3-10 The energy per photon, $E = hf$ and the total energy E transmitted in a time t is Pt where power $P = 100\text{ kW}$. Since $E = nhf$ where n is the total number of photons transmitted in the time t, and $f = 94\text{ MHz}$, there results $nhf = (100\text{ kW})t = (10^5\text{ W})t$, or

$$\frac{n}{t} = \frac{10^5\text{ W}}{hf} = \frac{10^5\text{ J/s}}{6.63\times10^{-34}\text{ J s}}\left(94\times10^6\text{ s}^{-1}\right) = 1.60\times10^{30}\text{ photons/s}.$$

3-14 (a) $K = hf - \phi = \frac{hc}{\lambda - \phi} = \frac{1\,240\text{ eV nm}}{350\text{ nm}} - 2.24\text{ eV} = 1.30\text{ eV}$

(b) At $\lambda = \lambda_c$, $K = 0$ and $\lambda = \frac{hc}{\phi} = \frac{1\,240\text{ eV nm}}{2.24\text{ eV}} = 554\text{ nm}$

3-16 (a) $\phi = \frac{hc}{\lambda} - K$, $\phi = \frac{1\,240\text{ eV nm}}{300\text{ nm}} - 2.23\text{ eV} = 1.90\text{ eV}$

(b) $V_s = \frac{1\,240\text{ eV nm}}{400\text{ nm e}} - 1.90\text{ eV/e} = 1.20\text{ V}$

3-18 (a) $K_{\max} = eV_s = s(0.45\text{ V}) = 0.45\text{ eV}$

(b) $\phi = \frac{hc}{\lambda - K} = \frac{1\,240\text{ eV nm}}{500\text{ nm}} - 0.45\text{ eV} = 2.03\text{ eV}$

(c) $\lambda_c = \frac{hc}{\phi} = \frac{1\,240\text{ eV nm}}{2.03\text{ eV}} = 612\text{ nm}$

3-20 $K_{\max} = hf - \phi = \frac{hc}{\lambda} - \phi \Rightarrow \phi = \frac{hc}{\lambda} - K_{\max}$;

First Source: $\phi = \frac{hc}{\lambda} - 1.00\text{ eV}$.

Second Source: $\phi = \frac{hc}{\frac{\lambda}{2}} - 4.00\text{ eV} = \frac{2hc}{\lambda} - 4.00\text{ eV}$.

As the work function is the same for both sources (a property of the metal),

$\frac{hc}{\lambda} - 100\text{ eV} = \frac{2hc}{\lambda} - 4.00\text{ eV} \Rightarrow \frac{hc}{\lambda} = 3.00\text{ eV}$ and

$\phi = \frac{hc}{\lambda} - 1.00\text{ eV} = 3.00\text{ eV} - 1.00\text{ eV} = 2.00\text{ eV}$.

3-25 $E = 300\text{ keV}$, $\theta = 30°$

(a) $\Delta\lambda = \lambda' - \lambda_0 = \frac{h}{m_e c}(1 - \cos\theta) = (0.002\,43\text{ nm})\left[1 - \cos(30°)\right] = 3.25\times10^{-13}\text{ m}$

$= 3.25\times10^{-4}\text{ nm}$

(b) $E = \frac{hc}{\lambda_0} \Rightarrow \lambda_0 = \frac{hc}{E_0} = \frac{\left(4.14 \times 10^{-15} \text{ eVs}\right)\left(3 \times 10^8 \text{ m/s}\right)}{300 \times 10^3 \text{ eV}} = 4.14 \times 10^{-12} \text{ m}$; thus,

$\lambda' = \lambda_0 + \Delta\lambda = 4.14 \times 10^{-12} \text{ m} + 0.325 \times 10^{-12} \text{ m} = 4.465 \times 10^{-12} \text{ m}$, and

$E' = \frac{hc}{\lambda'} \Rightarrow E' = \frac{\left(4.14 \times 10^{-15} \text{ eV s}\right)\left(3 \times 10^8 \text{ m/s}\right)}{4.465 \times 10^{-12} \text{ m}} = 2.78 \times 10^5 \text{ eV}$.

(c) $\frac{hc}{\lambda_0} = \frac{hc}{\lambda'} + K_e$, (conservation of energy)

$$K_e = hc\left(\frac{1}{\lambda_0} - \frac{1}{\lambda'}\right) = \frac{\left(4.14 \times 10^{-15} \text{ eV s}\right)\left(3 \times 10^8 \text{ m/s}\right)}{\frac{1}{4.14 \times 10^{-12}} - \frac{1}{4.465 \times 10^{-12}}} = 22 \text{ keV}$$

3-28 (a) From conservation of energy we have $E_0 = E' + K_e = 120 \text{ keV} + 40 \text{ keV} = 160 \text{ keV}$. The photon energy can be written as $E_0 = \frac{hc}{\lambda_0}$. This gives

$$\lambda_0 = \frac{hc}{E_0} = \frac{1\,240 \text{ nm eV}}{160 \times 10^3 \text{ eV}} = 7.75 \times 10^{-3} \text{ nm} = 0.007\,75 \text{ nm}.$$

(b) Using the Compton scattering relation $\lambda' - \lambda_0 = \lambda_c(1 - \cos\theta)$ where $\lambda_c = \frac{h}{m_e c} = 0.002\,43 \text{ nm}$ and $\lambda' = \frac{hc}{E'} = \frac{1\,240 \text{ nm eV}}{120 \times 10^3 \text{ eV}} = 10.3 \times 10^3 \text{ nm} = 0.010\,3 \text{ nm}$. Solving the Compton equation for $\cos\theta$, we find

$$-\lambda_c \cos\theta = \lambda' - \lambda_0 - \lambda_c$$

$$\cos\theta = 1 - \frac{\lambda' - \lambda_0}{\lambda_c} = 1 - \frac{0.010\,3 \text{ nm} - 0.007\,5 \text{ nm}}{0.002\,43 \text{ nm}} = 1 - 1.049 = -0.049$$

The principle angle is $87.2°$ or $\theta = 92.8°$.

(c) Using the conservation of momentum Equations 3.30 and 3.31 one can solve for the recoil angle of the electron.

$$p = p'\cos\theta + p_e \cos\phi$$

$p_e \sin\phi = p' \sin\theta$; dividing these equations one can solve for the recoil angle of the electron

$$\tan\phi = \frac{p'\sin\theta}{p - p'\cos\theta} = \left(\frac{h}{\lambda'}\right)\frac{\sin\theta}{\frac{h}{\lambda_0} - \frac{h}{\lambda'\cos\theta}} = \left(\frac{hc}{\lambda'}\right)\frac{\sin\theta}{\frac{hc}{\lambda_0} - \frac{hc}{\lambda'\cos\theta}}$$

$$= \frac{120 \text{ keV}(0.998\,8)}{160 \text{ keV} - 120 \text{ keV}(-0.049)} = 0.723\,2$$

and $\phi = 35.9°$.

3-29 Symmetric Scattering, $\theta = \phi$. First, use the equations of conservations of momentum given by Equations 3.30 and 3.31 for this two dimensional scattering process with $\theta = \phi$:

(a) $\frac{h}{\lambda_0} = \left(\frac{h}{\lambda'}\right)\cos\theta + p_e\cos\theta$ (1)

$$\frac{h}{\lambda'}\sin\theta = p_e \sin\theta \text{ or } p_e = \frac{h}{\lambda} \quad (2)$$

Substituting (2) into (1) yields $\lambda' = 2\lambda_0 \cos\theta$ (3)

Next, express the Compton scattering formula as

$$\lambda' - \lambda_0 = \lambda_c(1-\cos\theta) \quad (4)$$

where $\lambda_c = \frac{h}{m_e c} = 0.002\,43 \text{ nm}$. Combining (3) and (4) yields $\cos\theta = \frac{\lambda_c + \lambda_0}{\lambda_c + 2\lambda_0}$. In this case, because $E = 1.02 \text{ MeV}$, and $E = \frac{hc}{\lambda_0}$ there results

$$\lambda_0 = \frac{hc}{E} = \frac{1\,240 \text{ eV nm}}{1.20 \times 106 \text{ eV}} = 0.001\,22 \text{ nm}.$$

Thus, $\cos\theta = \frac{0.002\,43 \text{ nm} + 0.001\,22 \text{ nm}}{0.002\,42 \text{ nm} + 0.002\,44 \text{ nm}} = 0.749\,5$, and solving for the scattering angle, $\theta = 41.5°$.

(b) $\lambda' = \lambda_0 + \lambda_c(1-\cos\theta)$

$\lambda' = 0.001\,22 \text{ nm} + (0.002\,43 \text{ nm})[1-\cos(41.5°)] = 0.001\,83 \text{ nm}$

$E = \frac{hc}{\lambda'} = \frac{1\,240 \text{ eV}\cdot\text{nm}}{0.001\,83 \text{ nm}} = 0.679 \text{ MeV}$

3-30 Maximum energy transfer occurs when the scattering angle is 180 degrees. Assuming the electron is initially at rest, conservation of momentum gives

$$hf + hf' = p_e c = \sqrt{(m_e c^2 + K)^2 - m^2 c^4} = \sqrt{(511+50)^2} = 178 \text{ keV}$$

while conservation of energy gives $hf - hf' = K = 30 \text{ keV}$. Solving the two equations gives $E = hf = 104 \text{ keV}$ and $hf = 74 \text{ keV}$. (The wavelength of the incoming photon is $\lambda = \frac{hc}{E} = 0.012\,0 \text{ nm}$.

3-31 (a) $E' = \frac{hc}{\lambda'}$, $\lambda' = \lambda_0 + \Delta\lambda$

$\lambda_0 = \frac{hc}{E_0} = \frac{(6.63\times10^{-34} \text{ J}\cdot\text{s})(3\times10^8 \text{ m/s})}{0.1 \text{ MeV}} = 1.243\times10^{-11} \text{ m}$

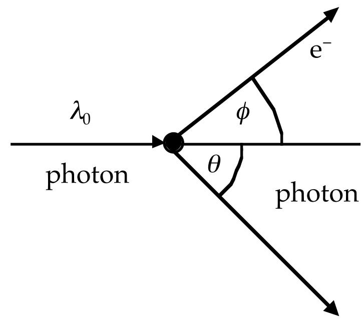
$\Delta\lambda = \left(\frac{h}{m_e c}\right)(1-\cos\theta) = \frac{(6.63\times10^{-34} \text{ J}\cdot\text{s})(1-\cos 60°)}{(9.11\times10^{-34} \text{ kg})(3\times10^8 \text{ m/s})} = 1.215\times10^{-12} \text{ m}$

$\lambda' = \lambda_0 + \Delta\lambda = 1.364\times10^{-11} \text{ m}$

$E' = \frac{hc}{\lambda'} = \frac{(6.63\times10^{-34} \text{ J}\cdot\text{s})(3\times10^8 \text{ m/s})}{1.364\times10^{-11} \text{ m}} = 9.11\times10^4 \text{ eV}$

(b) $\frac{hc}{\lambda_0} = \frac{hc}{\lambda'} + K_e$

$K_e = 0.1\text{ MeV} - 91.1\text{ keV} = 8.90\text{ keV}$



(c) Conservation of momentum along x: $\frac{h}{\lambda_0} = \left(\frac{h}{\lambda'}\right)\cos\theta + \gamma\, m_e v\cos\phi$. Conservation of momentum along y: $\left(\frac{h}{\lambda'}\right)\sin\theta = \gamma\, m_e v\sin\phi$. So that

$$\frac{\gamma\, m_e v\sin\phi}{\gamma\, m_e v\cos\phi} = \left(\frac{h}{\lambda'}\right)\sin\theta\left[\left(\frac{h}{\lambda_0}\right) - \left(\frac{h}{\lambda'}\right)\cos\theta\right]$$

$$\tan\phi = \frac{\lambda_0\sin\theta}{(\lambda' - \lambda_0)\cos\theta}$$

Here, $\theta = 60°$, $\lambda_0 = 1.243\times10^{-11}\text{ m}$, and $\lambda' = 1.364\times10^{-11}\text{ m}$. Consequently,

3-35 (a) The energy vs wavelength relation for a photon is $E = \frac{hc}{\lambda}$. For a photon of wavelength given by $\lambda_0 = 0.071\,1\text{ nm}$ the photon's energy is

$$E = \frac{(6.626\times10^{-34}\text{ J}\cdot\text{s})(3\times10^{8}\text{ m/s})}{(0.071\,1\times10^{-9}\text{ m})(1.602\times10^{-19}\text{ J/eV})} = 17.4\text{ keV}$$

(b) For the case of back scattering, $\theta = \pi$ the Compton scattering relation becomes $\lambda' - \lambda_0 = \left(\frac{2hc}{m_e c^2}\right)$. Setting $\lambda_0 = 0.071\,1\text{ nm}$ we obtain

$$\lambda' = 0.711\text{ nm} + \frac{2hc}{m_e c^2} = 7.60\times10^{-11}$$

or 0.076 0 nm.

(c) $$E' = \frac{hc}{\lambda'} = \frac{(6.626\times10^{-34}\text{ J}\cdot\text{s})(3\times10^{8}\text{ m/s})}{(7.60\times10^{-11}\text{ m})(1.602\times10^{-19}\text{ J/eV})} = 16.3\text{ keV}.$$

(d) $\Delta E = 17.45\text{ keV} - 16.33\text{ keV} = 1.12\text{ keV} \sim 1.1\text{ keV}$.

3-36 A scattered photon has an energy of 80 keV and the recoiled electron has an energy of 25 keV.

(a) From conservation of energy we require that:

$E_{\text{photon}} = 80\text{ keV} = 25\text{ keV} = 105\text{ keV}$. As $E_0 = \frac{hc}{\lambda_0}$, we have

$$\lambda_0 = \frac{hc}{E_0} = \frac{\left(6.626\times10^{-34}\text{ J}\cdot\text{s}\right)\left(3\times10^{8}\text{ m/s}\right)}{\left(105\text{ keV}\right)\left(1.602\times10^{-19}\text{ J/eV}\right)} = 0.011\,8\text{ nm}.$$

(b) The incident photon energy is $E_0 = \frac{hc}{\lambda_0}$, and the energy of the scattered photon is $E' = \frac{hc}{\lambda'}$. One can then take their ratio,

$$\frac{E_0}{E'} = \frac{\lambda'}{\lambda_0} \Rightarrow \lambda' = \frac{\lambda_0 E_0}{E'} = 0.011\,8\text{ nm}\times\left(\frac{105\text{ keV}}{80\text{ keV}}\right) = 0.015\,4\text{ nm}.$$

4-1 F corresponds to the charge passed to deposit one mole of monovalent element at a cathode. As one mole contains Avogadro's number of atoms,

$$e = \frac{96\,500\text{ C}}{6.02\times10^{23}} = 1.60\times10^{-19}\text{ C}.$$

4-3 Thomson's device will work for positive and negative particles, so we may apply

$$\frac{q}{m} \approx \frac{V\theta}{B^2 ld}.$$

(a) $$\frac{q}{m} \approx \frac{V\theta}{B^2 ld} = \left(2\,000\text{ V}\right)\frac{0.20\text{ radians}}{\left(4.57\times10^{-2}\text{ T}\right)^2}\left(0.10\text{ m}\right)\left(0.02\text{ m}\right) = 9.58\times10^{7}\text{ C/kg}$$

(b) As the particle is attracted by the negative plate, it carries a positive charge and is a proton. $\left(\frac{q}{m_p} = \frac{1.60\times10^{-19}\text{ C}}{1.67\times10^{-27}\text{ kg}} = 9.58\times10^{7}\text{ C/kg}\right)$

(c) $$v_x = \frac{E}{B} = \frac{V}{\text{d}B} = \frac{2\,000\text{ V}}{0.02\text{ m}}\left(4.57\times10^{-2}\text{ T}\right) = 2.19\times10^{6}\text{ m/s}$$

(d) As $v_x \sim 0.01c$ there is no need for relativistic mechanics.