PHOTOELECTRIC EFFECT 30 APRIL 2013

Lesson Description

In this lesson we:

- Describe the Photoelectric Effect
- Explain the terms photon, threshold frequency and work function
- Demonstrate the effect of changing the intensity of electromagnetic radiation when the frequency of the radiation is less or more than the threshold frequency.
- Discuss the dual nature of light

Key Concepts

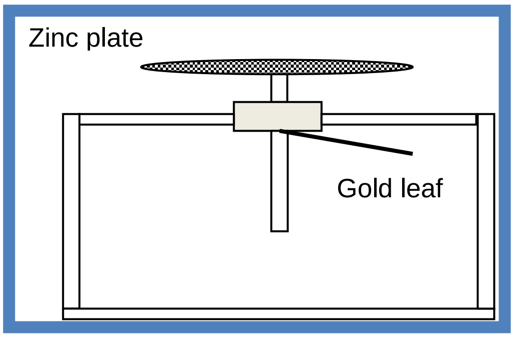
Photoelectric Effect

Photoelectric effect is a phenomenon observed when electromagnetic radiation of a certain frequency falls onto a metal surface and causes electrons to be ejected from the surface.

Electrons are not ejected from metal surfaces when electromagnetic radiation with a low frequency of falls on them.

Threshold frequency is the minimum frequency needed to cause electrons to be ejected from a metal surface. Different metals have different threshold frequencies.

Demonstration of photoelectric effect



- Charge a gold leaf electroscope negatively.
- Allow red light of different intensities to shine on the zinc metal of the gold leaf electroscope and observe what happens.
- Allow Ultraviolet radiation of different intensities to shine on the negatively charged electroscope and observe what happens.
- Use a specific intensity of UV for a long time onto the zinc plate and observe further what happens.

Discussion of Observations

- When red light of different intensities is shone onto the zinc surface of the negatively charged gold leaf electroscope, nothing happens to the leaves. This is because the frequency of red light is less than the threshold frequency of the zinc metal. When the frequency of electromagnetic radiation is less than the threshold frequency, no electrons will be ejected even if the intensity is increased.

- When UV radiation shines onto the zinc surface of the negatively charged electroscope, the gold leaves collapse. The gold leaves collapse because the electrons are now ejected on the surface of the zinc metal so that the force of repulsion between the leaves becomes less. The frequency of UV radiation is greater than the threshold frequency of zinc metal. Electrons are ejected even at low intensity. When the intensity of UV is increased, the number of photons bombarding the zinc surface. So more electrons absorb the energy from the photons and more electrons get ejected from the metal surface.

- When the gold leaf electroscope is exposed to the UV radiation of specific intensity for a longer period of time, the gold leaves open up again. Further exposure of the electroscope to UV radiation leads to more and more electrons ejected from the gold leaves through the zinc metal. As a result the gold leaves become positively charged and therefore begin to repel each other.

Explanation of Photoelectric Effect

The energy of a wave is related to its amplitude. For light, amplitude is related to brightness or intensity. The wave model of light **cannot** explain why brighter light does not cause electrons to be ejected from the surface of a metal.

Einstein explained the Photoelectric effect by recognizing that electromagnetic radiation has a particle nature. He proposed that the energy of the particles is quantised and not continuous. He called the particles of light **photons**. The energy of a photon is found by using the equation:

E = hf where ***h*** is the ***Plank's Constant = 6,63 x*** $\boldsymbol{10^{-34}}$ ***Js*** and ***f*** is the frequency of the electromagnetic radiation measured in Hertz (Hz).

When photons have a frequency equal to the threshold frequency of a metal we call this energy the ***Work Function (***$\boldsymbol{W_o}$***)***.

$W_o = hf_o$ where f_o is the ***threshold frequency***.

Both the threshold frequency and the Work Function are properties of a specific metal. Thus different metals will have different work functions. This is so because different metals have different ionisation energies due to the specific arrangement of electrons in their energy levels.

When the energy carried by a photon is **less than the work function** of specific metal no electrons will be ejected from such a metal surface.

When the energy of the incident photon is **greater than the work function** of the metal, electrons will be ejected from the metal surface. The electron absorbs the energy equal to the work function so that it can be ejected from the metal surface and then uses the remaining energy to move away from the surface. We say the ejected electron has gained kinetic energy. Thus:

Energy of the photon = Work function + Kinetic Energy of the photoelectron

$$(hf = W_o + K)$$

Questions

Question 1

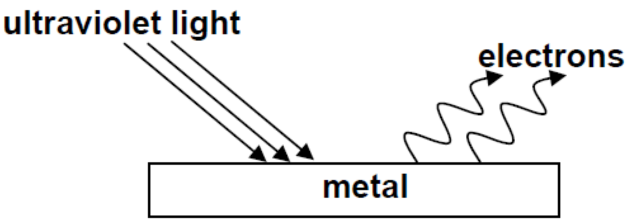
Calculate the energy of a photon of a photon of visible light which has

a.) A frequency of 3.0×10^{14} Hz
b.) A wavelength of 700 nm

Question 2

(Adapted from Nov 2011, NSC, Paper 1, Question 12)

A metal surface is illuminated with ultraviolet light of wavelength 330 nm. Electrons are emitted from the metal surface. The minimum amount of energy required to emit an electron from the surface of this metal is $3,5 \times 10^{-19}$ J.



a.) Give ONE word or term for the underlined sentence in the above paragraph.
b.) Calculate the frequency of the ultraviolet light.
c.) Calculate the kinetic energy of a photoelectron emitted from the surface of the metal when the ultraviolet light shines on it.

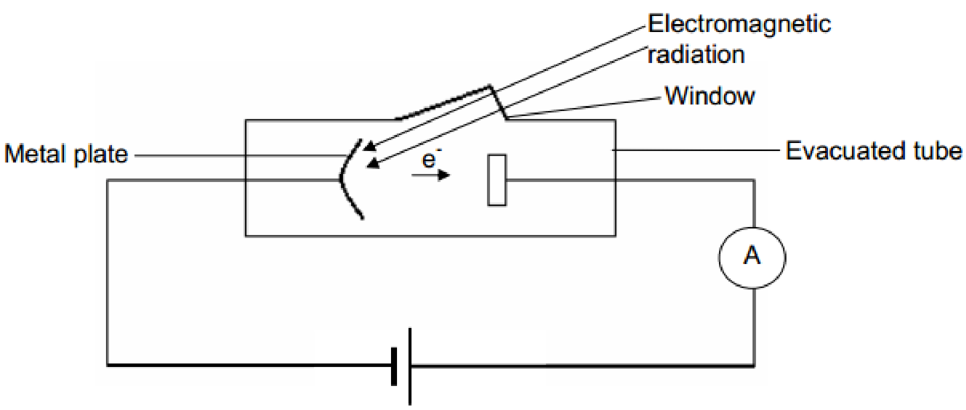
The intensity of the ultraviolet light illuminating the metal is now **increased**. What effect will this change have on the following:

d.) Kinetic energy of the emitted photoelectrons
(Write down only INCREASES, DECREASES or REMAINS THE SAME.)
e.) Number of photoelectrons emitted per second
(Write down only INCREASES, DECREASES or REMAINS THE SAME.)

Question 3

(Adapted from Nov 2009, NSC, Paper 1, Question 14)

The diagram below shows a metal plate that emits electrons when a certain frequency of electromagnetic radiation is incident on it. The plate is connected to a source of potential difference and an ammeter as shown in the circuit below.



a.) Name the phenomenon described above. (1)

When radiation of wavelength 555 nm is incident on the metal plate, electrons are released with zero kinetic energy.

b.) Define the term *work function* of a metal. (2)

c.) Calculate the work function of this metal. (6)

d.) How will the reading on the ammeter change if the intensity of the electromagnetic radiation is increased? Write down only INCREASES, DECREASES or REMAINS THE SAME.
Give a reason for your answer. (3)

e.) Incident radiation with a longer wavelength is now used. How will the reading on the ammeter change? Write down only INCREASES, DECREASES or REMAINS THE SAME. (1)

[13]