Photoelectric effect

Worksheet 1

Look over your gr 10 revision on EMR first on pg 362 to 365.

They do still ask theory questions containing this information in matric

To stay on track: This section should take you about a week and a half

The next test will cover **Doppler effect and photoelectric effect**.

Think of a frying pan with a few drops of water on the pan. If the pan is heated up and the drops get hotter and hotter and keep gaining energy, they will eventually start vibrating. If they are given enough energy they will eventually gain so much energy that they will 'jump' off the surface and evaporate.

Similarly when you shine light (which is a form of energy) onto a metal it will give off electrons.

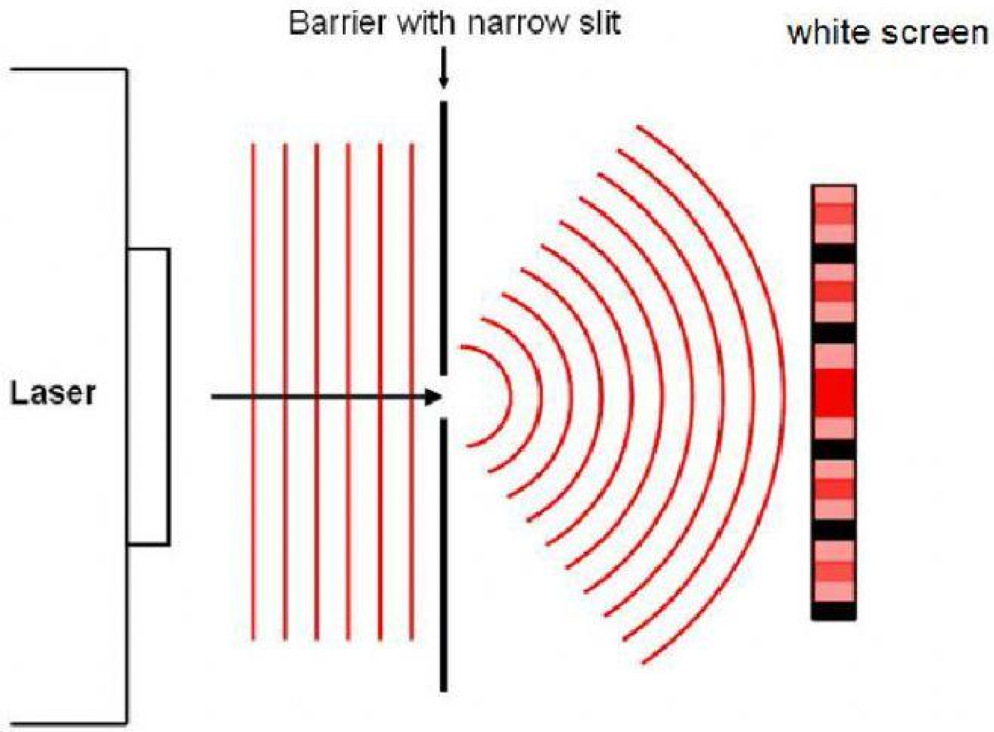
The photoelectric effect

Around the turn of the twentieth century, it was observed by a number of physicists (including Hertz, Thomson and Von Lenard) that when light was shone onto a metal plate, electrons were emitted by the metal. This is called the photoelectric effect. (*photo* for light, *electric* for the electron.)

The characteristics of the photoelectric effect were a surprise and a very important development in modern Physics. To understand why it was a surprise we need to look at the history to understand what physicists were expecting to happen and then understand the implications for Physics going forward.

It’s useful at this point to think back to what Huygens said light was:

Huygens said that light was a wave, since it interfered constructively and destructively (as seen by the following pattern- that we studied in gr 11)

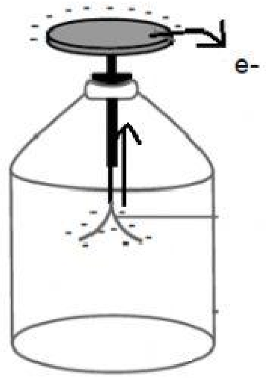


The first scientists who investigate how a metal behaves when light is shone onto it, shone white light onto a metal plate of an electroscope to see what would happen.

An electroscope is a device that can be charge positively or negatively.

It is used since the gold leaves at the bottom of the electroscope will repel each other when the electroscope is negatively or positively charged.

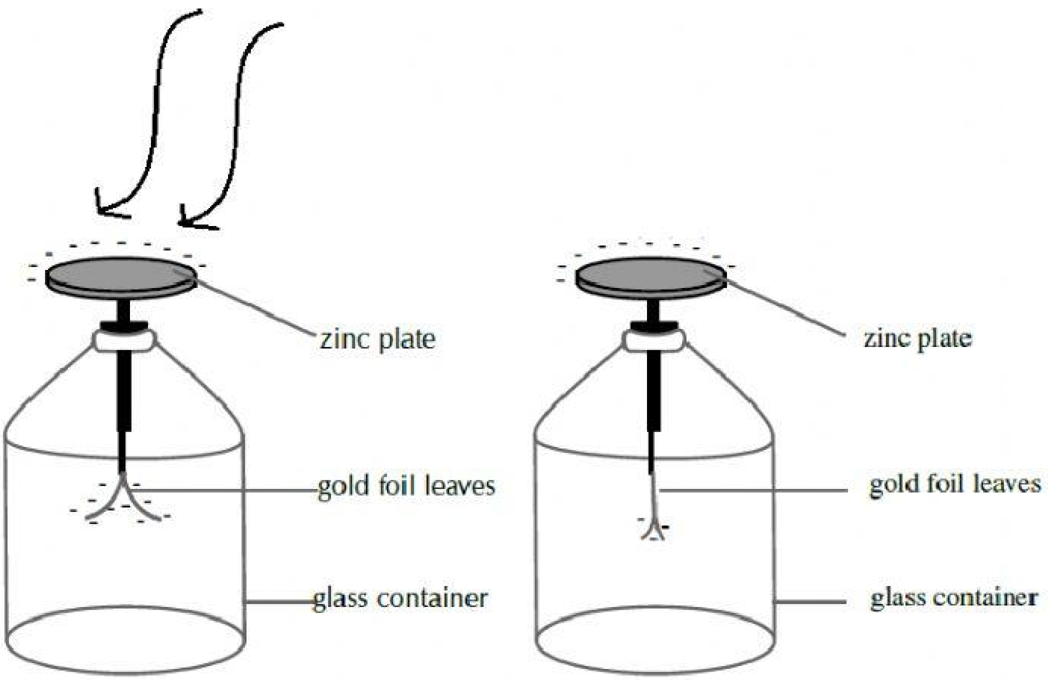
In this experiment the electroscope is charged negatively, and thus if it loses electrons the electrons will move from the leaves to the top and 'jump' off the metal plate at the top. The gold leaves will stop repelling each other as much.



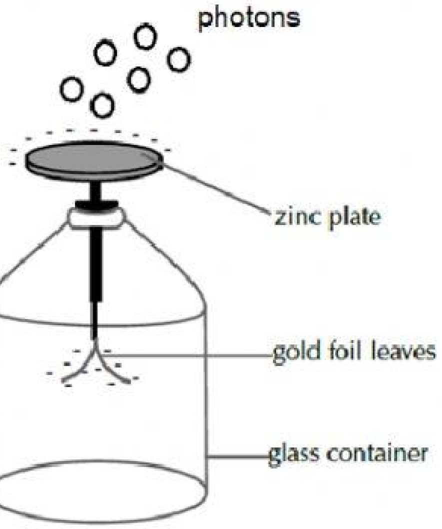
Thus if light was a wave, it would continuously be transferring energy to the metal plate and eventually transfer enough energy to the electrons that the electrons would start vibrating and 'jump' off the plate.

However this did not occur. The white light did make electrons 'jump' from the plate.

Then UV light was shone onto a negatively charged electroscope. This time electrons did jump off the metal plate. We know this since the gold leaves start to fall flat and no longer repelled each other as much. (Even dim UV light ejected electrons)



This led Einstein to believe that light was not made up of waves, but rather little **packets of light energy called photons**. One photon would transfer its energy to one electron, and if that energy was enough the electron would 'leap' off the plate.



So why did the white light not eject electrons?

Remember the electromagnetic radiation (EMR) spectrum.

RICKY MUST INSIST VACHARIYA USE XRAY GOGGLES

RADIO MICROWAVES INFRARED VISIBLE UV XRAY GAMMA

Lowest f/E

ROYGBIV

RED ORANGE YELLOW GREEN BLUE INDIGO VIOLET

Highest f/E

Frequency increases

Wavelength decreases $f \propto \frac{1}{\lambda}$

Energy increases $E \propto f$

This trend works for the EMF and the colours of light

Answer the following questions by choosing between the words (radio, microwaves, infrared, visible, uv, x-ray, gamma, red, orange, yellow, green, blue, indigo, violet

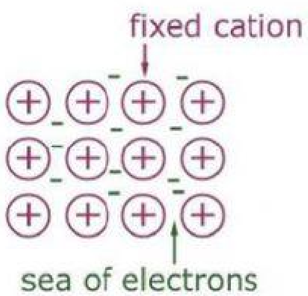
Which wave will have:

1. the longest wavelength
2. the lowest frequency
3. the greatest energy
4. the lowest penetrating ability
5. the highest frequency (out of the visible spectrum)
6. the shortest wavelength (out of the visible spectrum)
7. is used to sterilize medical equipment
8. is given off by hot objects

White light falls under 'Visible' light in the above spectrum. Thus the energy of the white light is not as high as the energy of the UV light.

If light is seen as made up of little packets of energy – the UV light packets will have more energy than the photons of white light. If each packet has enough energy, then it will transfer its energy to the electron and then that electrons will be ejected off the plate.

Not every metal's electrons will require the same amount of energy in order to be ejected. **The determining factor is how strong each metal holds onto its free electrons in the metallic bond.**



Do you think non-metals will emit electrons if light with a high enough energy is shone onto it _______________

Photoelectric effect

The photoelectric effect is the process whereby electrons are ejected from a metal surface when light of suitable frequency is incident on that surface.

The minimum energy that each metal will need for electrons to be removed is called the work function. The added energy needs to overcome the forces that the ions of the material exert on that electron.

Work function(W_o)

The minimum energy that an electron in the metal needs to be emitted from the metal surface.

These are the work functions of some metals (you do not need to learn these)

Element	Work Function (J)
Aluminium	$6{,}9 \times 10^{-19}$
Beryllium	$8{,}0 \times 10^{-19}$
Calcium	$4{,}6 \times 10^{-19}$
Copper	$7{,}5 \times 10^{-19}$
Gold	$8{,}2 \times 10^{-19}$
Lead	$6{,}9 \times 10^{-19}$
Silicon	$1{,}8 \times 10^{-19}$
Silver	$6{,}9 \times 10^{-19}$
Sodium	$3{,}7 \times 10^{-19}$

Work function = h x threshold frequency

$\mathbf{W_o = h.f_o}$

So if the frequency of the photon is lower than the threshold frequency, then energy is simply absorbed by the metal and no electrons are given off.

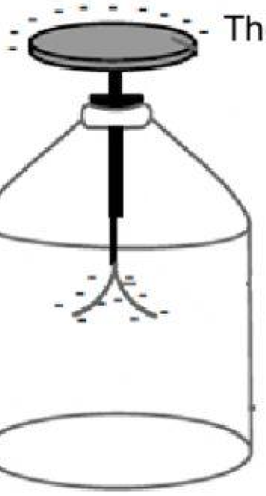
Electrons are ejected if the Energy of the photon is greater than the work function. Then a photon (from the light) collides with an electron and all the energy from the photon is transferred to the electron (then the photon no longer exists). This creates a **photoelectron.**

Let's consider 3 situations, using the same metal, to understand this better:

Situation 1: The energy of the light shone onto the metal plate is too low to emit electrons.

Energy of the light (E) = 100J

The minimum energy the metal needs to emit e^-'s(W_o)= 120 J



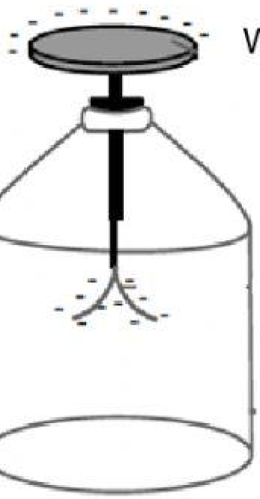
No electrons will be given off

Since $E < W_o$

Situation 2: The energy of the light equals to the energy the metal needs to emit electrons.

E= 120 J

W_O = 120 J



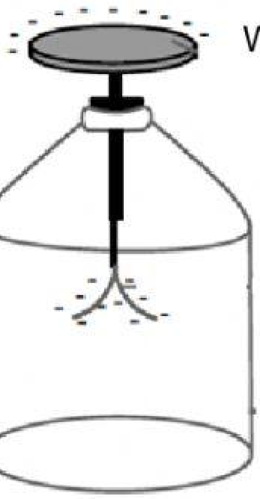
Electrons will be emitted

Since $E = W_o$

The leftover energy will be left on the photoelectrons that are ejected. This energy is called Ek.

Ek = 0J (since there was no surplus/extra energy left over.)

Situation 3: The energy of the light is greater than the energy the metal needs to emit electrons.



Electrons will be emitted

Since **$E > W_o$**

The leftover energy will be left on the photoelectrons that are ejected. This energy is called Ek.

Ek = 150 – 120

= 30 J

How do you calculate the energy that the electrons have that are 'knocked' off the plate.

$E_k = E - W_o$

When manipulated the formula looks like this

$E = W_O + Ek$ - the formula is written like this on the data sheet

The reality is that the energy of the light won't always be given. Sometimes the wavelength or frequency of the light will be given and you will first have to calculate the energy of the light.

$E = h.f$

$E = \frac{h.c}{\lambda}$

E – energy of the light that is hitting the metal plate (J)

h – Planck's constant ($6,63 \times 10^{-34}$ J.s)

c – speed of any EMR (3×10^{8} $m.s^{-1}$)

These 2 constants will be on the data sheet

λ – wavelength of the light (m)

Likewise the minimum energy that the metal needs before electrons are ejected isn't always going to be given. Sometimes the minimum frequency the metal needs will be given. This is called the threshold frequency

Threshold frequency

The minimum frequency of light needed to emit electrons to emit electrons from a certain metal surface

The threshold frequency is related to a certain minimum frequency. It is the frequency of light which will emit photoelectrons with zero kinetic energy from the surface of the material. Remember that frequency and Energy are directly proportional, thus the minimum energy relates to the minimum frequency.

But energy and wavelength are inversely proportional. When asked to calculate the minimum energy/frequency the metal needs to eject electrons, this relates to the **maximum wavelength** that the metal can take. Since wavelength and frequency are inversely proportional.

Watch this video to check if you understood the 3 examples above