Group Problems #15 - Solutions

Wednesday, September 28

Problem 1 *Photoelectric effect*

The work function for tungsten (W) is $\phi_W = 4.52$ eV.

(a) What is the longest light wavelength (sometimes referred to as the cutoff wavelength, λ_c) that can result in production of a photocurrent?

To eject an electron, a photon must have at least as much energy as ϕ_W. Using $E_\gamma = hc/\lambda_c = \phi_W$ gives $\lambda_c = hc/\phi_W = 1240/4.52$ eV-nm/eV $= 274.3$ nm.

(b) What is the maximum kinetic energy, K_{max}, of emitted electrons when light of wavelength $\lambda = 200$ nm is used to irradiate a piece of W?

If the enegy of the photon is greater than the work function, $hc/\lambda > \phi$, then the extra energy goes into kinetic energy of the photoelectrons. In this case, we have $K_{max} = hc/\lambda - \phi_W = 1240/200 - 4.52 = 1.68$ eV.

(c) What is the stopping potential (voltage) for this case ($\lambda = 200$ nm)?

The potential energy of an electron in an electric potential is $q{\cdot}V = e{\cdot}V$, where $q = e$ is the charge of an electron, and V is the applied voltage. The stopping potential is given by the voltage needed to stop the electrons with kinetic energy K_{max} when that voltage is applied across two electrodes, one of which is the photocathode - the metal plate from which the electrons are emitted in the photoelectric process. As the electrons travel from the photocathode to the other electrode, they increase their electric potential energy, and thus their kinetic energy decreases - they slow down. If the voltage is adjusted so that the potential energy increases by exactly K_{max} just before the electrons reach the second electrode, they will stop and thus no current will be recorded. Thus we have $K_{max} = 1.68$ eV $= e \cdot V$, so the stopping potential is exactly 1.68 V.

Problem 2 *Quantization of light*

(a) A diode laser (we'll get to these later, hopefully) used in fiber-optic telecommunications technologies (e.g., broadband internet) has a wavelength of $\lambda_{TC} = 1310$ nm and a typical output power of $P_{TC} = 5$ milliwatts (mW). How many photons does such a laser put out per second?

Power P is energy per unit time, so a Watt $= 1$ Joule/s $= 6.24 \times 10^{18}$ eV/s. The energy of a single photon of wavelength $\lambda = 1310$ nm is $hc/\lambda = 1240/1310 = 0.95$ eV. So to calculate the number of photons per second, we divide the power by the energy per photon:

$$N_{ph} = \frac{(5 \times 10^{-3}\text{ Watts})(6.24 \times 10^{18}\text{ eV/s/Watt})}{0.95\text{ eV/photon}} = 3.28 \times 10^{16}\text{ photons/s.} \quad (1)$$

(b) A Blu-Ray player uses a diode laser with a wavelength of $\lambda_{BR} = 405$ nm, and is reported also to have a power of $P_{BR} = 5$ mW. How many photons does the Blu-Ray laser put out per second?

In this case, the energy per photon is $hc/\lambda = 1240/405 = 3.06$ eV. Using the same equation as above, we have:

$$N_{ph} = \frac{(5 \times 10^{-3}\text{ Watts})(6.24 \times 10^{18}\text{ eV/s/Watt})}{3.06\text{ eV/photon}} = 1.02 \times 10^{16}\text{ photons/s.} \quad (2)$$