Photo Electric Effect - Grade 12 PHYSICAL SCIENCES NOTES

Life Sciences (High School - South Africa)

Photo Electric Effect

Key Concepts

This lesson will focus on the following:

- The dual nature of light
- Particle nature and the photons of light
- Work function and metal surfaces
- Energy equation, E = hf
- Ejected electrons and kinetic energy

Terminology & definitions

- Photoelectric effect is the phenomenon where light of particular frequency causes electrons to be ejected from a metal surface.
- Dual nature of light – light can be explained in two ways; light having a wave nature and light having a particle nature.
- Work function – the minimum energy package needed to eject an electron from a metal surface. Threshold frequency – the minimum frequency of light needed to eject an electron from a metal surface
- Photon – energy package of a specific electromagnetic radiation, also called a quantum of energy.
- Electromagnetic radiation – Radiation that consists of wave-like electric and magnetic fields in space, including white light (***red, orange, yellow, green, blue, indigo, violent***), microwave, radio signals and x-rays. Electromagnetic radiations with higher frequencies are useful to mankind as some, like violent light, can be used to kill bacteria. Violent light is used mainly in killing bacteria in butcheries.
- Planck's constant (h) – a constant used in calculating the energy of a photon.
  $h = 6{,}63 \times 10^{-34}$ J.s

X-planation of key concepts and terminologies

The *photoelectric effect theory* is used to explain the particle nature of light while *diffraction of light* is used to explain the wave nature of light. When photoelectric effect occurs, the ejected electrons are able to move with a particular speed after being ejected, provided they contain enough energy. If the incident photons of light contain energies greater than the work function of the metal, the remaining energy will be used to set the electrons on motion. A photon contains a specific amount of energy. We say that the energy of a photon is quantized. The energy carried by a photon of light is found by using the equation ***E = hf***. From the equation, it is evident that the energy of a photon of a specific light is quantized, since its magnitude depends on the frequency which is associated with specific colours of light or electromagnetic radiation. If the wavelength of a particular light wave is given instead of its frequency, the wave equation is used to find the frequency of the light where the speed of light in a vacuum is given as a constant, $c = 3 \times 10^{8} m{\cdot}s^{-1}$.

Light (electromagnetic radiation) of frequency lower than the threshold frequency does not lead to electrons being ejected from a metal surface. Alternatively, this would mean that the energy of the photon is less than the work function of the metal. Increasing the intensity of light for which the frequency is less than the threshold frequency, would not cause electrons to be ejected.

Photons of light carrying energy packages equal to that of the work function of a metal would cause the electrons to be ejected but will not give the electrons enough energy (kinetic) to move off the metal surface. Increasing the intensity of this light will only cause more electrons to be ejected from the metal surface, but not enough to set them on motion.

However, if the incident photons carry energies that are greater than the work function of the metal, electrons will be ejected and will be provided with enough (kinetic) energy to move off the metal surface. The energy carried by a photon of this light will be given by $\boldsymbol{E = W_0 + E_k}$, where, E is the total energy of the photon, W_0 is the work function of the metal and E_k is the kinetic energy of the electron. If the magnitude of the kinetic energy gained by an electron is known, the velocity of the electron can be calculated using the kinetic energy formula; $\boldsymbol{E_k = \frac{1}{2}mv^2}$, where ***m*** is the mass of the electron and ***v*** is the velocity of the electron.

X-ample Questions

1. How much energy does electromagnetic radiation of the following frequencies have?
   (a) $3{,}0 \times 10^{14}$ Hz (infrared)
   (b) $5{,}0 \times 10^{14}$ Hz (orange light)
   (c) $6{,}0 \times 10^{14}$ Hz (UV light)

2. Violet light has a wavelength of about 410 nm.
   (a) What is the frequency of a photon of this light?
   (b) Calculate the energy of one photon of violet light.
   (c) Will electrons from a metal surface of work function $2{,}3 \times 10^{-8}$J be ejected by photons of violet light? Explain your answer.

3. The wavelength of red light is 750 nm.
   (a) Calculate the energy of a photon of red light.
   (b) Calculate the kinetic energy of an electron ejected by red light from a surface of a metal with a work function of 1.4×10^{-19} J.
   (c) Calculate the velocity attained by the ejected electron when red light is shone on this metal.
   (mass of an electron = $9{,}11 \times 10^{-31}$ kg).

X-ercise

1. A learner wants to demonstrate the photoelectric effect. He uses a disk of zinc placed on an electroscope. The work function of zinc is 6,9 X 10^{-19} J.

   1.1 Define the concept ***work function***.

   1.2 Calculate the maximum wavelength of light that will eject electrons from the zinc disk.

   1.3 The electroscope is negatively charged and then exposed to ultraviolet light. One of the wavelengths of the light is 260 nm. Calculate the kinetic energy of an electron emitted from the zinc disk by a photon of this light.

   1.4 When the student attempts the experiment with a positively charged electroscope, he finds that the ultraviolet light has no apparent effect. Explain this observation.

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

   2.1 Calculate the work function of this metal.

   2.2 How will the number of ejected electrons from the metal surface change if the intensity of the electromagnetic radiation is increased. Write only INCREASES, DECREASES or REMAIN THE SAME and give reason for your answer.

Answers

1.1 The minimum amount of energy needed to remove an electron from a metal surface.

1.2 2,88 X 10^{-7} m

1.3 7,5 X 10^{-20} J

1.4 A positive plate will attract electrons rather than emit them.

2.1 E = 3,58 x 10^{-19} J

2.2 Increase