

Physics 111 Homework Solutions Collected on Wednesday 11/5

Friday, October 31, 2014

None due to Exam 2

Monday, November 3, 2014

Chapter 24

Questions

- 24.2 In a photoelectric experiment the intensity refers to the number of photons incident on the metal surface per second. Let a beam of green light with intensity I be incident on the surface and note that it produces a photocurrent. If we switch to blue light of the *same intensity* I , the energy of the individual photons is greater and thus the maximum kinetic energy of the ejected photoelectrons is greater. The intensity is a constant, which is the total energy of the photons in the beam of light. The total energy is a product of the energy of each photon multiplied by the total number of photons. If the energy of each individual photon increases then the number of photons in the beam decreases since we want the total energy of the beam (which is proportional to the intensity) to remain constant. Since the number of photons decreases the number of photoelectrons decreases and the photocurrent decreases.
- 24.4 If for a particular wavelength of green light we find a stopping potential of -1.5V , this allows us to determine the work function ϕ , or the minimum energy needed to eject a photoelectron. Now, if we switch to a blue light the wavelength is shorter than that of green light and the maximum kinetic energy of the ejected photoelectrons will thus be greater using blue light as opposed to green light.

Multiple-Choice

- 24.2 B
24.3 C
24.4 D
24.6 C

Problems

24.7 For a $1.2 \times 10^6 \text{ eV} \times \frac{1.6 \times 10^{-19} \text{ J}}{1 \text{ eV}} = 1.92 \times 10^{-13} \text{ J photon}$,

a. its momentum is given by $p = \frac{E}{c} = \frac{1.92 \times 10^{-13} \text{ J}}{3 \times 10^8 \frac{\text{m}}{\text{s}}} = 6.4 \times 10^{-22} \frac{\text{kgm}}{\text{s}}$.

b. its wavelength is given by the de Broglie relation

$$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34} \text{ Js}}{6.4 \times 10^{-22} \frac{\text{kgm}}{\text{s}}} = 1.04 \times 10^{-12} \text{ m}.$$

c. its frequency is given by $f = \frac{c}{\lambda} = \frac{3 \times 10^8 \frac{\text{m}}{\text{s}}}{1.04 \times 10^{-12} \text{ m}} = 2.9 \times 10^{20} \text{ s}^{-1}$.

24.8 Photoelectric effect in cesium

We are given the work function for cesium is $\phi = 2.9 \text{ eV} = 4.64 \times 10^{-19} \text{ J}$.

a. The maximum wavelength corresponds to the minimum frequency. Therefore,

$$KE_{\min} = hf_{\min} - \phi = 0 \text{ which gives } f_{\min} = \frac{\phi}{h} = \frac{4.64 \times 10^{-19} \text{ J}}{6.63 \times 10^{-34} \text{ Js}} = 7.0 \times 10^{14} \text{ s}^{-1}. \text{ From}$$

$$c = f_{\min} \lambda_{\max} \rightarrow \lambda_{\max} = \frac{c}{f_{\min}} = \frac{3 \times 10^8 \frac{\text{m}}{\text{s}}}{7.0 \times 10^{14} \text{ s}^{-1}} = 4.28 \times 10^{-7} \text{ m} = 428 \text{ nm}.$$

b. If 400 nm photons are used, their energy is given by

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \text{ Js} \times 3 \times 10^8 \frac{\text{m}}{\text{s}}}{400 \times 10^{-9} \text{ m}} = 4.97 \times 10^{-19} \text{ J} \times \frac{1 \text{ eV}}{1.6 \times 10^{-19} \text{ J}} = 3.11 \text{ eV}.$$

Therefore the maximum kinetic energy is given as

$$KE_{\max} = hf - \phi = 3.11 \text{ eV} - 2.9 \text{ eV} = 0.21 \text{ eV} \times \frac{1.6 \times 10^{-19} \text{ J}}{1 \text{ eV}} = 3.33 \times 10^{-20} \text{ J}.$$

c. A 1 W beam of photons corresponds to 1 J of photons incident per second. In 1 J

of photons there are $\frac{1 \text{ J}}{4.97 \times 10^{-19} \frac{\text{J}}{\text{photon}}} = 2.01 \times 10^{18}$ photons. If the photo ejection

of an electron is 100% efficient, then for each photon lost, one electron is produced. Thus the photocurrent is the amount of charge produced each second, where 1 electron has $1.6 \times 10^{-19} \text{ C}$ of charge. This corresponds to a total charge of $Q = 2.01 \times 10^{18} \times 1.6 \times 10^{-19} \text{ C} = 0.322 \text{ C}$ of charge in 1 second. Therefore the photocurrent is $0.322 \text{ A} = 322 \text{ mA}$.

d. If green photons are used with a wavelength of 500 nm , this corresponds to an energy of

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \text{ Js} \times 3 \times 10^8 \frac{\text{m}}{\text{s}}}{500 \times 10^{-9} \text{ m}} = 3.98 \times 10^{-19} \text{ J} \times \frac{1 \text{ eV}}{1.6 \times 10^{-19} \text{ J}} = 2.49 \text{ eV}.$$

The maximum f that will allow for photo ejection of electrons is the one where the electrons are ejected with a maximum kinetic energy equal to zero. Therefore

$$KE_{\min} = hf_{\min} - \phi = 0, \text{ and solving for } \phi \text{ we obtain } hf_{\min} = \phi = 2.49 \text{ eV}.$$

24.9 The maximum KE is given by the product of the stopping potential (0.82 V) and the electron's charge (e^-). Thus the maximum $KE = eV_{\text{stop}} = 0.82 \text{ eV}$. This is equal to the energy of the photons incident minus the work function (the minimum energy needed to eject a photoelectron). In symbols,

$$KE_{\max} = hf - \phi = \frac{hc}{\lambda} - \phi$$

$$\rightarrow 0.82 \text{ eV} = \left(\frac{6.63 \times 10^{-34} \text{ Js} \times 3 \times 10^8 \frac{\text{m}}{\text{s}}}{400 \times 10^{-9} \text{ m}} \right) \times \frac{1 \text{ eV}}{1.6 \times 10^{-19} \text{ J}} - \phi \rightarrow \phi = 2.29 \text{ eV}$$

24.10 A photoelectric effect experiment

- a. The maximum kinetic energy is given by

$$KE_{\max} = hf - \phi = \frac{hc}{\lambda} - \phi$$

$$KE_{\max} = \left(\frac{6.63 \times 10^{-34} \text{ Js} \times 3 \times 10^8 \frac{\text{m}}{\text{s}}}{410 \times 10^{-9} \text{ m}} \right) \times \frac{1 \text{ eV}}{1.6 \times 10^{-19} \text{ J}} - 2.28 \text{ eV}$$

$$KE_{\max} = 3.03 \text{ eV} - 2.28 \text{ eV} = 0.75 \text{ eV}$$

In order to calculate the speed, we use the expression for the relativistic kinetic energy. We have

$$KE = 0.75 \text{ eV} = (\gamma - 1)m_e c^2 = (\gamma - 1)0.511 \text{ MeV}$$

$$\gamma = 1 + \frac{0.75 \text{ eV}}{0.511 \times 10^6 \text{ eV}} = 1 + 0.000015 = 1.000015$$

and the speed is therefore $\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \rightarrow v^2 = 2.94 \times 10^{-6} c^2 \rightarrow v = 0.0017c$

- b. Based on the speed calculated in *part a*, the electron is not relativistic.
 c. The minimum frequency corresponds to an electron ejected with a kinetic energy equal to zero. Therefore, $KE_{\min} = hf_{\min} - \phi = 0$ which gives

$$f_{\min} = \frac{\phi}{h} = \frac{2.28 \text{ eV} \times \frac{1.6 \times 10^{-19} \text{ J}}{1 \text{ eV}}}{6.63 \times 10^{-34} \text{ Js}} = 5.5 \times 10^{14} \text{ s}^{-1}$$

- d. The minimum frequency corresponds to the maximum wavelength. Therefore we

$$\text{have } c = f_{\min} \lambda_{\max} \rightarrow \lambda_{\max} = \frac{c}{f_{\min}} = \frac{3 \times 10^8 \frac{\text{m}}{\text{s}}}{5.5 \times 10^{14} \text{ s}^{-1}} = 5.45 \times 10^{-7} \text{ m} = 545 \text{ nm}.$$

- e. For 700 nm photons we have the maximum kinetic energy given as

$$KE_{\max} = hf - \phi = \frac{hc}{\lambda} - \phi$$

$$KE_{\max} = \left(\frac{6.63 \times 10^{-34} \text{ Js} \times 3 \times 10^8 \frac{\text{m}}{\text{s}}}{700 \times 10^{-9} \text{ m}} \right) \times \frac{1 \text{ eV}}{1.6 \times 10^{-19} \text{ J}} - 2.28 \text{ eV}$$

$$KE_{\max} = 1.78 \text{ eV} - 2.28 \text{ eV} = -0.50 \text{ eV}$$

Or, we have that no photoelectrons are produced. In addition we know that the maximum wavelength for photo production is 545 nm , and we are well beyond this, so no photocurrent would be produced.

24.15 To determine the number of photos that strike a screen every second, we divide the total energy per second (1 mW) by the energy per photon. The energy of a

photon is given as $E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34}\text{ Js} \times 3 \times 10^8 \frac{\text{m}}{\text{s}}}{633 \times 10^{-9}\text{ m}} = 3.14 \times 10^{-19}\text{ J}$. Therefore

the number of photons that strike per second is

$$\frac{\#}{s} = \frac{P}{E_{ph}} = \frac{1 \times 10^{-3} \frac{\text{J}}{\text{s}}}{3.14 \times 10^{-19} \frac{\text{J}}{\text{photon}}} = 3.2 \times 10^{15} \frac{\text{photons}}{s}.$$