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

(a) $$\Delta\lambda = \lambda' - \lambda_0 = \frac{h}{m_e c}(1-\cos\theta) = (0.002\,43\text{ nm})[1-\cos(30°)] = 3.25\times10^{-13}\text{ m}$$
$$= 3.25\times10^{-4}\text{ nm}$$

(b) $$E = \frac{hc}{\lambda_0} \Rightarrow \lambda_0 = \frac{hc}{E_0} = \frac{(4.14\times10^{-15}\text{ eVs})(3\times10^{8}\text{ m/s})}{300\times10^{3}\text{ eV}} = 4.14\times10^{-12}\text{ m}$$; thus,

$\lambda' = \lambda_0 + \Delta\lambda = 4.14\times10^{-12}\text{ m} + 0.325\times10^{-12}\text{ m} = 4.465\times10^{-12}\text{ m}$, and

$$E' = \frac{hc}{\lambda'} \Rightarrow E' = \frac{(4.14\times10^{-15}\text{ eV s})(3\times10^{8}\text{ m/s})}{4.465\times10^{-12}\text{ m}} = 2.78\times10^{5}\text{ eV}.$$

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

$$K_e = hc\left(\frac{1}{\lambda_0} - \frac{1}{\lambda'}\right) = \frac{(4.14\times10^{-15}\text{ eV s})(3\times10^{8}\text{ m/s})}{\frac{1}{4.14\times10^{-12}} - \frac{1}{4.465\times10^{-12}}} = 22\text{ keV}$$

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

$$\lambda_0 = \frac{hc}{E_0} = \frac{1\,240\text{ nm eV}}{160\times10^{3}\text{ eV}} = 7.75\times10^{-3}\text{ nm} = 0.007\,75\text{ nm}.$$

(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 $\lambda' = \frac{hc}{E'} = \frac{1\,240\text{ nm eV}}{120\times10^{3}\text{ eV}} = 10.3\times10^{3}\text{ nm} = 0.010\,3\text{ nm}$. 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 $\phi = 35.9°$.

3-30 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)

$$E' = \frac{hc}{\lambda'},\ \lambda' = \lambda_0 + \Delta\lambda$$

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

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

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

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

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

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

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

4-8 (a) From Equation 4.16 we have $\Delta n \infty \left(\frac{\sin\phi}{2}\right)^{-4}$ or $\Delta n_2 = \Delta n_1 \frac{\left(\frac{\sin\phi_1}{2}\right)^4}{\left(\frac{\sin\phi_2}{2}\right)^4}$. Thus the number of α's scattered at 40 degrees is given by

$$\Delta n_2 = (100\ \text{cpm})\frac{\left(\sin\frac{20}{2}\right)^4}{\left(\sin\frac{40}{2}\right)^4} = (100\ \text{cpm})\left(\frac{\sin 10}{\sin 20}\right)^4 = 6.64\ \text{cpm}.$$

Similarly

$$\Delta n \text{ at 60 degrees} = 1.45 \text{ cpm}$$
$$\Delta n \text{ at 80 degrees} = 0.533 \text{ cpm}$$
$$\Delta n \text{ at 100 degrees} = 0.264 \text{ cpm}$$

(b) From 4.16 doubling $\left(\frac{1}{2}\right)m_\alpha v_\alpha^2$ reduces Δn by a factor of 4. Thus Δn at 20 degrees $= \left(\frac{1}{4}\right)(100\ \text{cpm}) = 25\ \text{cpm}$.

(c) From 4.16 we find $\frac{\Delta n_{\text{Cu}}}{\Delta n_{\text{Au}}} = \frac{Z_{\text{Cu}}^2 N_{\text{Cu}}}{Z_{\text{Au}}^2 N_{\text{Au}}}$, $Z_{\text{Cu}} = 29$, $Z_{\text{Au}} = 79$.

$$\begin{aligned} N_{\text{Cu}} &= \text{number of Cu nuclei per unit area} \\ &= \text{number of Cu nuclei per unit volume * foil thickness} \\ &= \left[(8.9\ \text{g/cm}^3)\left(\frac{6.02\times 10^{23}\ \text{nuclei}}{63.54\ \text{g}}\right)\right]t = 8.43\times 10^{22}t \end{aligned}$$

$$N_{\text{Au}} = \left[(19.3\ \text{g/cm}^3)\left(\frac{6.02\times 10^{23}\ \text{nuclei}}{197.0\ \text{g}}\right)\right]t = 5.90\times 10^{22}t$$

So $\Delta n_{\text{Cu}} = \Delta n_{\text{Au}}(29)^2 \frac{8.43\times 10^{22}}{(79)^2}\left(5.90\times 10^2\right) = (100)\left(\frac{29}{79}\right)^2\left(\frac{8.43}{5.90}\right) = 19.3\ \text{cpm}$.

4-9 The initial energy of the system of α plus copper nucleus is 13.9 MeV and is just the kinetic energy of the α when the α is far from the nucleus. The final energy of the system may be evaluated at the point of closest approach when the kinetic energy is zero and the potential energy is $k(2e)\frac{Ze}{r}$ where r is approximately equal to the nuclear radius of copper. Invoking conservation of energy $E_i = E_f$, $K_\alpha = (k)\frac{2Ze^2}{r}$ or

$$r = (k)\frac{2Ze^2}{K_\alpha} = \frac{(2)(29)\left(1.60\times 10^{-19}\right)^2\left(8.99\times 10^9\right)}{\left(13.9\times 10^6\ \text{eV}\right)\left(1.60\times 10^{-19}\ \text{J/eV}\right)} = 6.00\times 10^{-15}\ \text{m}.$$