# Optoelectronics — B McMULLEN

①

## Inverse Square Law

$$I = \frac{P}{A}$$

- $I$ — Irradiance ($Wm^{-2}$)
- $P$ — Power (W)
- $A$ — Surface Area ($m^2$)

⇐ In DB!!

As $P = \frac{E}{t}$ — Power (W), Energy (J), time (s)

FROM NATIONAL 5 !!

$P = \frac{E}{t}$ ✓

$E = Pt$ ✓

$P = Et$ ✗ No!!!

$$\Rightarrow \quad I = \frac{\frac{E}{t}}{A}$$

**Definition** ⇒ Irradiance is the light energy per second on a surface area of $1m^2$.

eg A 60Watt lamp has 60Joules of electrical energy supplied to it per second.

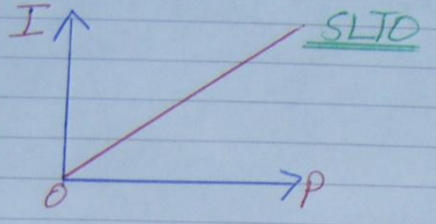
ie $1W = 1Js^{-1}$

1 Watt = 1 Joule per second.

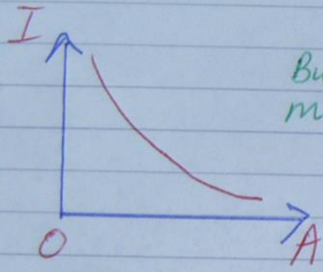
∴ Power is the energy transformed per second.

From $I = \frac{P}{A}$

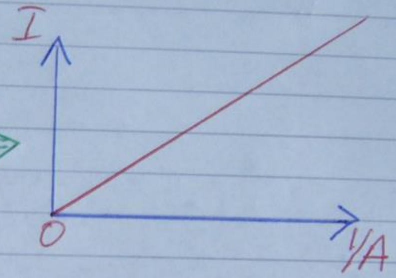
## Graphs




$I \propto P$ when A is a constant.




But of much more use ⇒




ie Irradiance is inversely proportional to surface area.

or

Irradiance is directly proportional to 1/surface area.

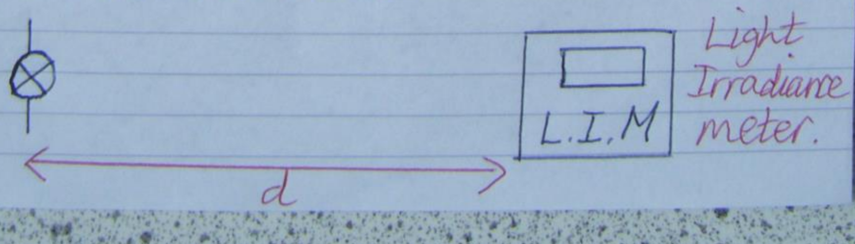
$$I_1 d_1^2 = I_2 d_2^2$$

$Id^2 = \text{Constant}$

$\Rightarrow Id^2 = k$

$\Rightarrow I = \frac{k}{d^2} \Rightarrow I \propto \frac{1}{d^2}$

What does this mean?



a) If you double the distance between the lamp and the L.I.M then:

- $d \times 2 \therefore d^2 \times 2^2 \therefore d^2 \times 4$
- As $d^2 \times 4 \therefore I \div 4$

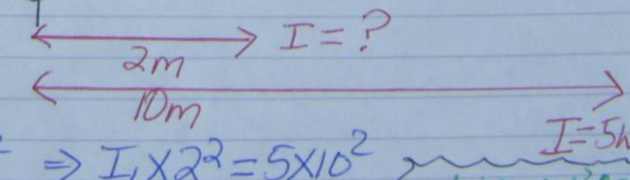
ie If you double the distance then you will reduce the Light Irradiance by a factor of 4.

b) If you reduce the distance by a factor of 3 between the lamp and the L.I.M then:

- $d \div 3 \therefore d^2 \div 3^2 \therefore d^2 \div 9$
- As $d^2 \div 9 \therefore I \times 9$

ie If you reduce the distance by a factor of 3 then you will increase the Light Irradiance by a factor of 9.

Ex1



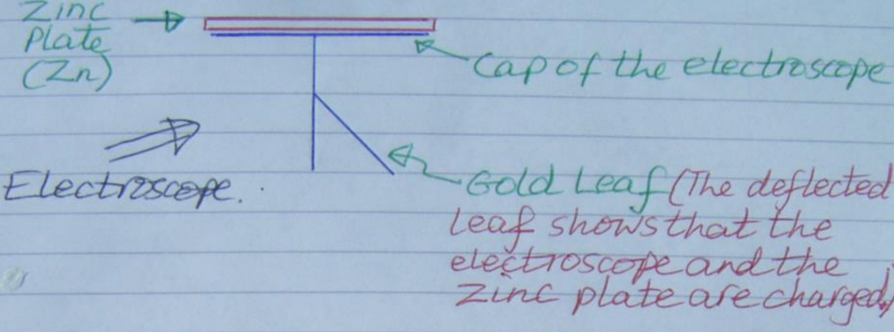

$I = 5Wm^{-2}$

- $d \div 5 \therefore d^2 \div 25$
- $d^2 \div 25 \therefore I \times 25$

$I_1 d_1^2 = I_2 d_2^2 \Rightarrow I_1 \times 2^2 = 5 \times 10^2$

$\Rightarrow 4I_1 = 500 \Rightarrow I_1 = \frac{500}{4} = 125Wm^{-2}$

# Photoelectric Effect



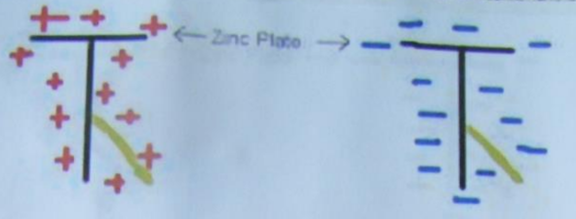

- An electroscope with a zinc plate on its cap is given a negative charge from a rod.

- An ultraviolet lamp is shone across the zinc plate, which results in the Leaf on the electroscope falling to zero.
∴ The zinc plate and the electroscope are now uncharged.

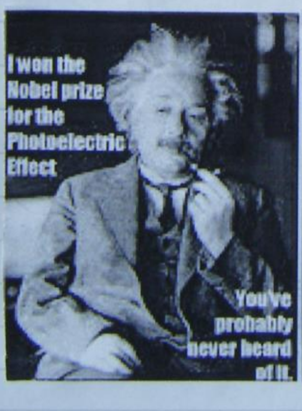
- If the zinc plate and the electroscope are positively charged using another type of rod then the UV light will not be able to bring the leaf to zero and become uncharged.

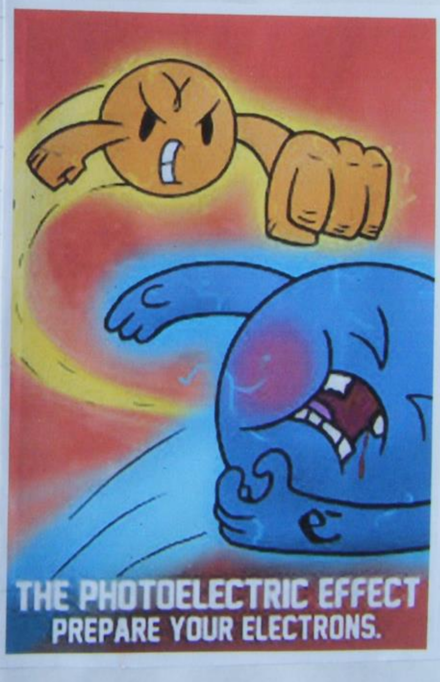
- The discharge is due to UV light being of a high enough frequency and energy of photons to allow the electrons to eject from the surface of the zinc plate.

- For the discharge to take place
  1) Negatively charged zinc plate
  2) High frequency photons from the light source (UV light)




| | | |
|---|---|---|
| Torch | No Effect | No Effect |
| Microwave | No Effect | No Effect |
| UV source | No Effect | Gold Leaf drops -> charge has been lost (electrons have bounced off) |

## Electromagnetic Spectrum

- Gamma Rays → high frequency
- X-Rays
- UV light
- Visible light → Violet / → Red. {ROYGBIV}
- Infra-Red
- Microwaves
- TV Waves
- Radio Waves. → Low frequency

UV light produces high frequency photons which will allow the photoelectric effect to take place.

- What is a photon?

* A photon is a packet or bundle of wave energy.

- When will photoelectric emission take place?

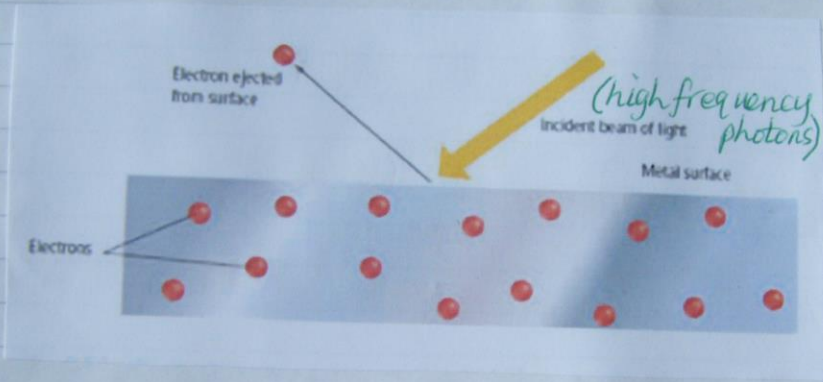
If radiation of a lower frequency than UV light was shone on to a negatively charged zinc plate on an electroscope, then the electrons will not eject from the zinc plate.

If the Irradiance of this particular radiation was increased then this would make no difference ie still no photoelectric emission.

## Quality not quantity

The overall energy is not important but the energy in each photon is important.

In conclusion, high frequency / high energy photons will eject electrons from the surface of a metal.




## Threshold frequency ($f_0$)

This is the minimum frequency which will allow electrons to be ejected from the surface of a metal.

- frequency of photons $\geq f_0 \Rightarrow$ Photoelectric Emission ✓
- frequency of photons $< f_0 \Rightarrow$ Photoelectric Emission ✗

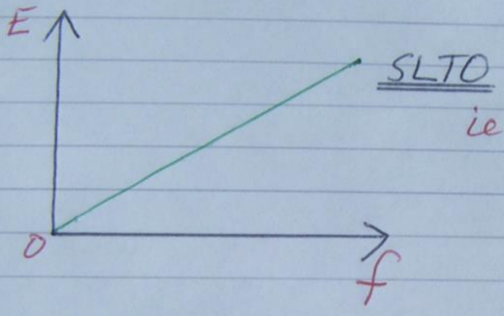
** The metal must also be negatively charged **

# Energy of a photon

$$E = hf$$

- $E$ → Energy of a photon (J)
- $h$ → Plancks Constant ($6{\cdot}63 \times 10^{-34}$ Js)
- $f$ → frequency of a photon (Hz)

In DB!!




$E \propto f$

ie The higher the frequency of the photons then the higher the energy of the photons.

## McMullen's Miller time equation

$$E = E_0 + E_K$$

- $E$ → Energy of a photon (J) ⇓ Monthly Salary
- $E_0$ → Work function of the metal (J) ⇓ All of your bills and expenses.
- $E_K$ → Kinetic energy of the electrons leaving the metal plate (J) ⇓ Miller-time Money (Clothes, cinema, meals, holidays, non alcoholic refreshments etc)

From $E = hf$ then $E_0 = hf_0$

$E_0$ is the work function of the metal. This is the minimum energy required to allow photoelectric emission to take place.

From $E = E_0 + E_K$

$$\Rightarrow hf = hf_0 + \tfrac{1}{2}mv^2$$

$$\Rightarrow \boxed{E_K = hf - hf_0} \Leftarrow \text{In DB!!}$$

## Conversions

If you are given a wavelength in a question on the photoelectric effect then you need to convert it into a frequency using $V = f\lambda$

$$\Rightarrow \boxed{f = \frac{V}{\lambda} = \frac{3\times10^8}{\lambda}}$$

## Ex2

The threshold frequency for the emission of electrons from a zinc surface is $1{\cdot}02 \times 10^{15}$ Hz.

Q/ a) Would photons of wavelength 300nm allow photoelectric emission to take place?

A a) $v = f\lambda \Rightarrow f = \frac{v}{\lambda} = \frac{3\times10^{8}}{300\times10^{-9}} = 1\times10^{15}\,Hz$

As $f < f_0$ ie $1\times10^{15}\,Hz < 1.02\times10^{15}\,Hz$

Then No photoelectric emission takes place.

Q b) Calculate the work function of the zinc metal.

A b) $E_0 = hf_0 = 6.63\times10^{-34} \times 1.02\times10^{15}$

$\Rightarrow E_0 = 6.76\times10^{-19}\,J$

Q c) A photon of wavelength 200nm strikes an electron on the zinc surface.

I) Show that the photon allows photoelectric emission to take place.

II) Calculate the kinetic energy of the photoelectrons emitted.

A c) I) $v = f\lambda \Rightarrow f = \frac{v}{\lambda} = \frac{3\times10^{8}}{200\times10^{-9}} = 1.5\times10^{15}\,Hz$

As $f > f_0$ ie $1.5\times10^{15}\,Hz > 1.02\times10^{15}\,Hz$

$\therefore$ Photoelectric emission takes place.

$(E_K = E - E_0)$

c) ii) $E_K = hf - hf_0$

$\Rightarrow E = hf = 6.63 \times 10^{-34} \times 1.5 \times 10^{15} = 9.945 \times 10^{-19} J$

$E_0 = hf_0 = 6.76 \times 10^{-19} J$ (From b)).

$\Rightarrow E_K = 9.945 \times 10^{-19} J - 6.76 \times 10^{-19} J$

$\Rightarrow E_K = 3.185 \times 10^{-19} J = 3.19 \times 10^{-19} J$ (3 sig figs!!)

Q d) Calculate the speed of the photoelectrons leaving the zinc plate.

A d) $E_K = \frac{1}{2} m v^2$

$\Rightarrow 3.19 \times 10^{-19} = \frac{1}{2} \times 9.11 \times 10^{-31} \times v^2$

$\Rightarrow v^2 = \frac{3.19 \times 10^{-19}}{\frac{1}{2} \times 9.11 \times 10^{-31}} = \frac{3.19 \times 10^{-19}}{4.555 \times 10^{-31}}$

$\Rightarrow v^2 = 7.003 \times 10^{11} \Rightarrow v = 8.37 \times 10^5 ms^{-1}$

## Ex3

The minimum frequency of incident light that allows photoelectric emission to take place is $3.33 \times 10^{14} Hz$.

Q a) What name is given to this minimum frequency of light mentioned above?

A Threshold frequency ($f_0$).

Q b) If light of wavelength 530nm is incident on the material then calculate the kinetic energy of the photoelectrons emitted from the material.

A b) $E_K = hf - hf_0$

From $v = f\lambda \Rightarrow f = \frac{v}{\lambda} = \frac{3\times10^{8}}{530\times10^{-9}}$

$\Rightarrow f = 5.66\times10^{14}\,Hz$

$\Rightarrow E_K = hf - hf_0$

$\Rightarrow E_K = (6.63\times10^{-34}\times5.66\times10^{14}) - (6.63\times10^{-34}\times3.33\times10^{14})$

$\Rightarrow E_K = 3.75\times10^{-19} - 2.21\times10^{-19}$

$\Rightarrow E_K = 1.54\times10^{-19}\,J$

Q c) Calculate the speed of the electrons as they leave the material surface.

A c) $E_K = \frac{1}{2}mv^2$

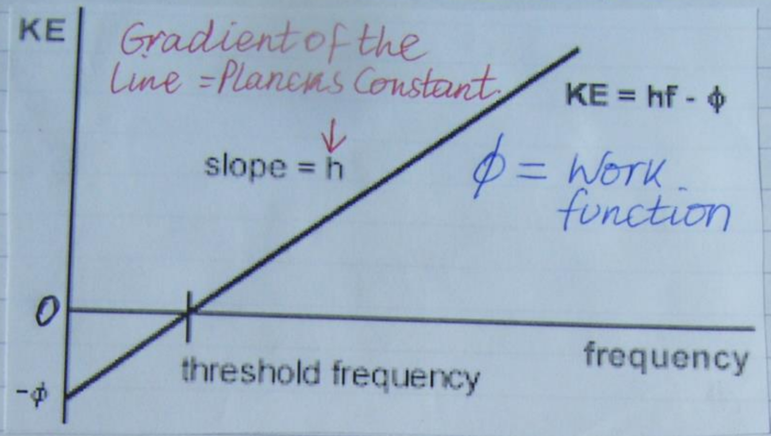
$\Rightarrow 1.54\times10^{-19} = \frac{1}{2}\times9.11\times10^{-31}\times v^2$

$\Rightarrow v^2 = \frac{1.54\times10^{-19}}{\frac{1}{2}\times9.11\times10^{-31}} = \frac{1.54\times10^{-19}}{4.555\times10^{-31}}$

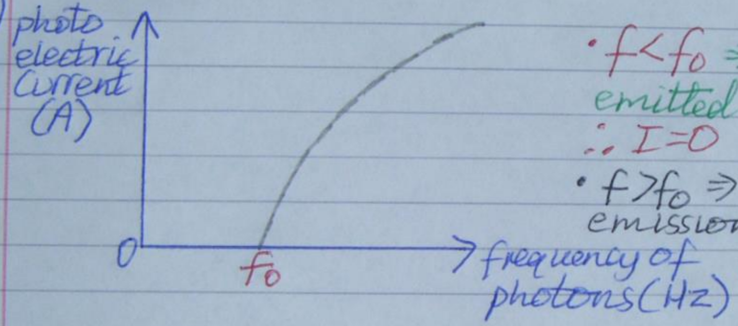
$\Rightarrow v^2 = 3.38\times10^{11} \Rightarrow v = 5.82\times10^{5}\,ms^{-1}$

# Photoelectric Effect Graphs

1)

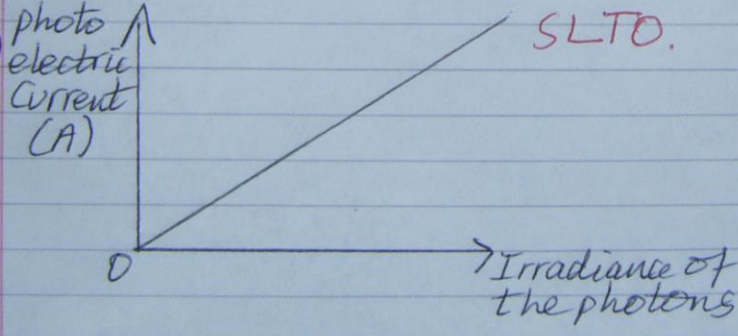



2)




- $f < f_0 \Rightarrow$ No electrons emitted from metal $\therefore I = 0$
- $f > f_0 \Rightarrow$ photoelectric emission takes place $\therefore I > 0$

3)




SLTO.

This graph can only be produced when $f \geq f_0$.

As the Irradiance of the radiation increases then the photoelectric current increases in direct proportion ie SLTO graph.

(14)

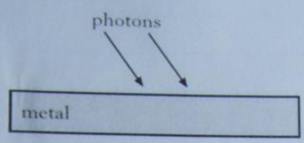
# Ex4 — 2008 PAST PAPER Q29

**Q**

To explain the photoelectric effect, light can be considered as consisting of tiny bundles of energy. These bundles of energy are called photons.

(*a*) Sketch a graph to show the relationship between photon energy and frequency. **1**

(*b*) Photons of frequency $6{\cdot}1 \times 10^{14}$ Hz are incident on the surface of a metal.




This releases photoelectrons from the surface of the metal.

The maximum kinetic energy of any of these photoelectrons is $6{\cdot}0 \times 10^{-20}$ J.

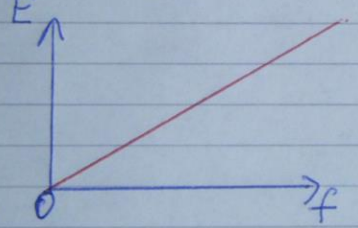
Calculate the work function of the metal. **3**

(*c*) The irradiance due to these photons on the surface of the metal is now reduced.

Explain why the maximum kinetic energy of each photoelectron is unchanged. **1**

**(5)**

**A** a)




SLTO

$E \propto f$

Energy $\propto$ frequency

b) $E_K = hf - hf_0 \Rightarrow hf_0 = \text{work function}$

$\Rightarrow hf_0 = hf - E_K$

$\Rightarrow hf_0 = (6{\cdot}63 \times 10^{-34} \times 6{\cdot}1 \times 10^{14}) - (6{\cdot}0 \times 10^{-20})$

$\Rightarrow hf_0 = 4{\cdot}04 \times 10^{-19} - 6{\cdot}0 \times 10^{-20}$

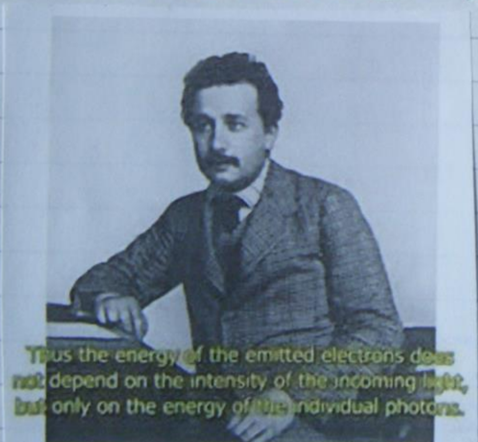
$\Rightarrow$ Work function $hf_0 = 3{\cdot}44 \times 10^{-19}$ J

c) The kinetic energy of each photoelectron is unchanged as it dependant on the frequency of the radiation only.

* The Irradiance decreasing will reduce the number of the photoelectrons leaving the metal plate per second. This has no bearing on the kinetic energy of the photoelectrons. *

- frequency → The energy of the photoelectrons

- Irradiance → The number of photoelectrons leaving the metal plate per second.




Think of different balls thrown at a Coconut shy.
Coconuts ⇒ electrons on the metal surface.
balls ⇒ photons of light.