Chapter 38

2. Let

$$\frac{1}{2}m_e v^2 = E_{\text{photon}} = \frac{hc}{\lambda}$$

and solve for v:

$$v = \sqrt{\frac{2hc}{\lambda m_e}} = \sqrt{\frac{2hc}{\lambda m_e c^2}c^2} = c\sqrt{\frac{2hc}{\lambda\left(m_e c^2\right)}}$$

$$= \left(2.998\times10^8\text{ m/s}\right)\sqrt{\frac{2\left(1240\,\text{eV}\cdot\text{nm}\right)}{\left(590\,\text{nm}\right)\left(511\times10^3\text{ eV}\right)}} = 8.6\times10^5\text{ m/s}.$$

Since $v \ll c$, the nonrelativistic formula $K = \frac{1}{2}mv^2$ may be used. The $m_e c^2$ value of Table 37-3 and $hc = 1240\text{eV}\cdot\text{nm}$ are used in our calculation.

4. We denote the diameter of the laser beam as d. The cross-sectional area of the beam is $A = \pi d^2/4$. From the formula obtained in Problem 38-3, the rate is given by

$$\frac{R}{A} = \frac{\lambda P}{hc\left(\pi d^2/4\right)} = \frac{4\left(633\text{nm}\right)\left(5.0\times10^{-3}\text{ W}\right)}{\pi\left(6.63\times10^{-34}\text{ J}\cdot\text{s}\right)\left(2.998\times10^8\text{ m/s}\right)\left(3.5\times10^{-3}\text{ m}\right)^2}$$

$$= 1.7\times10^{21}\,\text{photons/m}^2\cdot\text{s}.$$

12. Following Sample Problem — "Emission and absorption of light as photons," we have

$$P = \frac{Rhc}{\lambda} = \frac{\left(100/\text{s}\right)\left(6.63\times10^{-34}\text{ J}\cdot\text{s}\right)\left(2.998\times10^8\text{ m/s}\right)}{550\times10^{-9}\text{ m}} = 3.6\times10^{-17}\text{ W}.$$

20. Using the value hc = 1240 eV·nm, the number of photons emitted from the laser per unit time is

$$R = \frac{P}{E_{\text{ph}}} = \frac{2.00\times10^{-3}\text{ W}}{(1240\text{ eV}\cdot\text{nm}/600\text{ nm})(1.60\times10^{-19}\text{ J/eV})} = 6.05\times10^{15}\text{ /s},$$

of which $(1.0\times10^{-16})(6.05\times10^{15}/\text{s}) = 0.605/\text{s}$ actually cause photoelectric emissions. Thus the current is

$$i = (0.605/\text{s})(1.60 \times 10^{-19}\ \text{C}) = 9.68 \times 10^{-20}\ \text{A}.$$

26. To find the longest possible wavelength $\lambda_{\max}$ (corresponding to the lowest possible energy) of a photon that can produce a photoelectric effect in platinum, we set $K_{\max} = 0$ in Eq. 38-5 and use $hf = hc/\lambda$. Thus $hc/\lambda_{\max} = \Phi$. We solve for $\lambda_{\max}$:

$$\lambda_{\max} = \frac{hc}{\Phi} = \frac{1240\,\text{eV}\cdot\text{nm}}{5.32\,\text{nm}} = 233\,\text{nm}.$$

47. If K is given in electron volts, then

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mK}} = \frac{6.626\times10^{-34}\,\text{J}\cdot\text{s}}{\sqrt{2(9.109\times10^{-31}\,\text{kg})(1.602\times10^{-19}\,\text{J/eV})K}} = \frac{1.226\times10^{-9}\,\text{m}\cdot\text{eV}^{1/2}}{\sqrt{K}}$$
$$= \frac{1.226\,\text{nm}\cdot\text{eV}^{1/2}}{\sqrt{K}},$$

where K is the kinetic energy. Thus,

$$K = \left(\frac{1.226\,\text{nm}\cdot\text{eV}^{1/2}}{\lambda}\right)^2 = \left(\frac{1.226\,\text{nm}\cdot\text{eV}^{1/2}}{590\,\text{nm}}\right)^2 = 4.32\times10^{-6}\ \text{eV}.$$

50. (a) The momentum of the electron is

$$p = \frac{h}{\lambda} = \frac{6.63\times10^{-34}\ \text{J}\cdot\text{s}}{0.20\times10^{-9}\ \text{m}} = 3.3\times10^{-24}\ \text{kg}\cdot\text{m/s}.$$

(b) The momentum of the photon is the same as that of the electron: $p = 3.3\times10^{-24}\,\text{kg}\cdot\text{m/s}$.

(c) The kinetic energy of the electron is

$$K_e = \frac{p^2}{2m_e} = \frac{\left(3.3\times10^{-24}\,\text{kg}\cdot\text{m/s}\right)^2}{2\left(9.11\times10^{-31}\,\text{kg}\right)} = 6.0\times10^{-18}\,\text{J} = 38\ \text{eV}.$$

(d) The kinetic energy of the photon is

$$K_{\text{ph}} = pc = \left(3.3\times10^{-24}\ \text{kg}\cdot\text{m/s}\right)\left(2.998\times10^{8}\ \text{m/s}\right) = 9.9\times10^{-16}\ \text{J} = 6.2\ \text{keV}.$$

63. If the momentum is measured at the same time as the position, then

$$\Delta p \approx \frac{\hbar}{\Delta x} = \frac{6.63\times 10^{-34}\ \text{J}\cdot\text{s}}{2\pi(50\,\text{pm})} = 2.1\times 10^{-24}\ \text{kg}\cdot\text{m/s}\ .$$

64. (a) Using the value $hc = 1240\text{nm}\cdot\text{eV}$, we have

$$E = \frac{hc}{\lambda} = \frac{1240\,\text{nm}\cdot\text{eV}}{10.0\times 10^{-3}\ \text{nm}} = 124\,\text{keV}\ .$$

(b) The kinetic energy gained by the electron is equal to the energy decrease of the photon:

$$\Delta E = \Delta\left(\frac{hc}{\lambda}\right) = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda+\Delta\lambda}\right) = \left(\frac{hc}{\lambda}\right)\left(\frac{\Delta\lambda}{\lambda+\Delta\lambda}\right) = \frac{E}{1+\lambda/\Delta\lambda}$$
$$= \frac{E}{1+\frac{\lambda}{\lambda_C(1-\cos\phi)}} = \frac{124\text{keV}}{1+\frac{10.0\,\text{pm}}{(2.43\text{pm})(1-\cos 180°)}}$$
$$= 40.5\text{keV}.$$

(c) It is impossible to "view" an atomic electron with such a high-energy photon, because with the energy imparted to the electron the photon would have knocked the electron out of its orbit.

79. The de Broglie wavelength for the bullet is

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63\times 10^{-34}\ \text{J.s}}{(40\times 10^{-3}\ \text{kg})(1000\,\text{m/s})} = 1.7\times 10^{-35}\ \text{m}\ .$$

82. The difference between the electron-photon scattering process in this problem and the one studied in the text (the Compton shift, see Eq. 38-11) is that the electron is in motion relative with speed v to the laboratory frame. To utilize the result in Eq. 38-11, shift to a new reference frame in which the electron is at rest before the scattering. Denote the quantities measured in this new frame with a prime ($'$), and apply Eq. 38-11 to yield

$$\Delta\lambda' = \lambda' - \lambda_0' = \frac{h}{m_e c}(1-\cos\pi) = \frac{2h}{m_e c},$$

where we note that $\phi = \pi$ (since the photon is scattered back in the direction of incidence). Now, from the Doppler shift formula (Eq. 38-25) the frequency f'_0 of the photon prior to the scattering in the new reference frame satisfies

$$f_0' = \frac{c}{\lambda_0'} = f_0\sqrt{\frac{1+\beta}{1-\beta}},$$

where $\beta = v/c$. Also, as we switch back from the new reference frame to the original one after the scattering

$$f = f'\sqrt{\frac{1-\beta}{1+\beta}} = \frac{c}{\lambda'}\sqrt{\frac{1-\beta}{1+\beta}} \ .$$

We solve the two Doppler-shift equations above for λ' and λ'_0 and substitute the results into the Compton shift formula for $\Delta\lambda'$:

$$\Delta\lambda' = \frac{1}{f}\sqrt{\frac{1-\beta}{1+\beta}} - \frac{1}{f_0}\sqrt{\frac{1-\beta}{1+\beta}} = \frac{2h}{m_e c^2} \ .$$

Some simple algebra then leads to

$$E = hf = hf_0\left(1+\frac{2h}{m_e c^2}\sqrt{\frac{1+\beta}{1-\beta}}\right)^{-1} \ .$$