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, $e = \frac{96\ 500\ \text{C}}{6.02 \times 10^{23}} = 1.60 \times 10^{-19}\ \text{C}$.

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) $$\frac{q}{m} \approx \frac{V\theta}{B^2 ld} = (2\ 000\ \text{V})\frac{0.20\ \text{radians}}{\left(4.57 \times 10^{-2}\ \text{T}\right)^2}(0.10\ \text{m})(0.02\ \text{m}) = 9.58 \times 10^7\ \text{C/kg}$$

(b) As the particle is attracted by the negative plate, it carries a positive charge and is a proton. $\left(\frac{q}{m_p} = \frac{1.60 \times 10^{-19}\ \text{C}}{1.67 \times 10^{-27}\ \text{kg}} = 9.58 \times 10^7\ \text{C/kg}\right)$

(c) $$v_x = \frac{E}{B} = \frac{V}{dB} = \frac{2\ 000\ \text{V}}{0.02\ \text{m}}\left(4.57 \times 10^{-2}\ \text{T}\right) = 2.19 \times 10^6\ \text{m/s}$$

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

4-7 $m = \rho V = \left(0.956\ 1\ \text{g/cm}^3\right)\left(\frac{4}{3}\right)\pi a^3 = 8.418 \times 10^{-11}\ \text{g}$, $\frac{mg}{E}$ for use in $q = \left(\frac{mg}{E}\right)\frac{v + v_1'}{v}$ has the value $\frac{mg}{E} = \left(8.418 \times 10^{-14}\ \text{kg}\right)\frac{9.80\ \text{m/s}^2}{\frac{5\ 085\ \text{V}}{0.016\ 00\ \text{m}}} = 25.9 \times 10^{-19}\ \text{C}$. Using $q = \left(\frac{mg}{E}\right)\frac{v + v_1'}{v}$ we find the different charges on the drops to be:

$$q_1 = \left(25.96 \times 10^{-19}\ \text{C}\right)\frac{0.858\ 42 + 0.126\ 5}{0.858\ 42} = 29.78 \times 10^{-19}\ \text{C}$$

$$q_2 = 39.76 \times 10^{-19}\ \text{C}$$
$$q_3 = 28.16 \times 10^{-19}\ \text{C}$$
$$q_4 = 29.84 \times 10^{-19}\ \text{C}$$
$$q_5 = 34.84 \times 10^{-19}\ \text{C}$$
$$q_6 = 36.51 \times 10^{-19}\ \text{C}$$

$\left[\lvert\text{Charge differences}\rvert\right] \times 10^{-19}\ \text{C}$	$\left[\frac{\lvert\text{Charge differences}\rvert}{n}\right] \times 10^{-19}\ \text{C}$ (n chosen by inspection)

$q_1 - q_2 = 9.98$	$\frac{9.98}{6} = 1.66$
$q_1 - q_3 = 1.62$	$\frac{1.62}{1} = 1.62$
$q_1 - q_4 = 0.060$	0.0
$q_1 - q_5 = 5.06$	$\frac{5.06}{3} = 1.69$
$q_1 - q_6 = 6.73$	$\frac{6.73}{4} = 1.68$
$q_3 - q_2 = 11.6$	$\frac{11.6}{7} = 1.66$
$q_4 - q_2 = 9.92$	$\frac{9.92}{6} = 1.65$
$q_5 - q_2 = 4.92$	$\frac{4.92}{3} = 1.64$
$q_6 - q_2 = 3.25$	$\frac{3.25}{2} = 1.63$
$q_4 - q_3 = 1.68$	$\frac{1.68}{2} = 1.68$
$q_5 - q_3 = 6.68$	$\frac{6.68}{4} = 1.67$
$q_6 - q_3 = 8.35$	$\frac{8.35}{5} = 1.67$
$q_5 - q_4 = 5.00$	$\frac{5.00}{3} = 1.67$
$q_6 - q_4 = 6.67$	$\frac{6.67}{4} = 1.66$
$q_6 - q_5 = 1.67$	$\frac{1.67}{1} = 1.67$

Average $q = 1.661 \times 10^{-19}$ C

4-8 (a) From Equation 4.16 we have $\Delta n \propto \left(\frac{\sin\phi}{2}\right)^{-4}$ 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 $\frac{\Delta n_{\text{Cu}}}{\Delta n_{\text{Au}}} = \frac{Z_{\text{Cu}}^2 N_{\text{Cu}}}{Z_{\text{Au}}^2 N_{\text{Au}}}$, $Z_{\text{Cu}} = 29$, $Z_{\text{Au}} = 79$.

$$\begin{aligned} N_{\text{Cu}} &= \text{number of Cu nuclei per unit area} \\ &= \text{number of Cu nuclei per unit volume*foil thickness} \\ &= \left[\left(8.9 \text{ g/cm}^3\right)\left(\frac{6.02\times10^{23} \text{ nuclei}}{63.54 \text{ g}}\right)\right]t = 8.43\times10^{22}t \\ N_{\text{Au}} &= \left[\left(19.3 \text{ g/cm}^3\right)\left(\frac{6.02\times10^{23} \text{ nuclei}}{197.0 \text{ g}}\right)\right]t = 5.90\times10^{22}t \end{aligned}$$

So $\Delta n_{\text{Cu}} = \Delta n_{\text{Au}}(29)^2 \frac{8.43\times10^{22}}{(79)^2}\left(5.90\times10^2\right) = (100)\left(\frac{29}{79}\right)^2\left(\frac{8.43}{5.90}\right) = 19.3 \text{ cpm}$.

4-12 $\frac{1}{\lambda} = R\left(\frac{1-1}{n^2}\right)$ where $n = 2, 3, 4, \ldots$ and $R = 1.097\,373\,2\times10^7 \text{ m}^{-1}$;

$$\text{For } n=2:\ \lambda = R^{-1}\left(1-\frac{1}{2^2}\right)^{-1} = 1.215\,02\times10^{-7} \text{ m} = 121.502 \text{ nm (UV)}$$
$$\text{For } n=3:\ \lambda = R^{-1}\left(1-\frac{1}{3^2}\right)^{-1} = 1.025\,17\times10^{-7} \text{ m} = 102.517 \text{ nm (UV)}$$
$$\text{For } n=4:\ \lambda = R^{-1}\left(1-\frac{1}{4^2}\right)^{-1} = 1.972\,018\times10^{-7} \text{ m} = 97.201\,8 \text{ nm (UV)}$$

4-13 (a) $\lambda = 102.6 \text{ nm}$; $\frac{1}{\lambda} = R\left(1-\frac{1}{n^2}\right) \Rightarrow n = \frac{R}{\left(R-\frac{1}{\lambda}\right)^{1/2}} = \frac{R}{\left(R-\frac{1}{102.6\times10^{-9} \text{ m}}\right)^{1/2}} = 2.99 \approx 3$

(b) This wavelength cannot belong to either series. Both the Paschen and Brackett series lie in the IR region, whereas the wavelength of 102.6 nm lies in the UV region.

4-14 (a) $r_n = \frac{n^2\hbar^2}{m_e k e^2}$; where $n = 1,\ 2,\ 3,\ \ldots$

$$r_n = n^2 \frac{\left(1.055\times10^{-34}\ \text{Js}\right)^2}{\left(9.11\times10^{-31}\ \text{kg}\right)\left(9.0\times19^{9}\ \text{Nm}^2/\text{C}^2\right)\left(1.6\times10^{-19}\ \text{C}\right)^2} = \left(0.052\,9\ \text{nm}\right)n^2$$

For $n = 1$: $r_n = 0.052\,9\ \text{nm}$

For $n = 2$: $r_n = 0.212\,1\ \text{nm}$

For $n = 3$: $r_n = 0.477\,2\ \text{nm}$

(b) From Equation 4.26, $v = \left(\frac{ke^2}{m_e r}\right)^{1/2}$

$$v_1 = \left[\frac{\left(8.99\times10^{9}\ \text{Nm}^2/\text{C}^2\right)\left(1.60\times10^{-19}\ \text{C}\right)^2}{\left(9.11\times10^{-31}\ \text{kg}\right)\left(0.052\,9\times10^{-9}\ \text{m}\right)}\right]^{1/2} = 2.19\times10^{6}\ \text{m/s}$$

$v_2 = 1.09\times10^{6}\ \text{m/s}$

$v_3 = 7.28\times10^{5}\ \text{m/s}$

(c) As $c = 3.0\times10^{8}\ \text{m/s}$, $v << c$ and no relativistic correction is necessary.

4-15 (a) The energy levels of a hydrogen-like ion whose charge number is 2 is given by $E_n = (-13.6\ \text{eV})\frac{Z^2}{n^2} = \frac{-54.4\ \text{eV}}{n^2}$ for $Z = 2$. $\left(\text{He}^+\right)$

______ 0
______ $E_3 = -6.04\ \text{eV}$
______ $E_2 = -13.6\ \text{eV}$

So $E_1 = -54.4\ \text{eV}$
$E_2 = -13.6\ \text{eV}$
$E_3 = -6.04\ \text{eV}$, etc.

______ $E_1 = -54.4\ \text{eV}$

(b) For He^+, $Z = 2$ so we see that the ionization energy (the energy required to take the electron from the state $n = 1$ to the state $n = \infty$ is $E = (-13.6\ \text{eV})\frac{2^2}{1^2} = \frac{-54.4\ \text{eV}}{n^2}$ for $Z = 2$. $\left(\text{He}^+\right)$

4-19 (a) $$\Delta E = (-13.6\text{ eV})\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right) = (-13.6\text{ eV})\left(\frac{1}{9} - \frac{1}{4}\right) = 1.89\text{ eV}$$

(b) $$E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E} = \left(4.14\times10^{-15}\text{ eV s}\right)\frac{3\times10^{8}\text{ m/s}}{1.89\text{ eV}} = 658\text{ nm}$$

(c) $$c = \lambda f \Rightarrow f = \frac{c}{\lambda} = \frac{3\times10^{8}\text{ m/s}}{657\times10^{-9}\text{ m}} = 4.56\times10^{14}\text{ Hz}$$

4-21 (a) For the Paschen series; $\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n_i^2}\right)$; the maximum wavelength corresponds to $n_i = 4$, $\frac{1}{\lambda_{max}} = R\left(\frac{1}{3^2} - \frac{1}{4^2}\right)$; $\lambda_{max} = 1\,874.606\text{ nm}$. For minimum wavelength, $n_i \to \infty$, $\frac{1}{\lambda_{min}} = R\left(\frac{1}{3^2} - \frac{1}{\infty}\right)$; $\lambda_{min} = \frac{9}{R} = 820.140\text{ nm}$.

(b) $$\frac{hc}{\lambda_{min}} = \frac{\left(\frac{hc}{1\,874.606\text{ nm}}\right)}{1.6\times10^{-19}\text{ J/eV}} = 0.662\,7\text{ nm}$$
$$\frac{hc}{\lambda_{min}} = \frac{\left(\frac{hc}{820.140\text{ nm}}\right)}{1.6\times10^{-19}\text{ J/eV}} = 1.515\text{ nm}$$

4-23 (a) $r_1 = (0.052\,9\text{ nm})n^2 = 0.052\,9\text{ nm}$ (when $n = 1$)

(b) $$m_e v = m_e\left(\frac{ke^2}{m_e r}\right)^{1/2}$$
$$m_e = \left[\frac{\left(9.1\times10^{-31}\text{ kg}\right)\left(9\times10^{9}\text{ Nm}^2/\text{C}^2\right)}{5.29\times10^{-11}\text{ m}}\right]^{1/2}\times\left(1.6\times10^{-19}\text{ C}\right)$$
$$M_e v = 1.99\times10^{-24}\text{ kg m/s}$$

(c) $L = m_e vr = \left(1.99\times10^{-24}\text{ kg m/s}\right)\left(5.29\times10^{-11}\text{ m}\right)$, $L = 1.05\times10^{-34}\left(\text{kg m}^2/\text{s}\right) = \hbar$

(d) $K = |E| = 13.6\text{ eV}$

(e) $U = -2K = -27.2\text{ eV}$

(f) $E = K + U = -13.6\text{ eV}$

4-25 (a) $\Delta E = hf = (13.6\text{ eV})\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$ or $f = (13.6\text{ eV})\left(\frac{\frac{1}{9} - \frac{1}{16}}{4.14\times10^{-15}\text{ eV s}}\right) = 1.60\times10^{14}\text{ Hz}$

(b) $T = \frac{2\pi r_n}{v}$ so $f_{\text{rev}} = \frac{1}{T} = \frac{v}{2\pi r_n}$. Using $v = \left(\frac{ke^2}{m_e r_n}\right)^{1/2}$, $f_{\text{rev}} = \left(\frac{ke^2}{m r_n}\right)^{1/2}$. For $n = 3$, $r_3 = (3)^2 a_0$ and

$$f_{\text{rev}} = \frac{\left(8.99\times10^9\ \text{Nm}^2/\text{C}^2\right)\left(1.60\times10^{-19}\ \text{C}\right)^2}{\frac{\left[\left(9.11\times10^{-31}\ \text{kg}\right)(9)\left(5.29\times10^{-11}\ \text{m}\right)\right]^{1/2}}{(2)(3.14)(9)\left(5.29\times10^{-11}\ \text{m}\right)}}$$

$$f_{\text{rev}} = 2.44\times10^{14}\ \text{Hz}\ (n = 3)$$

$$f_{\text{rev}} = 1.03\times10^{14}\ \text{Hz}\ (n = 4)$$

Thus the photon frequency is about halfway between the two frequencies of the revolution.

4-32 (a)

$$\mu_{1\text{H}} = \frac{m_e M}{m_e + M} = \frac{\left(9.109\,390\times10^{-31}\ \text{kg}\right)\left(1.672\,63\times10^{-27}\ \text{kg}\right)}{\left(9.109\,390\times10^{-31}\ \text{kg}\right)+\left(1.672\,63\times10^{-27}\ \text{kg}\right)}$$

$$= \frac{\left(9.109\,390\times10^{-31}\ \text{kg}\right)\left(1.672\,63\times10^{-27}\ \text{kg}\right)}{\left(0.000\,910\,939\,0\times10^{-27}\ \text{kg}\right)+\left(1.672\,63\times10^{-27}\ \text{kg}\right)} = 9.104\,431\times10^{-31}\ \text{kg}$$

$$\frac{1}{\lambda} = \frac{\mu}{m_e}(k)\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) = \left(\frac{9.104\,431\,6\times10^{-31}\ \text{kg}}{9.109\,390\times10^{-31}\ \text{kg}}\right)\left(1.097\,315\,3\times10^7\ \text{m}^{-1}\right)\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$$

$$\lambda_{1\text{H}} = 656.469\,1\ \text{nm}$$

(b) Similarly, we find $\lambda_{2\text{H}} = 656.292\,5$ nm.

(c) $\lambda_{3\text{H}} = 656.232\,5$ nm