Photoelectric Effect

Problem 1. Photons in the beam of monochromatic light have an energy of 5 eV and are incident on a copper plate (electron emitter) with a work function $\Phi = 4.7$ eV (the Planck's constant $h = 6.63 \cdot 10^{-34}$ J·s & $hc = 1240$ eV·nm). The photocurrent is measured as a function of the applied voltage.

(A) Calculate the wavelength and frequency of photons in the beam.

(B) Determine the maximum kinetic energy of photoelectrons and calculate the negative stopping potential.

(C) What is the cutoff frequency f_C needed to observe the photoelectric effect using a copper plate as an electron emitter? Explain.

(D) The energy of incoming photons in the light beam is doubled to 10 eV while the photon flux, i.e. the number of photons that hit the copper plate per unit time, remains unchanged. The photocurrent is measured again as a function of the applied voltage. Which one of the following quantities will change: (a) the speed of photons, (b) the current of photoelectrons, or (c) the negative stopping potential. Explain.

(A) $$\lambda = \frac{hc}{E} = \frac{1240 \text{ eV}\cdot\text{nm}}{5 \text{ eV}} = \underline{248 \text{ nm}}$$

$$f = \frac{c}{\lambda} = \frac{3\times10^{8} \cancel{m}}{s\cdot 248\times10^{-9} \cancel{m}} = \frac{\cancel{300}}{248} \times 10^{15} s^{-1}$$

$$= \underline{1.21\times10^{15} \text{ Hz}}$$

(B) $$K_{max} = E - \phi = \underline{0.3 \text{eV}}$$

$$\Delta V_{stop} = \underline{-0.3 \text{eV}}$$

(C) $$h f_c = \phi \Rightarrow f_c = \frac{\phi}{h} = \frac{\phi\cdot c}{hc}$$

$$= \frac{4.7 \cancel{eV}\cdot 3\times10^{8+9} \cancel{nm}}{124\cancel{0} \cancel{eV}\cdot\cancel{nm}\ s} =$$

$$= \frac{4700.3}{1240}\times10^{14} \text{ Hz} = \underline{1.14\times10^{15} \text{ Hz}}$$

(D) (c)

Wave Optics

Problem 2. A Young's interference experiment is performed with monochromatic light of wavelength $\lambda = 500$ nm and two parallel slits separated by $d = 0.1$ mm. *Hint: Use a small angle approximation but be careful with the units.*

(A) Calculate *all* the angles of interference maxima in the range $-1° < \theta < 1°$.

(B) We want to capture the interference maxima defined and calculated in (A) on the screen behind the double slit. Determine the distance L between the double-slit and the screen that will allow us to see the maxima on the screen separated by 1 cm?

(A) $\theta_{max} \approx m \frac{\lambda}{d}$ $\frac{\lambda}{d} = \frac{5 \times 10^{-7} m}{10^{-4} m} = 5 \times 10^{-3}$

$m = 0$: $\theta_{max} = 0$

$m = \pm 1$: $\theta_{max} = \pm 5 \times 10^{-3}$ rad $= \pm 0.286°$

$m = \pm 2$: $\theta_{max} = \pm 10^{-2}$ rad $= \pm 0.573°$

$m = \pm 3$: $\theta_{max} = \pm 1.5 \times 10^{-2}$ rad $= \pm 0.859°$

(B) $\Delta y = L \cdot \Delta \theta_{max} = L \cdot \frac{\lambda}{d} \Rightarrow L = \frac{d}{\lambda} \Delta y$

$L = \frac{10^3}{5} \cdot 10^{-2}\ m = \underline{\underline{2m}}$

Blackbody Radiation

Problem 3. We are measuring the spectra of two neighboring stars, 1 and 2, and determine that the peaks of the wavelength distributions are at the wavelengths $\lambda_{max,1} =$ 500 nm and $\lambda_{max,2} =$ 700 nm. Assume that the radiation from the stars is blackbody radiation and the emissivity $e = 1$ (Stefan's constant $\sigma = 5.7 \cdot 10^{-8}$ W/(m^2·K^4)).

(A) Calculate the surface temperatures, T_1 and T_2, of each of the two stars.

(B) Assume that the surface areas of the two stars, A_1 and A_2, are approximately the same, $A_1 = A_2 \approx A$. Which of the two stars has a larger total power of emitted radiation, $\mathcal{P}$? Calculate the ratio of the total emitted power from the two stars, $\mathcal{P}_1/\mathcal{P}_2$.

(A) $\lambda_{max} T = 2.898 \times 10^{-3}$ mK

$$T_1 = \frac{2.898 \times 10^{-3} \cancel{m}K}{500 \times 10^{-9} \cancel{m}} = \frac{2.898}{5} \times 10^4 K$$

$$= \underline{\underline{5796 K}}$$

$$T_2 = \underline{\underline{4140 K}}$$

(B) $$\frac{P_1}{P_2} = \left(\frac{T_1}{T_2}\right)^4 = \underline{\underline{3.84}}$$

Problem 4. According to Niels Bohr the lowest four energy levels of the hydrogen atom are: -13.6 eV ($n = 1$), -3.4 eV ($n = 2$), -1.5 eV ($n = 3$), and -0.9 eV ($n = 4$). Consider atomic hydrogen gas. Assume that the energy states of electrons within hydrogen atoms are distributed over all the four possible quantum levels, $n = 1, 2, 3, 4$.

(A) Light of what wavelength is required to excite an electron from $n = 1$ to $n = 4$?

(B) A free electron with the kinetic energy of 11 eV passes through a gas of atomic hydrogen and collides in-elastically with electrons bound to hydrogen atoms. Can this 11 eV electron ionize one hydrogen atom? Explain your reasoning.

(A) $$\lambda = \frac{hc}{\Delta E} = \frac{hc}{E_4 - E_1} = \frac{1240\ \cancel{\text{eV}} \cdot \text{nm}}{12.7\ \cancel{\text{eV}}} = \underline{\underline{97.6\ \text{nm}}}$$

(B) only $n = 2, 3, 4$