Physics 111 Homework Solutions for Tuesday, 3/3/15 and Wednesday 3/4/15

Tuesday, March 3, 2015

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

24.10 A photoelectric effect experiment

a. The maximum kinetic energy is given by

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

$$KE_{\max} = \left(\frac{6.63\times10^{-34}\,Js \times 3\times10^{8}\,\frac{m}{s}}{410\times10^{-9}\,m} \right) \times \frac{1eV}{1.6\times10^{-19}\,J} - 2.28eV$$

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

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

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

$$\gamma = 1 + \frac{0.75eV}{0.511\times10^{6}\,eV} = 1 + 0000015 = 1.0000015$$

and the speed is therefore $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \rightarrow v^2 = 2.94\times10^{-6}c^2 \rightarrow v = 0.0017c$

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

$$f_{\min} = \frac{\phi}{h} = \frac{2.28eV \times \frac{1.6\times10^{-19}J}{1eV}}{6.63\times10^{-34}Js} = 5.5\times10^{14}s^{-1}.$$

d. The minimum frequency corresponds to the maximum wavelength. Therefore we have $c = f_{\min}\lambda_{\max} \rightarrow \lambda_{\max} = \frac{c}{f_{\min}} = \frac{3\times10^8 \frac{m}{s}}{5.5\times10^{14}s^{-1}} = 5.45\times10^{-7}m = 545nm$.

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

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

$$KE_{\max} = \left(\frac{6.63\times10^{-34}Js \times 3\times10^8 \frac{m}{s}}{700\times10^{-9}m}\right) \times \frac{1eV}{1.6\times10^{-19}J} - 2.28eV$$

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

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

24.11 A Compton Effect experiment

a. The wavelength and momentum of the incident gamma ray are given as

$$E = \frac{hc}{\lambda} \rightarrow \lambda = \frac{hc}{E} = \frac{(6.63\times10^{-34}Js)(3\times10^8 \frac{m}{s})}{1.6\times10^6 eV \times \frac{1.6\times10^{-19}J}{1eV}} = 7.77\times10^{-13}m \text{ and}$$

$$p = \frac{h}{\lambda} = \frac{E}{c} = \frac{6.63\times10^{-34}Js}{7.77\times10^{-13}m} = 8.53\times10^{-22}\frac{kgm}{s} \text{ respectively.}$$

b. Using the Compton formula for the wavelength of the scattered photon and the fact that the energy is inversely proportional to the wavelength we can write

$$\lambda' = \lambda + \frac{h}{m_e c}(1-\cos\phi) \rightarrow \frac{\lambda'}{hc} = \frac{\lambda}{hc} + \frac{1}{m_e c^2}(1-\cos\phi) \rightarrow \frac{1}{E'} = \frac{1}{E} + \frac{(1-\cos\phi)}{m_e c^2}.$$

c. The energy of the scattered gamma ray photon is

$$\frac{1}{E'} = \frac{1}{1.6MeV} + \frac{(1-\cos 50)}{0.511MeV} = 1.324MeV^{-1} \rightarrow E' = 0.755MeV$$ where the rest mass of the electron is given as

$$m_e c^2 = (9.11\times10^{-31}kg)(3\times10^8 \tfrac{m}{s})^2 \times \frac{1eV}{1.6\times10^{-19}J} = 0.511MeV.$$

d. The kinetic energy of the recoiling electron is found using conservation of energy where when the incident gamma ray photon interacts with electrons in the sample, the gamma ray photon loses some energy to the electron as it scatters. Thus the kinetic energy of the recoiling electron is

$$E_{incident} = E_{scattered} + KE_{e^-}$$

$$\therefore KE_{e^-} = E_{incident} - E_{scattered} = 1.6MeV - 0.755MeV = 0.845MeV$$

e. The speed of the recoiling electron is given by using the expression for the relativistic kinetic energy. We have

$$KE = 0.845MeV = (\gamma - 1)m_e c^2 = (\gamma - 1)0.511MeV$$

$$\gamma = 1 + \frac{0.845MeV}{0.511MeV} = 1 + 1.654 = 2.654 = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \rightarrow v^2 = 0.858c^2 \rightarrow v = 0.926c$$

24.12 X-rays on a foil target

a. The energy is given by $E = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34}Js)(3\times10^8 \frac{m}{s})}{0.012\times10^{-9}m} = 1.66\times10^{-14}J = 0.104MeV$.

b. The scattered wavelength is given by

$$\lambda_f - \lambda_i = \frac{h}{mc}(1-\cos\phi) = \frac{2h}{mc} = \frac{2(6.63\times10^{-34}Js)}{(9.11\times10^{-31}kg)(3\times10^8 \frac{m}{s})} = 4.86\times10^{-12}m.$$ Thus,

$\lambda_f = 4.86\times10^{-12}m + 1.2\times10^{-11}m = 1.686\times10^{-11}m$. The energy is given by the formula in part a, and is $1.18\text{x}10^{-14}$ J = 0.0741 MeV.

c. The energy given to the foil is

$$\Delta E_{foil} = E_{incident} = E_{backscattered} = 0.104MeV - 0.0741MeV = 0.03MeV = 30keV.$$

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 $E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}Js\times3\times10^8 \frac{m}{s}}{633\times10^{-9}m} = 3.14\times10^{-19}J$. Therefore the number of photons that strike per second is

$$\frac{\#}{s} = \frac{P}{E_{ph}} = \frac{1\times10^{-3}\frac{J}{s}}{3.14\times10^{-19}\frac{J}{photon}} = 3.2\times10^{15}\frac{photons}{s}.$$

Wednesday, March 4, 2015

Chapter 26

Questions

26.1 The atomic number Z is the number of protons in the nucleus. It distinguishes the different types of atoms. N is the number of neutrons in the atom. If we sum the number of neutrons (N) and the number of protons (Z) we get the mass of the nucleus (and the atom if we assume the mass of the electrons are negligible).

α decay is characterized by the following reaction: therefore the mass number of the nucleus decreases by 4 and the atomic number decreases by 2.

β^- decay (for a high speed electron) is characterized by the following reaction: ${}^{A}_{Z}X \rightarrow {}^{0}_{-1}e + {}^{A}_{Z+1}Y$ therefore the mass number of the nucleus is unaffected and the atomic number increases by 1.

β decay (for a high speed positron) is characterized by the following reaction: ${}^{A}_{Z}X \rightarrow {}^{0}_{+1}e + {}^{A}_{Z-1}Y$ therefore the mass number of the nucleus is unaffected and the atomic number decreases by 1.

γ decay is characterized by the following reaction: ${}^{A}_{Z}X^{*} \rightarrow {}^{0}_{0}\gamma + {}^{A}_{Z}X$ therefore the mass number of the nucleus and the atomic number remain unchanged.

26.4 The three requirements for stability are as follows. 1) The number of neutrons in the nucleus. As more protons are packed into the nucleus those nuclides with significantly more neutrons than protons will tend to produce a stable nucleus. The extra neutrons tend to shield the individual protons from one another. 2) The binding energy of the nucleus. 3) The nuclear energy levels (like those of the electron) should be closed shells. That is the most stable nuclei have equal numbers of protons and neutrons (these numbers are called the magic numbers).

Multiple-Choice

26.1 D
26.2 A
26.4 A

Problems

26.2 A neutron star

a) To calculate the mass of the neutron star we need to know the density of nuclear material and the volume of the star. We model the star as being spherical so it has a volume given by $\frac{4}{3}\pi r^3 = \frac{4}{3}\pi(1\times10^4 m)^3 = 4.19\times10^{12} m^3$. Given that the nuclear density is $2\text{x}10^{17}$ kg/m^3 (assuming the nuclear radius is $1.2\text{x}10^{-15}$ m) we have the mass M = ρV = $8.4\text{x}10^{29}$ kg. Since the mass of the sun is 2x1030kg this gives the mass of the neutron star as 0.41 solar masses. As an aside, this is almost ½ the mass of the sun packed in to a sphere of radius 10 km ~ 6 miles!!

b) Assuming that the mass of a nucleon (either a proton or neutron) is $1.67\text{x}10^{-27}$ kg, this gives the number of nucleons as ($8.4\text{x}10^{29}$ kg) / ($1.67\text{x}10^{-27}$ kg/nucleon) = $5.03\text{x}10^{56}$ particles.

26.3 The density is given by $\rho = \frac{M}{V} \rightarrow V = 4\pi r^3 = \frac{M}{\rho}$ and therefore the radius is given as

$$r = \sqrt[3]{\frac{M}{4\pi\rho}} = \sqrt[3]{\frac{2\times10^{30}\,\text{kg}}{4\pi\left(2\times10^{17}\,\frac{\text{kg}}{\text{m}^3}\right)}} = 11{,}675\,\text{m} = 11.7\,\text{km}.$$