PHYS 250 Worksheet 2 Solutions

1. Photoelectric Current

A light source with power P = 1 milliWatt and wavelength λ = 300 nm shines on a caesium surface with work function ϕ = 2.10 eV.

A. If every photon creates a photoelectron, and all photoelectrons are collected by the anode, what would the current I be in Amperes ?

$I_{\text{Amperes}} = \dfrac{\text{electrons}}{\text{second}} \cdot q_{\text{electron}}$ and $\dfrac{\text{electrons}}{\text{second}} = \dfrac{\text{photons}}{\text{second}} = \dfrac{\text{power}}{E_{\text{photon}}}$.

It's convenient to change power from Joules/second to eV/second,

and use the photon energy in eV. Then $\dfrac{\text{electrons}}{\text{second}} = \dfrac{P_{\text{Joule/s}} / q_{\text{electron}}}{E_{eV}}$.

Combine the above into $I_{\text{Amperes}} = \dfrac{P_{\text{Joule/s}} / q_{\text{electron}}}{E_{\text{photon, eV}}} \cdot q_{\text{electron}} = \dfrac{P_{\text{Joule/s}}}{E_{\text{photon, eV}}}$. The electron charge cancels!

Now we need $E_{\text{photon, eV}} = hf = \dfrac{hc}{\lambda} = \dfrac{1240 \text{ eV-nm}}{300 \text{ nm}} = 4.13 \text{ eV}$

Finally $I = \dfrac{P}{V} = \dfrac{10^{-3} \text{ Watts}}{4.13 \text{ Volts}} = 2.421 \times 10^{-4} \text{ Amperes}$

B. What is the maximum photoelectron energy in electron-Volts ?

$$E_{\max} = hf - \phi = \frac{hc}{\lambda} - \phi = \frac{1240 \text{ eV-nm}}{300 \text{ nm}} - 2.10 \text{ eV} = 4.13 - 2.10 = 2.03 \text{ eV}$$

2. Photoelectric Voltage

An aluminum sphere (work function 4.10 eV) is suspending by an insulating glass fiber inside a metal vacuum chamber. Light with wavelength 250 nm shines on the aluminum sphere. What voltage does the aluminum sphere charge to, relative to the vacuum chamber, including the sign?

The photon energy is $E = \frac{hc}{\lambda} = \frac{1240 \text{ eV-nm}}{250 \text{ nm}} = 4.960 \text{ eV}$. The maximum photoelectron energy is 4.960 – 4.10 = 0.860 eV. Photoelectrons will be knocked out of the sphere, leaving a positive charge, and be absorbed by the vacuum chamber walls. But when the sphere charges up to +0.86 Volts, the photoelectrons will be attracted back to the sphere, so the charging stops.

3. Fun with X-Rays

A. An X-ray tube is operated with voltage of 150 kV. What is the minimum X-ray wavelength?

$$E = hf = \frac{hc}{\lambda} \rightarrow \lambda_{\text{min}} = \frac{hc}{E} = \frac{1240 \text{ eV-nm}}{150 \times 10^3 \text{ eV}} = 8.267 \times 10^{-3} \text{ nm} = 8.267 \text{ pm}$$

B. A Bragg spectrometer using a crystal with plane spacing of 80 pm is used to measure the X-ray spectrum. What is the minimum surface incidence angle for Bragg diffraction?

$$2d \sin\theta_{\text{surface}} = n\lambda \rightarrow \theta = \sin^{-1}\frac{\lambda}{2d} = \sin^{-1}\frac{8.267 \text{ pm}}{2 \cdot 80 \text{ pm}} = \sin^{-1} 5.167 \times 10^{-2} = 2.962° = 51.69 \text{ milliradians}$$

C. If an X-ray of the minimum wavelength is Compton-scattered through 90° by an electron, what is the wavelength of the scattered X-ray?

$$\lambda' - \lambda = \frac{h}{mc}\left(1 - \cos\theta\right) \rightarrow \lambda' = \lambda + \frac{h}{mc}\left(1 - \cos\theta\right).$$

Since cos 90° = 0, $\lambda' = \lambda + \frac{h}{mc}$. The Compton wavelength $\frac{h}{mc} = 2.426 \text{ pm}$.

So $\lambda' = 8.267 \text{ pm} + 2.426 \text{ pm} = 10.69 \text{ pm}$