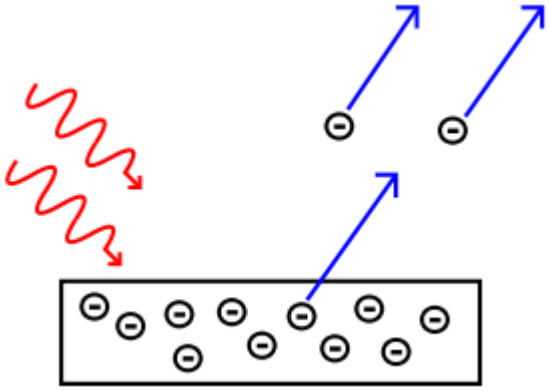
The Photoelectric Effect



Photons with energy E = hν

shine on a metal with work function ϕ_M

and release electrons with kinetic energy E_K .

So $h\nu = \phi_M + E_K$ $\quad E_K = \frac{1}{2} m_e u^2$ where m_e = mass of an electron = 9.1094×10^{-28} g

and u = (maximum) speed of the electron leaving the metal.

ϕ_M can also be written as $h\nu_0$ where $h = 6.626 \times 10^{-34}$ J·s and ν_0 is the threshold frequency.

When $\nu < \nu_0$ no electron is released from the metal. When $\nu = \nu_0$ an electron is released with no kinetic energy. When $\nu > \nu_0$ and electron is released with a (maximum) speed u. Different metals have different work functions and correspondingly different threshold frequencies.

Problems:

1. Indium has a threshold frequency of 9.96×101^{14} Hz. (a) What is the maximum wavelength of electromagnetic radiation that will release an electron from indium metal? (b) Will green light (495 to 570 nm) shining on indium cause a photoelectric effect? (c) Will ultraviolet light (λ<380 nm) shining on indium cause a photoelectric effect. (d) Determine the (maximum) kinetic energy of electrons released from indium by photons with energy 1.00 femtojoule. (e) What will be the (maximum) speed of electrons in (d)?

2. When light with wavelength 358.1 nm shines on the surface of potassium metal, the speed of the released electrons is 6.40×10^5 m/s. (a) Determine the kinetic energy of the released electrons. (b) Determine the value of the work function for potassium in joules. (c) Determine the threshold frequency for potassium. (d) will blue light with wavelength 475.0 nm cause a photoelectric effect on potassium?

Answers:

1. a. 3.01×10^{-7} m b. No c. Yes d. 1.32×10^{-19} J e. 1.70×10^6 m/s

2. a. 1.87×10^{-19} J b. 3.68×10^{-19} J c. 5.55×10^{14} s^{-1} d. Yes

Solutions:

1. a. $\lambda\nu = c = 3.00\text{x}10^{8}$ m/s $\quad \lambda = \frac{c}{\nu} = \frac{3.00\text{x}10^{8}\ \frac{\text{m}}{\text{s}}}{9.96\text{x}10^{14}\text{s}^{-1}} = 3.01\text{x}10^{-7}$ m

   b. No, green light has wavelength greater than $4.80\text{x}10^{-7}$ m and frequency less than the threshold.

   c. Yes, ultraviolet light has wavelength less than $4.00\text{x}10^{-7}$ m and frequency greater than the threshold.

   d. $E_K = h\nu - \phi_M$ where $\phi_M = h\nu_0 = 6.626\text{x}10^{-34}\ \text{J}\cdot\text{s} \times 9.96\text{x}10^{14}/\text{s} = 6.60\text{x}10^{-19}$ J

   so $E_K = 1.00\ \text{fJ} \times \frac{10^{-15}\ \text{J}}{1\ \text{fJ}} - 6.60\text{x}10^{-19}\ \text{J} = 1.32\text{x}10^{-18}$ J

   e. $1.32\text{x}10^{-18}\ \text{J} = \tfrac{1}{2} m_e u^2 \quad u = \sqrt{\frac{1.32\text{x}10^{-18}\ \text{J}}{\frac{1}{2} \times 9.1094\text{x}10^{-28}\ \text{g}} \times \frac{1\ \text{kg}\ \frac{\text{m}^2}{\text{s}^2}}{1\ \text{J}} \times \frac{1000\ \text{g}}{1\ \text{kg}}} = \sqrt{2.90 \times 10^{12}\ \frac{\text{m}^2}{\text{s}^2}} = 1.70\text{x}10^{6}$ m/s

2. a. $E_K = \tfrac{1}{2} m_e u^2 = 0.5 \times 9.1094\text{x}10^{-}28\ \text{g} \times (6.40\text{x}10^{5}\ \frac{\text{m}}{\text{s}})^2 \times \frac{1\ \text{J}}{1\ \text{kg}\ \frac{\text{m}^2}{\text{s}^2}} \times \frac{1\ \text{kg}}{1000\ \text{g}} = 1.87\text{x}10^{-19}$ J

   b. $\phi_M = E_K - h\nu = E_K - \frac{hc}{\lambda} = 1.87\text{x}10^{-19}\ \text{J} - \frac{6.626\text{x}10^{-34}\ \text{J}\cdot\text{s} \times 2.998\text{x}10^{8}\ \frac{\text{m}}{\text{s}}}{358.1\ \text{nm}} \times \frac{1\ \text{nm}}{10^{-9}\ \text{m}} =$

   $$\phi_M = 1.87\text{x}10^{-19}\ \text{J} - 5.547\text{x}10^{-19}\ \text{J} = 3.68\text{x}10^{-19}\ \text{J}$$

   c. $h\nu_0 = 3.68\text{x}10^{-19}$ J so $\nu_0 = \frac{3.68\text{x}10^{-19}\ \text{J}}{6.626\text{x}10^{-34}\ \text{J}\cdot\text{s}} = 5.55\text{x}10^{14}\ \text{s}^{-1}$

   d. $\lambda\nu = c$ so $\nu = \frac{c}{\lambda} = \frac{2.998\text{x}108\ \frac{\text{m}}{\text{s}}}{475.0\ \text{nm}} \times \frac{1\ \text{nm}}{10^{-9}\ \text{m}} = 6.31\text{x}10^{14}\ \text{s}^{-1} > \nu_0 = 5.55\text{x}10^{14}\ \text{s}^{-1}$ so yes.