.7×10^{-8}m)

7. Light of wavelength 6.0×10^{-7}m is incident on zinc plate. The electrons are emitted with maximum K.E of the 2.2×10^{-20}J. Calculate the maximum K.E of the electron emitted from the zinc plate with light of wavelength of 5.0×10^{-7}m (Ans: 8.83×10^{-20}J)

8. Sodium has a work function of 2.3eV. Calculate;

i) The threshold frequency of sodium

ii) The maximum velocity of the electrons produced when sodium is illuminated by light of wavelength 5×10^{-7}m

iii) The stopping potential with light of this wavelength

((i) 5.6×10^{14}Hz (ii) 2.5×10^{5}m/s (iii) 0.18V)

Hello out there reading this piece of work

I present to you this extract from my work on **advanced level physics**

If you find it useful, contact me for a **hard copy** of the complete work

My name is **Nyerere Julius** and currently teaching physics at Namilyango College

Call or whatsapp me directly on **0752496690**

Email: achieverzdream@gmail.com

Thank you