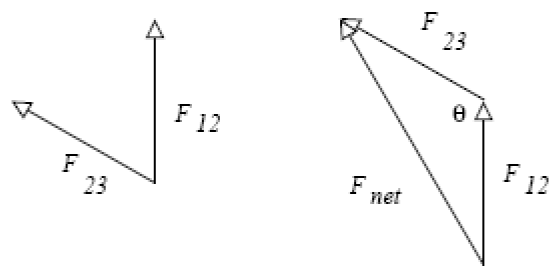
E25-5 (a) Use Eq. 25-4,

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r_{12}^2} = \frac{1}{4\pi(8.85\times10^{-12}\,\mathrm{C^2/N\cdot m^2})}\frac{(21.3\,\mu\mathrm{C})(21.3\,\mu\mathrm{C})}{(1.52\,\mathrm{m})^2} = 1.77\,\mathrm{N}$$

(b) In part (a) we found F_{12}; to solve part (b) we need to first find F_{13}. Since $q_3 = q_2$ and $r_{13} = r_{12}$, we can immediately conclude that $F_{13} = F_{12}$.

We must assess the direction of the force of q_3 on q_1; it will be directed along the line which connects the two charges, and will be directed away from q_3. The diagram below shows the directions.



From this diagram we want to find the magnitude of the *net* force on q_1. The cosine law is appropriate here:

$$\begin{aligned}
{F_{\mathrm{net}}}^2 &= F_{12}^2 + F_{13}^2 - 2F_{12}F_{13}\cos\theta,\\
&= (1.77\,\mathrm{N})^2 + (1.77\,\mathrm{N})^2 - 2(1.77\,\mathrm{N})(1.77\,\mathrm{N})\cos(120^\circ),\\
&= 9.40\,\mathrm{N}^2,\\
F_{\mathrm{net}} &= 3.07\,\mathrm{N}.
\end{aligned}$$

E25-11 This problem is similar to Ex. 25-7. There are some additional issues, however. It is easy enough to write expressions for the forces on the third charge

$$\begin{aligned}\vec{\mathbf{F}}_{31} &= \frac{1}{4\pi\epsilon_0}\frac{q_3q_1}{r_{31}^2}\hat{\mathbf{r}}_{31},\\ \vec{\mathbf{F}}_{32} &= \frac{1}{4\pi\epsilon_0}\frac{q_3q_2}{r_{32}^2}\hat{\mathbf{r}}_{32}.\end{aligned}$$

Then

$$\begin{aligned}\vec{\mathbf{F}}_{31} &= -\vec{\mathbf{F}}_{32},\\ \frac{1}{4\pi\epsilon_0}\frac{q_3q_1}{r_{31}^2}\hat{\mathbf{r}}_{31} &= -\frac{1}{4\pi\epsilon_0}\frac{q_3q_2}{r_{32}^2}\hat{\mathbf{r}}_{32},\\ \frac{q_1}{r_{31}^2}\hat{\mathbf{r}}_{31} &= -\frac{q_2}{r_{32}^2}\hat{\mathbf{r}}_{32}.\end{aligned}$$

The only way to satisfy the *vector* nature of the above expression is to have $\hat{\mathbf{r}}_{31} = \pm\hat{\mathbf{r}}_{32}$; this means that q_3 must be collinear with q_1 and q_2. q_3 could be between q_1 and q_2, or it could be on either side. Let's resolve this issue now by putting the values for q_1 and q_2 into the expression:

$$\begin{aligned}\frac{(1.07\,\mu\mathrm{C})}{r_{31}^2}\hat{\mathbf{r}}_{31} &= -\frac{(-3.28\,\mu\mathrm{C})}{r_{32}^2}\hat{\mathbf{r}}_{32},\\ r_{32}^2\hat{\mathbf{r}}_{31} &= (3.07)r_{31}^2\hat{\mathbf{r}}_{32}.\end{aligned}$$

Since squared quantities are positive, we can only get this to work if $\hat{\mathbf{r}}_{31} = \hat{\mathbf{r}}_{32}$, so q_3 is *not* between q_1 and q_2. We are then left with

$$r_{32}^2 = (3.07)r_{31}^2,$$

so that q_3 is closer to q_1 than it is to q_2. Then $r_{32} = r_{31} + r_{12} = r_{31} + 0.618\,\mathrm{m}$, and if we take the square root of both sides of the above expression,

$$\begin{aligned}r_{31} + (0.618\,\mathrm{m}) &= \sqrt{(3.07)}r_{31},\\ (0.618\,\mathrm{m}) &= \sqrt{(3.07)}r_{31} - r_{31},\\ (0.618\,\mathrm{m}) &= 0.752r_{31},\\ 0.822\,\mathrm{m} &= r_{31}\end{aligned}$$

E25-27 Equate the magnitudes of the forces:

$$\frac{1}{4\pi\epsilon_0}\frac{q^2}{r^2} = mg,$$

so

$$r = \sqrt{\frac{(8.99\times10^{9}\mathrm{N\cdot m^2/C^2})(1.60\times10^{-19}\mathrm{C})^2}{(9.11\times10^{-31}\mathrm{kg})(9.81\,\mathrm{m/s^2})}} = 5.07\,\mathrm{m}$$

P25-5 (a) Originally the balls would not repel, so they would move together and touch; after touching the balls would "split" the charge ending up with $q/2$ each. They would then repel again.

(b) The new equilibrium separation is

$$x' = \left(\frac{(q/2)^2L}{2\pi\epsilon_0 mg}\right)^{1/3} = \left(\frac{1}{4}\right)^{1/3} x = 2.96\ \mathrm{cm}.$$

P25-11 We can pretend that this problem is in a single plane containing all three charges. The magnitude of the force on the test charge q_0 from the charge q on the left is

$$F_1 = \frac{1}{4\pi\epsilon_0}\frac{q\,q_0}{(a^2+R^2)}.$$

A force of identical magnitude exists from the charge on the right. we need to add these two forces as vectors. Only the components along R will survive, and each force will contribute an amount

$$F_1 \sin\theta = F_1\frac{R}{\sqrt{R^2+a^2}},$$

so the net force on the test particle will be

$$\frac{2}{4\pi\epsilon_0}\frac{q\,q_0}{(a^2+R^2)}\frac{R}{\sqrt{R^2+a^2}}.$$

We want to find the maximum value as a function of R. This means take the derivative, and set it equal to zero. The derivative is

$$\frac{2q\,q_0}{4\pi\epsilon_0}\left(\frac{1}{(a^2+R^2)^{3/2}} - \frac{3R^2}{(a^2+R^2)^{5/2}}\right),$$

which will vanish when

$$a^2 + R^2 = 3R^2,$$

a *simple* quadratic equation with solutions $R = \pm a/\sqrt{2}$.

E26-7 Use Eq. 26-12 for points along the perpendicular bisector. Then

$$E = \frac{1}{4\pi\epsilon_0}\frac{p}{x^3} = (8.99\times10^9\mathrm{N\cdot m^2/C^2})\frac{(3.56\times10^{-29}\,\mathrm{C\cdot m})}{(25.4\times10^{-9}\,\mathrm{m})^3} = 1.95\times10^4\mathrm{N/C}.$$

E26-27 (a) The electric field does (negative) work on the electron. The magnitude of this work is $W = Fd$, where $F = Eq$ is the magnitude of the electric force on the electron and d is the distance through which the electron moves. Combining,

$$W = \vec{\mathbf{F}}\cdot\vec{\mathbf{d}} = q\vec{\mathbf{E}}\cdot\vec{\mathbf{d}},$$

which gives the work done by the electric field on the electron. The electron originally possessed a kinetic energy of $K = \frac{1}{2}mv^2$, since we want to bring the electron to a rest, the work done must be negative. The charge q of the electron is negative, so $\vec{\mathbf{E}}$ and $\vec{\mathbf{d}}$ are pointing in the same direction, and $\vec{\mathbf{E}}\cdot\vec{\mathbf{d}} = Ed$.

By the work energy theorem,

$$W = \Delta K = 0 - \frac{1}{2}mv^2.$$

We put all of this together and find d,

$$d = \frac{W}{qE} = \frac{-mv^2}{2qE} = \frac{-(9.11\times10^{-31}\mathrm{kg})(4.86\times10^6\,\mathrm{m/s})^2}{2(-1.60\times10^{-19}\mathrm{C})(1030\,\mathrm{N/C})} = 0.0653\,\mathrm{m}.$$

(b) $Eq = ma$ gives the magnitude of the acceleration, and $v_\mathrm{f} = v_\mathrm{i} + at$ gives the time. But $v_\mathrm{f} = 0$. Combining these expressions,

$$t = -\frac{mv_\mathrm{i}}{Eq} = -\frac{(9.11\times10^{-31}\mathrm{kg})(4.86\times10^6\,\mathrm{m/s})}{(1030\,\mathrm{N/C})(-1.60\times10^{-19}\mathrm{C})} = 2.69\times10^{-8}\,\mathrm{s}.$$

(c) We will apply the work energy theorem again, except now we don't assume the final kinetic energy is zero. Instead,

$$W = \Delta K = K_\mathrm{f} - K_\mathrm{i},$$

and dividing through by the initial kinetic energy to get the fraction lost,

$$\frac{W}{K_\mathrm{i}} = \frac{K_\mathrm{f} - K_\mathrm{i}}{K_\mathrm{i}} = \text{ fractional change of kinetic energy.}$$

But $K_\mathrm{i} = \frac{1}{2}mv^2$, and $W = qEd$, so the fractional change is

$$\frac{W}{K_\mathrm{i}} = \frac{qEd}{\frac{1}{2}mv^2} = \frac{(-1.60\times10^{-19}\mathrm{C})(1030\,\mathrm{N/C})(7.88\times10^{-3}\mathrm{m})}{\frac{1}{2}(9.11\times10^{-31}\mathrm{kg})(4.86\times10^6\,\mathrm{m/s})^2} = -12.1\%.$$

E26-37 Use $\tau = pE\sin\theta$, where θ is the angle between $\vec{\mathbf{p}}$ and $\vec{\mathbf{E}}$. For this dipole $p = qd = 2ed$ or $p = 2(1.6\times10^{-19}\,\mathrm{C})(0.78\times10^{-9}\,\mathrm{m}) = 2.5\times10^{-28}\,\mathrm{C\cdot m}$. For all three cases

$$pE = (2.5\times10^{-28}\,\mathrm{C\cdot m})(3.4\times10^6\mathrm{N/C}) = 8.5\times10^{-22}\,\mathrm{N\cdot m}.$$

The only thing we care about is the angle.

(a) For the parallel case $\theta = 0$, so $\sin\theta = 0$, and $\tau = 0$.

(b) For the perpendicular case $\theta = 90°$, so $\sin\theta = 1$, and $\tau = 8.5\times10^{-22}\,\mathrm{N\cdot m}$..

(c) For the anti-parallel case $\theta = 180°$, so $\sin\theta = 0$, and $\tau = 0$.

P26-1 (a) Let the positive charge be located *closer* to the point in question, then the electric field from the positive charge is

$$E_+ = \frac{1}{4\pi\epsilon_0}\frac{q}{(x-d/2)^2}$$

and is directed *away from* the dipole.

The negative charge is located farther from the point in question, so

$$E_- = \frac{1}{4\pi\epsilon_0}\frac{q}{(x+d/2)^2}$$

and is directed *toward* the dipole.

The net electric field is the sum of these two fields, but since the two component fields point in opposite direction we must actually subtract these values,

$$\begin{aligned} E &= E_+ - E_-, \\ &= \frac{1}{4\pi\epsilon_0}\frac{q}{(z-d/2)^2} - \frac{1}{4\pi\epsilon_0}\frac{q}{(z+d/2)^2}, \\ &= \frac{1}{4\pi\epsilon_0}\frac{q}{z^2}\left(\frac{1}{(1-d/2z)^2} - \frac{1}{(1+d/2z)^2}\right) \end{aligned}$$

We can use the binomial expansion on the terms containing $1 \pm d/2z$,

$$\begin{aligned} E &\approx \frac{1}{4\pi\epsilon_0}\frac{q}{z^2}\left((1+d/z)-(1-d/z)\right), \\ &= \frac{1}{2\pi\epsilon_0}\frac{qd}{z^3} \end{aligned}$$

(b) The electric field is directed away from the positive charge when you are closer to the positive charge; the electric field is directed toward the negative charge when you are closer to the negative charge. In short, along the axis the electric field is directed in the same direction as the dipole moment.

P26-3 (a) Each point on the ring is a distance $\sqrt{z^2+R^2}$ from the point on the axis in question. Since all points are equal distant and subtend the same angle from the axis then the top half of the ring contributes

$$E_{1z} = \frac{q_1}{4\pi\epsilon_0(x^2+R^2)}\frac{z}{\sqrt{z^2+R^2}},$$

while the bottom half contributes a similar expression. Add, and

$$E_z = \frac{q_1+q_2}{4\pi\epsilon_0}\frac{z}{(z^2+R^2)^{3/2}} = \frac{q}{4\pi\epsilon_0}\frac{z}{(z^2+R^2)^{3/2}},$$

which is identical to Eq. 26-18.

(b) The perpendicular component would be zero if $q_1 = q_2$. It isn't, so it must be the difference $q_1 - q_2$ which is of interest. Assume this charge difference is evenly distributed on the *top* half of the ring. If it is a positive difference, then $E_\perp$ must point down. We are only interested then in the vertical component as we integrate around the top half of the ring. Then

$$\begin{aligned} E_\perp &= \int_0^\pi \frac{1}{4\pi\epsilon_0}\frac{(q_1-q_2)/\pi}{z^2+R^2}\cos\theta\, d\theta, \\ &= \frac{q_1-q_2}{2\pi^2\epsilon_0}\frac{1}{z^2+R^2}. \end{aligned}$$

E27-1 $\Phi_E = (1800\,\mathrm{N/C})(3.2\times10^{-3}\mathrm{m})^2\cos(145^\circ) = -7.8\times10^{-3}\mathrm{N}\cdot\mathrm{m}^2/\mathrm{C}$.

E27-5 By Eq. 27-8,

$$\Phi_E = \frac{q}{\epsilon_0} = \frac{(1.84\,\mu\mathrm{C})}{(8.85\times10^{-12}\,\mathrm{C}^2/\mathrm{N}\cdot\mathrm{m}^2)} = 2.08\times10^5\,\mathrm{N}\cdot\mathrm{m}^2/\mathrm{C}.$$

E27-9 There is no flux through the sides of the cube. The flux through the top of the cube is $(-58\,\mathrm{N/C})(100\,\mathrm{m})^2 = -5.8\times10^5\mathrm{N}\cdot\mathrm{m}^2/\mathrm{C}$. The flux through the bottom of the cube is

$$(110\,\mathrm{N/C})(100\,\mathrm{m})^2 = 1.1\times10^6\mathrm{N}\cdot\mathrm{m}^2/\mathrm{C}.$$

The total flux is the sum, so the charge contained in the cube is

$$q = (8.85\times10^{-12}\mathrm{C}^2/\mathrm{N}\cdot\mathrm{m}^2)(5.2\times10^5\mathrm{N}\cdot\mathrm{m}^2/\mathrm{C}) = 4.60\times10^{-6}\mathrm{C}.$$

E27-15 The electric field from the plate on the left is of magnitude $E_1 = \sigma/2\epsilon_0$, and points directly toward the plate. The magnitude of the electric field from the plate on the right is the same, but it points directly away from the plate on the right.

(a) To the left of the plates the two fields cancel since they point in the opposite directions. This means that the electric field is $\vec{\mathbf{E}} = 0$.

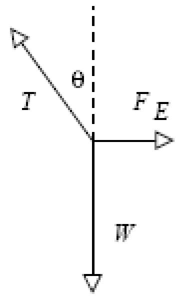
(b) Between the plates the two electric fields add since they point in the same direction. This means that the electric field is $\vec{\mathbf{E}} = -(\sigma/\epsilon_0)\hat{\mathbf{i}}$.

(c) To the right of the plates the two fields cancel since they point in the opposite directions. This means that the electric field is $\vec{\mathbf{E}} = 0$.

E27-17 We don't really need to write an integral, we just need the charge per unit length in the cylinder to be equal to zero. This means that the positive charge in cylinder must be $+3.60n\mathrm{C/m}$. This positive charge is uniformly distributed in a circle of radius $R = 1.50$ cm, so

$$\rho = \frac{3.60n\mathrm{C/m}}{\pi R^2} = \frac{3.60n\mathrm{C/m}}{\pi(0.0150\,\mathrm{m})^2} = 5.09\mu\mathrm{C/m}^3.$$

P27-3 The net force on the small sphere is zero; this force is the vector sum of the force of gravity W, the electric force F_E, and the tension T.



These forces are related by $Eq = mg\tan\theta$. We also have $E = \sigma/2\epsilon_0$, so

$$\begin{aligned}\sigma &= \frac{2\epsilon_0 mg\tan\theta}{q},\\ &= \frac{2(8.85\times10^{-12}\,\mathrm{C^2/N\cdot m^2})(1.12\times10^{-6}\mathrm{kg})(9.81\,\mathrm{m/s^2})\tan(27.4°)}{(19.7\times10^{-9}\mathrm{C})},\\ &= 5.11\times10^{-9}\mathrm{C/m^2}.\end{aligned}$$

P27-7 This problem is closely related to Ex. 27-25, except for the part concerning $q_{\rm enc}$. We'll set up the problem the same way: the Gaussian surface will be a (imaginary) cylinder centered on the axis of the physical cylinder. For Gaussian surfaces of radius $r < R$, there is *no* charge enclosed while for Gaussian surfaces of radius $r > R$, $q_{\rm enc} = \lambda l$.

We've already worked out the integral

$$\int_{\rm tube} \vec{\mathbf{E}}\cdot d\vec{\mathbf{A}} = 2\pi r l E,$$

for the cylinder, and then from Gauss' law,

$$q_{\rm enc} = \epsilon_0\int_{\rm tube} \vec{\mathbf{E}}\cdot d\vec{\mathbf{A}} = 2\pi\epsilon_0 r l E.$$

(a) When $r < R$ there is no enclosed charge, so the left hand vanishes and consequently $E = 0$ inside the physical cylinder.

(b) When $r > R$ there is a charge λl enclosed, so

$$E = \frac{\lambda}{2\pi\epsilon_0 r}.$$

E28-1 (a) Let U_{12} be the potential energy of the interaction between the two "up" quarks. Then

$$U_{12} = (8.99\times10^9\mathrm{N}\cdot\mathrm{m}^2/\mathrm{C}^2)\frac{(2/3)^2 e(1.60\times10^{-19}\mathrm{C})}{(1.32\times10^{-15}\mathrm{m})} = 4.84\times10^5\,\mathrm{eV}.$$

(b) Let U_{13} be the potential energy of the interaction between an "up" quark and a "down" quark. Then

$$U_{13} = (8.99\times10^9\mathrm{N}\cdot\mathrm{m}^2/\mathrm{C}^2)\frac{(-1/3)(2/3)e(1.60\times10^{-19}\mathrm{C})}{(1.32\times10^{-15}\mathrm{m})} = -2.42\times10^5\mathrm{eV}$$

Note that $U_{13} = U_{23}$. The total electric potential energy is the sum of these three terms, or zero.

E28-11 (a) $V = (1.60\times10^{-19}\mathrm{C})/4\pi(8.85\times10^{-12}\mathrm{C}^2/\mathrm{N}\cdot\mathrm{m}^2)(5.29\times10^{-11}\mathrm{m}) = 27.2\,\mathrm{V}$.

(b) $U = qV = (-e)(27.2\,\mathrm{V}) = -27.2$ eV.

(c) For uniform circular orbits $F = mv^2/r$; the force is electrical, or $F = e^2/4\pi\epsilon_0 r^2$. Kinetic energy is $K = mv^2/2 = Fr/2$, so

$$K = \frac{e^2}{8\pi\epsilon_0 r} = \frac{(1.60\times10^{-19}\mathrm{C})}{8\pi(8.85\times10^{-12}\mathrm{C}^2/\mathrm{N}\cdot\mathrm{m}^2)(5.29\times10^{-11}\mathrm{m})} = 13.6\ \mathrm{eV}.$$

(d) The ionization energy is $-(K+U)$, or

$$E_{\mathrm{ion}} = -[(13.6\ \mathrm{eV}) + (-27.2\ \mathrm{eV})] = 13.6\ \mathrm{eV}.$$

E28-19 (a) We evaluate V_A and V_B individually, and then find the difference.

$$V_A = \frac{1}{4\pi\epsilon_0}\frac{q}{r} = \frac{1}{4\pi(8.85\times10^{-12}\,\mathrm{C}^2/\mathrm{N}\cdot\mathrm{m}^2)}\frac{(1.16\mu\mathrm{C})}{(2.06\,\mathrm{m})} = 5060\,\mathrm{V},$$

and

$$V_B = \frac{1}{4\pi\epsilon_0}\frac{q}{r} = \frac{1}{4\pi(8.85\times10^{-12}\,\mathrm{C}^2/\mathrm{N}\cdot\mathrm{m}^2)}\frac{(1.16\mu\mathrm{C})}{(1.17\,\mathrm{m})} = 8910\,\mathrm{V},$$

The difference is then $V_A - V_B = -3850\,\mathrm{V}$.

(b) The answer is the same, since when concerning ourselves with electric potential we only care about distances, and not directions.

E28-27 The distance from C to either charge is $\sqrt{2}d/2 = 1.39\times10^{-2}$m.

(a) V at C is

$$V = (8.99\times10^9\mathrm{N}\cdot\mathrm{m}^2/\mathrm{C}^2)\frac{2(2.13\times10^{-6}\mathrm{C})}{(1.39\times10^{-2}\mathrm{m})} = 2.76\times10^6\mathrm{V}$$

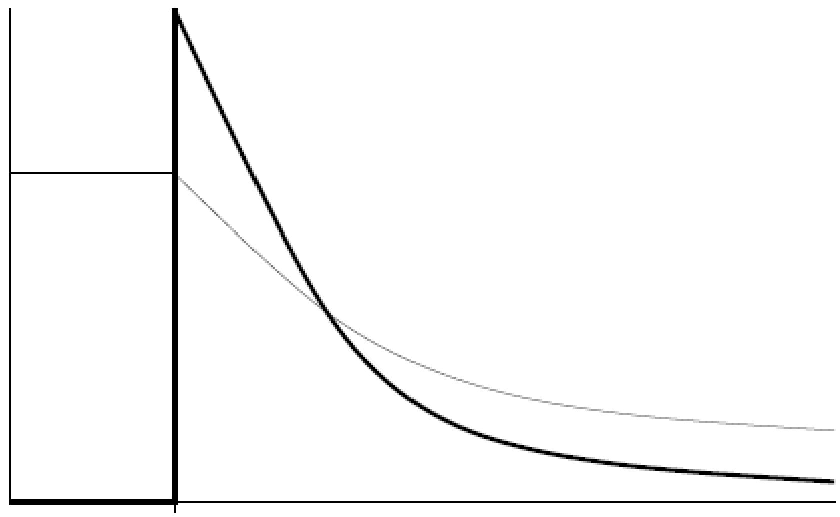
(b) $W = q\delta V = (1.91\times10^{-6}\mathrm{C})(2.76\times10^6\mathrm{V}) = 5.27\,\mathrm{J}$.

(c) Don't forget about the potential energy of the original two charges!

$$U_0 = (8.99\times10^9\mathrm{N}\cdot\mathrm{m}^2/\mathrm{C}^2)\frac{(2.13\times10^{-6}\mathrm{C})^2}{(1.96\times10^{-2}\mathrm{m})} = 2.08\,\mathrm{J}$$

Add this to the answer from part (b) to get 7.35 J.

E28-41 This can easily be done with a spreadsheet. The following is a *sketch*; the electric field is the bold curve, the potential is the thin curve.



P28-3 The negative charge is held in orbit by electrostatic attraction, or

$$\frac{mv^2}{r} = \frac{qQ}{4\pi\epsilon_0 r^2}.$$

The kinetic energy of the charge is

$$K = \frac{1}{2}mv^2 = \frac{qQ}{8\pi\epsilon_0 r}.$$

The electrostatic potential energy is

$$U = -\frac{qQ}{4\pi\epsilon_0 r},$$

so the total energy is

$$E = -\frac{qQ}{8\pi\epsilon_0 r}.$$

The work required to change orbit is then

$$W = \frac{qQ}{8\pi\epsilon_0}\left(\frac{1}{r_1} - \frac{1}{r_2}\right).$$

P28-11 Add the three contributions, and then do a series expansion for $d \ll r$.

$$\begin{aligned} V &= \frac{q}{4\pi\epsilon_0}\left(\frac{-1}{r+d}+\frac{1}{r}+\frac{1}{r-d}\right), \\ &= \frac{q}{4\pi\epsilon_0 r}\left(\frac{-1}{1+d/r}+1+\frac{1}{1-d/r}\right), \\ &\approx \frac{q}{4\pi\epsilon_0 r}\left(-1+\frac{d}{r}+1+1+\frac{d}{r}\right), \\ &\approx \frac{q}{4\pi\epsilon_0 r}\left(1+\frac{2d}{r}\right). \end{aligned}$$

P28-15 Calculating the fraction of excess electrons is the same as calculating the fraction of excess charge, so we'll skip counting the electrons. This problem is effectively the same as Exercise 28-47; we have a total charge that is divided between two unequal size spheres which are at the same potential on the surface. Using the result from that exercise we have

$$q_1 = \frac{Qr_1}{r_2+r_1},$$

where $Q = -6.2$ nC is the total charge available, and q_1 is the charge left on the sphere. r_1 is the radius of the small ball, r_2 is the radius of Earth. Since the fraction of charge remaining is q_1/Q, we can write

$$\frac{q_1}{Q} = \frac{r_1}{r_2+r_1} \approx \frac{r_1}{r_2} = 2.0\times 10^{-8}.$$

E29-1 (a) The charge which flows through a cross sectional surface area in a time t is given by $q = it$, where i is the current. For this exercise we have

$$q = (4.82\,\mathrm{A})(4.60 \times 60\,\mathrm{s}) = 1330\,\mathrm{C}$$

as the charge which passes through a cross section of this resistor.

(b) The number of electrons is given by $(1330\,\mathrm{C})/(1.60 \times 10^{-19}\,\mathrm{C}) = 8.31 \times 10^{21}$ electrons.

E29-11 The drift velocity is given by Eq. 29-6,

$$v_\mathrm{d} = \frac{j}{ne} = \frac{i}{Ane} = \frac{(115\,\mathrm{A})}{(31.2\times10^{-6}\mathrm{m}^2)(8.49\times10^{28}/m^3)(1.60\times10^{-19}\mathrm{C})} = 2.71\times10^{-4}\mathrm{m/s}.$$

The time it takes for the electrons to get to the starter motor is

$$t = \frac{x}{v} = \frac{(0.855\,\mathrm{m})}{(2.71\times10^{-4}\mathrm{m/s})} = 3.26\times10^{3}\mathrm{s}.$$

That's about 54 minutes.

E29-13 The resistance of an object with constant cross section is given by Eq. 29-13,

$$R = \rho\frac{L}{A} = (3.0 \times 10^{-7}\,\Omega\cdot\mathrm{m})\frac{(11,000\,\mathrm{m})}{(0.0056\,\mathrm{m}^2)} = 0.59\,\Omega.$$

E29-23 Conductivity is given by Eq. 29-8, $\vec{\mathrm{j}} = \sigma\vec{\mathrm{E}}$. If the wire is long and thin, then the magnitude of the electric field in the wire will be given by

$$E \approx \Delta V/L = (115\,\mathrm{V})/(9.66\,\mathrm{m}) = 11.9\,\mathrm{V/m}.$$

We can now find the conductivity,

$$\sigma = \frac{j}{E} = \frac{(1.42\times10^{4}\mathrm{A/m}^2)}{(11.9\,\mathrm{V/m})} = 1.19\times10^{3}(\Omega\cdot\mathrm{m})^{-1}.$$

E29-27 (a) The resistance is defined as

$$R = \frac{\Delta V}{i} = \frac{(3.55 \times 10^{6}\,\mathrm{V/A}^2)i^2}{i} = (3.55 \times 10^{6}\,\mathrm{V/A}^2)i.$$

When $i = 2.40$ mA the resistance would be

$$R = (3.55 \times 10^{6}\,\mathrm{V/A}^2)(2.40 \times 10^{-3}\mathrm{A}) = 8.52\,\mathrm{k}\Omega.$$

(b) Invert the above expression, and

$$i = R/(3.55 \times 10^{6}\,\mathrm{V/A}^2) = (16.0\,\Omega)/(3.55 \times 10^{6}\,\mathrm{V/A}^2) = 4.51\,\mu\mathrm{A}.$$

E29-31 (a) At the surface of a conductor of radius R with charge Q the magnitude of the electric field is given by

$$E = \frac{1}{4\pi\epsilon_0} QR^2,$$

while the potential (assuming $V = 0$ at infinity) is given by

$$V = \frac{1}{4\pi\epsilon_0} QR.$$

The ratio is $V/E = R$.

The potential on the sphere that would result in "sparking" is

$$V = ER = (3\times 10^6 \mathrm{N/C})R.$$

(b) It is "easier" to get a spark off of a sphere with a smaller radius, because any potential on the sphere will result in a larger electric field.

(c) The points of a lighting rod are like small hemispheres; the electric field will be large near these points so that this will be the likely place for sparks to form and lightning bolts to strike.

P29-3 (a) The resistance of the segment of the wire is

$$R = \rho L/A = (1.69\times 10^{-8}\Omega\cdot\mathrm{m})(4.0\times 10^{-2}\mathrm{m})/\pi(2.6\times 10^{-3}\mathrm{m})^2 = 3.18\times 10^{-5}\Omega.$$

The potential difference across the segment is

$$\Delta V = iR = (12\,\mathrm{A})(3.18\times 10^{-5}\Omega) = 3.8\times 10^{-4}\mathrm{V}.$$

(b) The tail is negative.

(c) The drift speed is $v = j/en = i/Aen$, so

$$v = (12\,\mathrm{A})/\pi(2.6\times 10^{-3}\mathrm{m})^2(1.6\times 10^{-19}\mathrm{C})(8.49\times 10^{28}/\mathrm{m}^3) = 4.16\times 10^{-5}\mathrm{m/s}.$$

The electrons will move 1 cm in $(1.0\times 10^{-2}\mathrm{m})/(4.16\times 10^{-5}\mathrm{m/s}) = 240\,\mathrm{s}$.

P29-7 (a) Solve $2\rho_0 = \rho_0[1 + \alpha(T - 20°\text{C})]$, or

$$T = 20°\text{C} + 1/(4.3\times10^{-3}/\text{C}°) = 250°\text{C}.$$

(b) Yes, ignoring changes in the physical dimensions of the resistor.

P29-15 The current is found from Eq. 29-5,

$$i = \int \vec{\mathbf{j}} \cdot d\vec{\mathbf{A}},$$

where the region of integration is over a spherical shell concentric with the two conducting shells but between them. The current density is given by Eq. 29-10,

$$\vec{\mathbf{j}} = \vec{\mathbf{E}}/\rho,$$

and we will have an electric field which is perpendicular to the spherical shell. Consequently,

$$i = \frac{1}{\rho}\int \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = \frac{1}{\rho}\int E\,dA$$

By symmetry we expect the electric field to have the same magnitude anywhere on a spherical shell which is concentric with the two conducting shells, so we can bring it out of the integral sign, and then

$$i = \frac{1}{\rho}E\int dA = \frac{4\pi r^2 E}{\rho},$$

where E is the magnitude of the electric field on the shell, which has radius r such that $b > r > a$.

The above expression can be inverted to give the electric field as a function of radial distance, since the current is a constant in the above expression. Then $E = i\rho/4\pi r^2$ The potential is given by

$$\Delta V = -\int_b^a \vec{\mathbf{E}} \cdot d\vec{s},$$

we will integrate along a radial line, which is parallel to the electric field, so

$$\begin{aligned}
\Delta V &= -\int_b^a E\,dr, \\
&= -\int_b^a \frac{i\rho}{4\pi r^2}\,dr, \\
&= -\frac{i\rho}{4\pi}\int_b^a \frac{dr}{r}, \\
&= \frac{i\rho}{4\pi}\left(\frac{1}{a} - \frac{1}{b}\right).
\end{aligned}$$

We divide this expression by the current to get the resistance. Then

$$R = \frac{\rho}{4\pi}\left(\frac{1}{a} - \frac{1}{b}\right)$$

E30-1 We apply Eq. 30-1,

$$q = C\Delta V = (50 \times 10^{-12}\,\mathrm{F})(0.15\,\mathrm{V}) = 7.5 \times 10^{-12}\,\mathrm{C};$$

E30-5 Eq. 30-11 gives the capacitance of a cylinder,

$$C = 2\pi\epsilon_0 \frac{L}{\ln(b/a)} = 2\pi(8.85\times10^{-12}\,\mathrm{F/m})\frac{(0.0238\,\mathrm{m})}{\ln((9.15\mathrm{mm})/(0.81\mathrm{mm}))} = 5.46\times10^{-13}\mathrm{F}.$$

E30-9 The potential difference across each capacitor in parallel is the same; it is equal to 110 V. The charge on each of the capacitors is then

$$q = C\Delta V = (1.00 \times 10^{-6}\,\mathrm{F})(110\,\mathrm{V}) = 1.10 \times 10^{-4}\,\mathrm{C}.$$

If there are N capacitors, then the total charge will be Nq, and we want this total charge to be 1.00 C. Then

$$N = \frac{(1.00\,\mathrm{C})}{q} = \frac{(1.00\,\mathrm{C})}{(1.10 \times 10^{-4}\,\mathrm{C})} = 9090.$$

E30-11 First find the equivalent capacitance of the series part:

$$\frac{1}{C_{\mathrm{eq}}} = \frac{1}{(10.3\times10^{-6}\mathrm{F})} + \frac{1}{(4.80\times10^{-6}\mathrm{F})} = 3.05\times10^{5}\mathrm{F}^{-1}.$$

The equivalent capacitance is 3.28×10^{-6}F. Then find the equivalent capacitance of the parallel part:

$$C_{\mathrm{eq}} = C_1 + C_2 = (3.28\times10^{-6}\mathrm{F}) + (3.90\times10^{-6}\mathrm{F}) = 7.18\times10^{-6}\mathrm{F}.$$

This is the equivalent capacitance for the entire arrangement.

E30-25 $V/r = q/4\pi\epsilon_0 r^2 = E$, so that if V is the potential of the sphere then $E = V/r$ is the electric field on the surface. Then the energy density of the electric field near the surface is

$$u = \frac{1}{2}\epsilon_0 E^2 = \frac{(8.85\times10^{-12}\mathrm{F/m})}{2}\left(\frac{(8150\,\mathrm{V})}{(0.063\,\mathrm{m})}\right)^2 = 7.41\times10^{-2}\mathrm{J/m^3}.$$

E30-29 Originally, $C_1 = \epsilon_0 A/d_1$. After the changes, $C_2 = \kappa\epsilon_0 A/d_2$. Dividing C_2 by C_1 yields $C_2/C_1 = \kappa d_1/d_2$, so

$$\kappa = d_2 C_2/d_1 C_1 = (2)(2.57\times10^{-12}\mathrm{F})/(1.32\times10^{-12}\mathrm{F}) = 3.89.$$

E30-33 The capacitance of a cylindrical capacitor is given by Eq. 30-11,

$$C = 2\pi(8.85\times10^{-12}\mathrm{F/m})(2.6)\frac{1.0\times10^{3}\mathrm{m}}{\ln(0.588/0.11)} = 8.63\times10^{-8}\mathrm{F}.$$

E30-39 $C = \kappa_e\epsilon_0 A/d$, so $d = \kappa_e\epsilon_0 A/C$.

(a) $E = \Delta V/d = C\Delta V/\kappa_e\epsilon_0 A$, or

$$E = \frac{(112\times10^{-12}\mathrm{F})(55.0\,\mathrm{V})}{(5.4)(8.85\times10^{-12}\mathrm{F/m})(96.5\times10^{-4}\mathrm{m^2})} = 13400\,\mathrm{V/m}.$$

(b) $Q = C\Delta V = (112\times10^{-12}\mathrm{F})(55.0\,\mathrm{V}) = 6.16\times10^{-9}\mathrm{C}$..

(c) $Q' = Q(1 - 1/\kappa_e) = (6.16\times10^{-9}\mathrm{C})(1 - 1/(5.4)) = 5.02\times10^{-9}\mathrm{C}$.

P30-7 (a) If terminal a is more positive than terminal b then current can flow that will charge the capacitor on the left, the current can flow through the diode on the top, and the current can charge the capacitor on the right. Current will not flow through the diode on the left. The capacitors are effectively in series.

Since the capacitors are identical and series capacitors have the same charge, we expect the capacitors to have the same potential difference across them. But the total potential difference across both capacitors is equal to 100 V, so the potential difference across either capacitor is 50 V.

The output pins are connected to the capacitor on the right, so the potential difference across the output is 50 V.

(b) If terminal b is more positive than terminal a the current can flow through the diode on the left. If we assume the diode is resistanceless in this configuration then the potential difference across it will be zero. The net result is that the potential difference across the output pins is 0 V.

In real life the potential difference across the diode would not be zero, even if forward biased. It will be somewhere around 0.5 Volts.

P30-9 (a) When S_2 is open the circuit acts as two parallel capacitors. The branch on the left has an effective capacitance given by

$$\frac{1}{C_l} = \frac{1}{(1.0\times10^{-6}\mathrm{F})} + \frac{1}{(3.0\times10^{-6}\mathrm{F})} = \frac{1}{7.5\times10^{-7}\mathrm{F}},$$

while the branch on the right has an effective capacitance given by

$$\frac{1}{C_l} = \frac{1}{(2.0\times10^{-6}\mathrm{F})} + \frac{1}{(4.0\times10^{-6}\mathrm{F})} = \frac{1}{1.33\times10^{-6}\mathrm{F}}.$$

The charge on *either* capacitor in the branch on the left is

$$q = (7.5\times10^{-7}\mathrm{F})(12\,\mathrm{V}) = 9.0\times10^{-6}\mathrm{C},$$

while the charge on *either* capacitor in the branch on the right is

$$q = (1.33\times10^{-6}\mathrm{F})(12\,\mathrm{V}) = 1.6\times10^{-5}\mathrm{C}.$$

(b) After closing S_2 the circuit is effectively two capacitors in series. The top part has an effective capacitance of

$$C_t = (1.0\times10^{-6}\mathrm{F}) + (2.0\times10^{-6}\mathrm{F}) = (3.0\times10^{-6}\mathrm{F}),$$

while the effective capacitance of the bottom part is

$$C_b = (3.0\times10^{-6}\mathrm{F}) + (4.0\times10^{-6}\mathrm{F}) = (7.0\times10^{-6}\mathrm{F}).$$

The effective capacitance of the series combination is given by

$$\frac{1}{C_{eq}} = \frac{1}{(3.0\times10^{-6}\mathrm{F})} + \frac{1}{(7.0\times10^{-6}\mathrm{F})} = \frac{1}{2.1\times10^{-6}\mathrm{F}}.$$

The charge on each part is $q = (2.1\times10^{-6}\mathrm{F})(12\,\mathrm{V}) = 2.52\times10^{-5}\mathrm{C}$. The potential difference across the top part is

$$\Delta V_t = (2.52\times10^{-5}\mathrm{C})/(3.0\times10^{-6}\mathrm{F}) = 8.4\,\mathrm{V},$$

and then the charge on the top two capacitors is $q_1 = (1.0\times10^{-6}\mathrm{F})(8.4\,\mathrm{V}) = 8.4\times10^{-6}\mathrm{C}$ and $q_2 = (2.0\times10^{-6}\mathrm{F})(8.4\,\mathrm{V}) = 1.68\times10^{-5}\mathrm{C}$. The potential difference across the bottom part is

$$\Delta V_t = (2.52\times10^{-5}\mathrm{C})/(7.0\times10^{-6}\mathrm{F}) = 3.6\,\mathrm{V},$$

and then the charge on the top two capacitors is $q_1 = (3.0\times10^{-6}\mathrm{F})(3.6\,\mathrm{V}) = 1.08\times10^{-5}\mathrm{C}$ and $q_2 = (4.0\times10^{-6}\mathrm{F})(3.6\,\mathrm{V}) = 1.44\times10^{-5}\mathrm{C}$.

P30-19 We will treat the system as two capacitors in series by pretending there is an infinitesimally thin conductor between them. The slabs are (I assume) the same thickness. The capacitance of one of the slabs is then given by Eq. 30-31,

$$C_1 = \frac{\kappa_{e1}\epsilon_0 A}{d/2},$$

where $d/2$ is the thickness of the slab. There would be a similar expression for the other slab. The equivalent series capacitance would be given by Eq. 30-21,

$$\begin{aligned}
\frac{1}{C_{eq}} &= \frac{1}{C_1} + \frac{1}{C_2}, \\
&= \frac{d/2}{\kappa_{e1}\epsilon_0 A} + \frac{d/2}{\kappa_{e2}\epsilon_0 A}, \\
&= \frac{d}{2\epsilon_0 A}\frac{\kappa_{e2} + \kappa_{e1}}{\kappa_{e1}\kappa_{e2}}, \\
C_{eq} &= \frac{2\epsilon_0 A}{d}\frac{\kappa_{e1}\kappa_{e2}}{\kappa_{e2} + \kappa_{e1}}.
\end{aligned}$$

E32-7 Both have the same velocity. Then $K_{\rm p}/K_{\rm e} = m_{\rm p}v^2/m_{\rm e}v^2 = m_{\rm p}/m_{\rm e} =$.

E32-9 (a) For a charged particle moving in a circle in a magnetic field we apply Eq. 32-10;

$$r = \frac{mv}{|q|B} = \frac{(9.11\times10^{-31}\text{kg})(0.1)(3.00\times10^{8}\,\text{m/s})}{(1.6\times10^{-19}\,\text{C})(0.50\,\text{T})} = 3.4\times10^{-4}\,\text{m}.$$

(b) The (non-relativistic) kinetic energy of the electron is

$$K = \frac{1}{2}mv^2 = \frac{1}{2}(0.511\text{ MeV})(0.10c)^2 = 2.6\times10^{-3}\text{ MeV}.$$

E32-17 $r = \sqrt{2mK}/|q|B = (\sqrt{m}/|q|)(\sqrt{2K}/B)$. All three particles are traveling with the same kinetic energy in the same magnetic field. The relevant factors are in front; we just need to compare the mass and charge of each of the three particles.

(a) The radius of the deuteron path is $\frac{\sqrt{2}}{1}r_{\rm p}$.

(b) The radius of the alpha particle path is $\frac{\sqrt{4}}{2}r_{\rm p} = r_{\rm p}$.

E32-21 Use Eq. 32-10, except we rearrange for the mass,

$$m = \frac{|q|rB}{v} = \frac{2(1.60\times10^{-19}\,\text{C})(4.72\,\text{m})(1.33\,\text{T})}{0.710(3.00\times10^{8}\,\text{m/s})} = 9.43\times10^{-27}\,\text{kg}$$

However, if it is moving at this velocity then the "mass" which we have here is not the true mass, but a relativistic correction. For a particle moving at 0.710c we have

$$\gamma = \frac{1}{\sqrt{1-v^2/c^2}} = \frac{1}{\sqrt{1-(0.710)^2}} = 1.42,$$

so the true mass of the particle is $(9.43\times10^{-27}\,\text{kg})/(1.42) = 6.64\times10^{-27}$kg. The number of nucleons present in this particle is then $(6.64\times10^{-27}\text{kg})/(1.67\times10^{-27}\,\text{kg}) = 3.97 \approx 4$. The charge was +2, which implies two protons, the other two nucleons would be neutrons, so this must be an alpha particle.

E32-33 Only the $\hat{\rm j}$ component of $\vec{\rm B}$ is of interest. Then $F = \int dF = i\int B_y\,dx$, or

$$F = (5.0\,\text{A})(8\times10^{-3}\text{T/m}^2)\int_{1.2}^{3.2} x^2\,dx = 0.414\,\text{N}.$$

The direction is $-\hat{\rm k}$.

P32-1 Since $\vec{\rm F}$ must be perpendicular to $\vec{\rm B}$ then $\vec{\rm B}$ must be along $\hat{\rm k}$. The magnitude of v is $\sqrt{(40)^2+(35)^2}$ km/s = 53.1 km/s; the magnitude of F is $\sqrt{(-4.2)^2+(4.8)^2}$fN = 6.38 fN. Then

$$B = F/qv = (6.38\times10^{-15}\text{N})/(1.6\times10^{-19}\text{C})(53.1\times10^{3}\text{m/s}) = 0.75\,\text{T}.$$

or $\vec{\rm B} = 0.75\,\text{T}\,\hat{\rm k}$.

P32-7 (a) Start with the equation in Problem 6, and take the square root of both sides to get

$$\sqrt{m} = \left(\frac{B^2 q}{8\Delta V}\right)^{\frac{1}{2}} x,$$

and then take the derivative of x with respect to m,

$$\frac{1}{2}\frac{dm}{\sqrt{m}} = \left(\frac{B^2 q}{8\Delta V}\right)^{\frac{1}{2}} dx,$$

and then consider finite differences instead of differential quantities,

$$\Delta m = \left(\frac{mB^2 q}{2\Delta V}\right)^{\frac{1}{2}} \Delta x,$$

(b) Invert the above expression,

$$\Delta x = \left(\frac{2\Delta V}{mB^2 q}\right)^{\frac{1}{2}} \Delta m,$$

and then put in the given values,

$$\begin{aligned}\Delta x &= \left(\frac{2(7.33\times 10^3\text{V})}{(35.0)(1.66\times 10^{-27}\text{kg})(0.520\text{ T})^2(1.60\times 10^{-19}\text{C})}\right)^{\frac{1}{2}} (2.0)(1.66\times 10^{-27}\text{kg}),\\ &= 8.02\text{ mm}.\end{aligned}$$

Note that we used 35.0 u for the mass; if we had used 37.0 u the result would have been closer to the answer in the back of the book.

P32-17 The torque on a current carrying loop depends on the orientation of the loop; the maximum torque occurs when the plane of the loop is parallel to the magnetic field. In this case the magnitude of the torque is from Eq. 32-34 with $\sin\theta = 1$—

$$\tau = NiAB.$$

The area of a circular loop is $A = \pi r^2$ where r is the radius, but since the circumference is $C = 2\pi r$, we can write

$$A = \frac{C^2}{4\pi}.$$

The circumference is *not* the length of the wire, because there may be more than one turn. Instead, $C = L/N$, where N is the number of turns.

Finally, we can write the torque as

$$\tau = Ni\frac{L^2}{4\pi N^2}B = \frac{iL^2 B}{4\pi N},$$

which is a maximum when N is a minimum, or $N = 1$.

E33-3 $B = \mu_0 i/2\pi d = (4\pi\times10^{-7}\text{T}\cdot\text{m/A})(50\,\text{A})/2\pi(1.3\times10^{-3}\,\text{m}) = 37.7\times10^{-3}\text{T}$.

E33-9 For a single long straight wire, $B = \mu_0 i/2\pi d$ but we need a factor of "2" since there are two wires, then $i = \pi d B/\mu_0$. Finally

$$i = \frac{\pi d B}{\mu_0} = \frac{\pi(0.0405\,\text{m})(296,\mu\text{T})}{(4\pi\times10^{-7}\text{N/A}^2)} = 30\,\text{A}$$

E33-19 (a) We can use Eq. 33-21 to find the magnetic field strength at the center of the large loop,

$$B = \frac{\mu_0 i}{2R} = \frac{(4\pi\times10^{-7}\text{T}\cdot\text{m/A})(13\,\text{A})}{2(0.12\,\text{m})} = 6.8\times10^{-5}\text{T}.$$

(b) The torque on the smaller loop in the center is given by Eq. 32-34,

$$\vec{\tau} = Ni\vec{\mathbf{A}}\times\vec{\mathbf{B}},$$

but since the magnetic field from the large loop is perpendicular to the plane of the large loop, and the plane of the small loop is also perpendicular to the plane of the large loop, the magnetic field is in the plane of the small loop. This means that $|\vec{\mathbf{A}}\times\vec{\mathbf{B}}| = AB$. Consequently, the magnitude of the torque on the small loop is

$$\tau = NiAB = (50)(1.3\,\text{A})(\pi)(8.2\times10^{-3}\text{m})^2(6.8\times10^{-5}\text{T}) = 9.3\times10^{-7}\text{N}\cdot\text{m}.$$

E33-29 Let $u = z - d$. Then

$$\begin{aligned}
B &= \frac{\mu_0 n i R^2}{2}\int_{d-L/2}^{d+L/2}\frac{du}{[R^2+u^2]^{3/2}},\\
&= \frac{\mu_0 n i R^2}{2}\left.\frac{u}{R^2\sqrt{R^2+u^2}}\right|_{d-L/2}^{d+L/2},\\
&= \frac{\mu_0 n i}{2}\left(\frac{d+L/2}{\sqrt{R^2+(d+L/2)^2}} - \frac{d-L/2}{\sqrt{R^2+(d-L/2)^2}}\right).
\end{aligned}$$

If L is much, much greater than R and d then $|L/2 \pm d| >> R$, and R can be ignored in the denominator of the above expressions, which then simplify to

$$\begin{aligned}
B &= \frac{\mu_0 n i}{2}\left(\frac{d+L/2}{\sqrt{R^2+(d+L/2)^2}} - \frac{d-L/2}{\sqrt{R^2+(d-L/2)^2}}\right).\\
&= \frac{\mu_0 n i}{2}\left(\frac{d+L/2}{\sqrt{(d+L/2)^2}} - \frac{d-L/2}{\sqrt{(d-L/2)^2}}\right).\\
&= \mu_0 i n.
\end{aligned}$$

It *is* important that we consider the relative size of $L/2$ and d!

E33-31 (a) The path is clockwise, so a positive current is *into* page. The net current is 2.0 A out, so $\oint\vec{\mathbf{B}}\cdot d\vec{s} = -\mu_0 i_0 = -2.5\times10^{-6}\text{T}\cdot\text{m}$.

(b) The net current is zero, so $\oint\vec{\mathbf{B}}\cdot d\vec{s} = 0$.

E33-35 The magnitude of the magnetic field due to the cylinder will be *zero* at the center of the cylinder and $\mu_0 i_0/2\pi(2R)$ at point P. The magnitude of the magnetic field field due to the wire will be $\mu_0 i/2\pi(3R)$ at the center of the cylinder but $\mu_0 i/2\pi R$ at P. In order for the net field to have different directions in the two locations the currents in the wire and pipe must be in different direction. The net field at the center of the pipe is $\mu_0 i/2\pi(3R)$, while that at P is then $\mu_0 i_0/2\pi(2R) - \mu_0 i/2\pi R$. Set these equal and solve for i;

$$i/3 = i_0/2 - i,$$

or $i = 3i_0/8$.

P33-7 We want to use the differential expression in Eq. 33-11, except that the limits of integration are going to be different. We have four wire segments. From the top segment,

$$
\begin{aligned}
B_1 &= \frac{\mu_0 i}{4\pi} \frac{d}{\sqrt{z^2+d^2}}\Bigg|_{-L/4}^{3L/4}, \\
&= \frac{\mu_0 i}{4\pi d}\left(\frac{3L/4}{\sqrt{(3L/4)^2+d^2}} - \frac{-L/4}{\sqrt{(-L/4)^2+d^2}}\right).
\end{aligned}
$$

For the top segment $d = L/4$, so this simplifies even further to

$$B_1 = \frac{\mu_0 i}{10\pi L}\left(\sqrt{2}(3\sqrt{5}+5)\right).$$

The bottom segment has the same integral, but $d = 3L/4$, so

$$B_3 = \frac{\mu_0 i}{30\pi L}\left(\sqrt{2}(\sqrt{5}+5)\right).$$

By symmetry, the contribution from the right hand side is the same as the bottom, so $B_2 = B_3$, and the contribution from the left hand side is the same as that from the top, so $B_4 = B_1$. Adding all four terms,

$$
\begin{aligned}
B &= \frac{2\mu_0 i}{30\pi L}\left(3\sqrt{2}(3\sqrt{5}+5) + \sqrt{2}(\sqrt{5}+5)\right), \\
&= \frac{2\mu_0 i}{3\pi L}(2\sqrt{2}+\sqrt{10}).
\end{aligned}
$$

P33-9 $B = \mu_0 i n$ and $mv = qBr$. Combine, and

$$i = \frac{mv}{\mu_0 q r n} = \frac{(5.11\times10^5\,\mathrm{eV}/c^2)(0.046c)}{(4\pi\times10^{-7}\mathrm{N/A^2})e(0.023\,\mathrm{m})(10000/\mathrm{m})} = 0.271\,\mathrm{A}.$$

E35-1 If the Earth's magnetic dipole moment were produced by a single current around the core, then that current would be

$$i = \frac{\mu}{A} = \frac{(8.0 \times 10^{22}\,\mathrm{J/T})}{\pi(3.5 \times 10^{6}\mathrm{m})^2} = 2.1\times 10^{9}\,\mathrm{A}$$

E35-7 $\mu = iA = i\pi(a^2 + b^2/2) = i\pi(a^2 + b^2)/2.$

E35-13 The magnetic dipole moment is given by $\mu = MV$, Eq. 35-13. Then

$$\mu = (5,300\,\mathrm{A/m})(0.048\,\mathrm{m})\pi(0.0055\,\mathrm{m})^2 = 0.024\,\mathrm{A}\cdot\mathrm{m}^2.$$

E35-15 The energy to flip the dipoles is given by $U = 2\mu B$. The temperature is then

$$T = \frac{2\mu B}{3k/2} = \frac{4(1.2\times 10^{-23}\mathrm{J/T})(0.5\,\mathrm{T})}{3(1.38\times 10^{-23}\mathrm{J/K})} = 0.58\,\mathrm{K}.$$

E35-23 (a) We'll assume, however, that all of the iron atoms are perfectly aligned. Then the dipole moment of the earth will be related to the dipole moment of one atom by

$$\mu_{\mathrm{Earth}} = N\mu_{\mathrm{Fe}},$$

where N is the number of iron atoms in the magnetized sphere. If m_A is the relative atomic mass of iron, then the total mass is

$$m = \frac{N m_A}{A} = \frac{m_A}{A}\frac{\mu_{\mathrm{Earth}}}{\mu_{\mathrm{Fe}}},$$

where A is Avogadro's number. Next, the volume of a sphere of mass m is

$$V = \frac{m}{\rho} = \frac{m_A}{\rho A}\frac{\mu_{\mathrm{Earth}}}{\mu_{\mathrm{Fe}}},$$

where ρ is the density.

And finally, the radius of a sphere with this volume would be

$$r = \left(\frac{3V}{4\pi}\right)^{1/3} = \left(\frac{3\mu_{\mathrm{Earth}} m_A}{4\pi\rho\mu_{\mathrm{Fe}} A}\right)^{1/3}.$$

Now we find the radius by substituting in the known values,

$$r = \left(\frac{3(8.0\times 10^{22}\mathrm{J/T})(56\ \mathrm{g/mol})}{4\pi(14\times 10^{6}\mathrm{g/m^3})(2.1\times 10^{-23}\mathrm{J/T})(6.0\times 10^{23}/\mathrm{mol})}\right)^{1/3} = 1.8\times 10^{5}\mathrm{m}.$$

(b) The fractional volume is the cube of the fractional radius, so the answer is

$$(1.8\times 10^{5}\,\mathrm{m}/6.4\times 10^{6})^3 = 2.2\times 10^{-5}.$$

E35-27 Here $L_{\mathrm{m}} = 90^\circ - 11.5^\circ = 78.5^\circ$, so

$$B = \frac{\mu_0\mu}{4\pi r^3}\sqrt{1 + 3\sin^2 L_{\mathrm{m}}} = \frac{(1.00\times 10^{-7}\mathrm{N/A^2})(8.0\times 10^{22}\mathrm{J/T})}{(6.37\times 10^{6}\mathrm{m})^3}\sqrt{1+3\sin^2(78.5^\circ)} = 61\mu\mathrm{T}.$$

The inclination is given by

$$\arctan(B_{\mathrm{v}}/B_{\mathrm{h}}) = \arctan(2\tan L_{\mathrm{m}}) = 84^\circ.$$

P35-1 We can imagine the rotating disk as being composed of a number of rotating rings of radius r, width dr, and circumference $2\pi r$. The surface charge density on the disk is $\sigma = q/\pi R^2$, and consequently the (differential) charge on any ring is

$$dq = \sigma(2\pi r)(dr) = \frac{2qr}{R^2}dr$$

The rings "rotate" with angular frequency ω, or period $T = 2\pi/\omega$. The effective (differential) current for each ring is then

$$di = \frac{dq}{T} = \frac{qr\omega}{\pi R^2}dr.$$

Each ring contributes to the magnetic moment, and we can glue all of this together as

$$\begin{aligned}\mu &= \int d\mu,\\ &= \int \pi r^2\, di,\\ &= \int_0^R \frac{qr^3\omega}{R^2}dr,\\ &= \frac{qR^2\omega}{4}.\end{aligned}$$

P35-5 (b) Point the thumb or your right hand to the left. Your fingers curl in the direction of the current in the wire loop.

(c) In the vicinity of the wire of the loop $\vec{\mathbf{B}}$ has a component which is directed radially outward. Then $\vec{\mathbf{B}} \times d\vec{s}$ has a component directed to the right. Hence, the net force is directed to the right.

P35-9 (a) $B = \sqrt{{B_\mathrm{h}}^2 + {B_\mathrm{v}}^2}$, so

$$B = \frac{\mu_0\mu}{4\pi r^3}\sqrt{\cos^2 L_\mathrm{m} + 4\sin^2 L_\mathrm{m}} = \frac{\mu_0\mu}{4\pi r^3}\sqrt{1 + 3\sin^2 L_\mathrm{m}}.$$

(b) $\tan\phi_\mathrm{i} = B_\mathrm{v}/B_\mathrm{h} = 2\sin L_\mathrm{m}/\cos L_\mathrm{m} = 2\tan L_\mathrm{m}$.

E36-1 The important relationship is Eq. 36-4, written as

$$\Phi_B = \frac{iL}{N} = \frac{(5.0\,\text{mA})(8.0\,\text{mH})}{(400)} = 1.0\times 10^{-7}\text{Wb}$$

E36-9 (a) If two inductors are connected in parallel then the current through each inductor will add to the total current through the circuit, $i = i_1 + i_2$, Take the derivative of the current with respect to time and then $di/dt = di_1/dt + di_2/dt$,

The potential difference across each inductor is the same, so if we divide by $\mathcal{E}$ and apply we get

$$\frac{di/dt}{\mathcal{E}} = \frac{di_1/dt}{\mathcal{E}} + \frac{di_2/dt}{\mathcal{E}},$$

But

$$\frac{di/dt}{\mathcal{E}} = \frac{1}{L},$$

so the previous expression can also be written as

$$\frac{1}{L_{\text{eq}}} = \frac{1}{L_1} + \frac{1}{L_2}.$$

(b) If the inductors are close enough together then the magnetic field from one coil will induce currents in the other coil. Then we will need to consider mutual induction effects, but that is a topic not covered in this text.

E36-11 Use Eq. 36-17, but rearrange:

$$\tau_L = \frac{t}{\ln[i_0/i]} = \frac{(1.50\,\text{s})}{\ln[(1.16\,\text{A})/(10.2\times 10^{-3}\text{A})]} = 0.317\,\text{s}.$$

Then $R = L/\tau_L = (9.44\,\text{H})/(0.317\,\text{s}) = 29.8\,\Omega$.

E36-19 (a) When the switch is just closed there is *no* current through the inductor. So $i_1 = i_2$ is given by

$$i_1 = \frac{\mathcal{E}}{R_1 + R_2} = \frac{(100\,\text{V})}{(10\,\Omega) + (20\,\Omega)} = 3.33\,\text{A}.$$

(b) A long time later there is current through the inductor, but it is as if the inductor has no effect on the circuit. Then the effective resistance of the circuit is found by first finding the equivalent resistance of the parallel part

$$1/(30\,\Omega) + 1/(20\,\Omega) = 1/(12\,\Omega),$$

and then finding the equivalent resistance of the circuit

$$(10\,\Omega) + (12\,\Omega) = 22\,\Omega.$$

Finally, $i_1 = (100\,\text{V})/(22\,\Omega) = 4.55\,\text{A}$ and

$$\Delta V_2 = (100\,\text{V}) - (4.55\,\text{A})(10\,\Omega) = 54.5\,\text{V};$$

consequently, $i_2 = (54.5\,\text{V})/(20\,\Omega) = 2.73\,\text{A}$. It didn't ask, but $i_2 = (4.55\,\text{A}) - (2.73\,\text{A}) = 1.82\,\text{A}$.

(c) After the switch is just opened the current through the battery stops, while that through the inductor continues on. Then $i_2 = i_3 = 1.82\,\text{A}$.

(d) All go to zero.

E36-27 The energy density of an electric field is given by Eq. 36-23; that of a magnetic field is given by Eq. 36-22. Equating,

$$\frac{\epsilon_0}{2}E^2 = \frac{1}{2\mu_0}B^2,$$

$$E = \frac{B}{\sqrt{\epsilon_0\mu_0}}.$$

The answer is then

$$E = (0.50\,\text{T})/\sqrt{(8.85\times 10^{-12}\text{C}^2/\text{N}\cdot\text{m}^2)(4\pi\times 10^{-7}\text{N/A}^2)} = 1.5\times 10^8\,\text{V/m}.$$

E36-31 This shell has a volume of

$$V = \frac{4\pi}{3}\left((R_\mathrm{E}+a)^3 - {R_\mathrm{E}}^3\right).$$

Since $a << R_\mathrm{E}$ we can expand the polynomials but keep only the terms which are linear in a. Then

$$V \approx 4\pi {R_\mathrm{E}}^2 a = 4\pi(6.37\times10^6\mathrm{m})^2(1.6\times10^4\mathrm{m}) = 8.2\times10^{18}\mathrm{m}^3.$$

The magnetic energy density is found from Eq. 36-22,

$$u_B = \frac{1}{2\mu_0}B^2 = \frac{(60\times10^{-6}\,\mathrm{T})^2}{2(4\pi\times10^{-7}\mathrm{N/A}^2)} = 1.43\times10^{-3}\mathrm{J/m}^3.$$

The total energy is then $(1.43\times10^{-3}\mathrm{J/m}^3)(8.2eex18\mathrm{m}^3) = 1.2\times10^{16}\mathrm{J}$.

E36-39 (a) $k = (8.13\,\mathrm{N})/(0.0021\,\mathrm{m}) = 3.87\times10^3\mathrm{N/m}$. $\omega = \sqrt{k/m} = \sqrt{(3870\,\mathrm{N/m})/(0.485\,\mathrm{kg})} =$ 89.3 rad/s.

(b) $T = 2\pi/\omega = 2\pi/(89.3\ \mathrm{rad/s}) = 7.03\times10^{-2}\mathrm{s}$.

(c) $LC = 1/\omega^2$, so

$$C = 1/(89.3\ \mathrm{rad/s})^2(5.20\,\mathrm{H}) = 2.41\times10^{-5}\mathrm{F}.$$

E36-41 (a) An LC circuit oscillates so that the energy is converted from all magnetic to all electrical *twice* each cycle. It occurs twice because once the energy is magnetic with the current flowing in one direction through the inductor, and later the energy is magnetic with the current flowing the other direction through the inductor.

The period is then *four* times 1.52μs, or 6.08μs.

(b) The frequency is the reciprocal of the period, or 164000 Hz.

(c) Since it occurs twice during each oscillation it is equal to half a period, or 3.04μs.

E36-49 (a) The frequency of such a system is given by Eq. 36-26, $f = 1/2\pi\sqrt{LC}$. Note that maximum frequency occurs with minimum capacitance. Then

$$\frac{f_1}{f_2} = \sqrt{\frac{C_2}{C_1}} = \sqrt{\frac{(365\ \mathrm{pF})}{(10\ \mathrm{pF})}} = 6.04.$$

(b) The desired ratio is $1.60/0.54 = 2.96$ Adding a capacitor in parallel will result in an effective capacitance given by

$$C_{1,\mathrm{eff}} = C_1 + C_\mathrm{add},$$

with a similar expression for C_2. We want to choose C_add so that

$$\frac{f_1}{f_2} = \sqrt{\frac{C_{2,\mathrm{eff}}}{C_{1,\mathrm{eff}}}} = 2.96.$$

Solving,

$$\begin{aligned} C_{2,\mathrm{eff}} &= C_{1,\mathrm{eff}}(2.96)^2, \\ C_2 + C_\mathrm{add} &= (C_1 + C_\mathrm{add})8.76, \\ C_\mathrm{add} &= \frac{C_2 - 8.76C_1}{7.76}, \\ &= \frac{(365\ \mathrm{pF}) - 8.76(10\ \mathrm{pF})}{7.76} = 36\ \mathrm{pF}. \end{aligned}$$

The necessary inductance is then

$$L = \frac{1}{4\pi^2 f^2 C} = \frac{1}{4\pi^2(0.54\times10^6\mathrm{Hz})^2(401\times10^{-12}\mathrm{F})} = 2.2\times10^{-4}\mathrm{H}.$$

P36-3 Choose the y axis so that it is parallel to the wires and directly between them. The field in the plane between the wires is

$$B = \frac{\mu_0 i}{2\pi}\left(\frac{1}{d/2+x} + \frac{1}{d/2-x}\right).$$

The flux per length l of the wires is

$$\begin{aligned}
\Phi_B &= l\int_{-d/2+a}^{d/2-a} B\,dx = l\frac{\mu_0 i}{2\pi}\int_{-d/2+a}^{d/2-a}\left(\frac{1}{d/2+x} + \frac{1}{d/2-x}\right)dx, \\
&= 2l\frac{\mu_0 i}{2\pi}\int_{-d/2+a}^{d/2-a}\left(\frac{1}{d/2+x}\right)dx, \\
&= 2l\frac{\mu_0 i}{2\pi}\ln\frac{d-a}{a}.
\end{aligned}$$

The inductance is then

$$L = \frac{\phi_B}{i} = \frac{\mu_0 l}{\pi}\ln\frac{d-a}{a}.$$

P36-11 (a) In Chapter 33 we found the magnetic field inside a wire carrying a uniform current density is

$$B = \frac{\mu_0 i r}{2\pi R^2}.$$

The magnetic energy density in this wire is

$$u_B = \frac{1}{2\mu_0}B^2 = \frac{\mu_0 i^2 r^2}{8\pi^2 R^4}.$$

We want to integrate in cylindrical coordinates over the volume of the wire. Then the volume element is $dV = (dr)(r\,d\theta)(dz)$, so

$$\begin{aligned}
U_B &= \int u_B dV, \\
&= \int_0^R\int_0^l\int_0^{2\pi}\frac{\mu_0 i^2 r^2}{8\pi^2 R^4}d\theta\,dz\,r dr, \\
&= \frac{\mu_0 i^2 l}{4\pi R^4}\int_0^R r^3\,dr, \\
&= \frac{\mu_0 i^2 l}{16\pi}.
\end{aligned}$$

(b) Solve

$$U_B = \frac{L}{2}i^2$$

for L, and

$$L = \frac{2U_B}{i^2} = \frac{\mu_0 l}{8\pi}.$$

P36-15 We start by focusing on the charge on the capacitor, given by Eq. 36-40 as

$$q = q_{\rm m} e^{-Rt/2L} \cos(\omega' t + \phi).$$

After one oscillation the cosine term has returned to the original value but the exponential term has attenuated the charge on the capacitor according to

$$q = q_{\rm m} e^{-RT/2L},$$

where T is the period. The fractional energy loss on the capacitor is then

$$\frac{U_0 - U}{U_0} = 1 - \frac{q^2}{q_m^2} = 1 - e^{-RT/L}.$$

For small enough damping we can expand the exponent. Not only that, but $T = 2\pi/\omega$, so

$$\frac{\Delta U}{U} \approx 2\pi R/\omega L.$$

E38-9 The magnitude of E is given by

$$E = \frac{(162\,\mathrm{V})}{(4.8\times 10^{-3}\mathrm{m})} \sin 2\pi(60/\mathrm{s})t;$$

Using the results from Sample Problem 38-1,

$$\begin{aligned} B_\mathrm{m} &= \left.\frac{\mu_0\epsilon_0 R}{2}\frac{dE}{dt}\right|_{t=0}, \\ &= \frac{(4\pi\times 10^{-7}\mathrm{H/m})(8.85\times 10^{-12}\mathrm{F/m})(0.0321\,\mathrm{m})}{2} 2\pi(60/\mathrm{s})\frac{(162\,\mathrm{V})}{(4.8\times 10^{-3}\mathrm{m})}, \\ &= 2.27\times 10^{-12}\mathrm{T}. \end{aligned}$$

E38-11 (a) Consider the path $abefa$. The closed line integral consists of *two* parts: $b \to e$ and $e \to f \to a \to b$. Then

$$\oint \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = -\frac{d\Phi}{dt}$$

can be written as

$$\int_{b\to e} \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} + \int_{e\to f\to a\to b} \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = -\frac{d}{dt}\Phi_{abef}.$$

Now consider the path $bcdeb$. The closed line integral consists of *two* parts: $b \to c \to d \to e$ and $e \to b$. Then

$$\oint \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = -\frac{d\Phi}{dt}$$

can be written as

$$\int_{b\to c\to d\to e} \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} + \int_{e\to b} \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = -\frac{d}{dt}\Phi_{bcde}.$$

These two expressions can be added together, and since

$$\int_{e\to b} \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = -\int_{b\to e} \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}}$$

we get

$$\int_{e\to f\to a\to b} \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} + \int_{b\to c\to d\to e} \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = -\frac{d}{dt}\left(\Phi_{abef} + \Phi_{bcde}\right).$$

The left hand side of this is just the line integral over the closed path $efadcde$; the right hand side is the net change in flux through the two surfaces. Then we can simplify this expression as

$$\oint \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = -\frac{d\Phi}{dt}.$$

(b) Do everything above again, except substitute B for E.

(c) If the equations were not self consistent we would arrive at different values of E and B depending on how we defined our surfaces. This multi-valued result would be quite unphysical.

E38-25 $I = P/4\pi r^2$, so

$$r = \sqrt{P/4\pi I} = \sqrt{(1.0\times 10^3\mathrm{W})/4\pi(130\,\mathrm{W/m^2})} = 0.78\,\mathrm{m}.$$

E38-31 (a) The electric field amplitude is related to the intensity by Eq. 38-26,

$$I = \frac{E_{\rm m}^2}{2\mu_0 c},$$

or

$$E_{\rm m} = \sqrt{2\mu_0 cI} = \sqrt{2(4\pi\times10^{-7}\text{H/m})(3.00\times10^{8}\text{m/s})(7.83\mu\text{W/m}^2)} = 7.68\times10^{-2}\,\text{V/m}.$$

(b) The magnetic field amplitude is given by

$$B_{\rm m} = \frac{E_{\rm m}}{c} = \frac{(7.68\times10^{-2}\,\text{V/m})}{(3.00\times10^{8}\text{m/s})} = 2.56\times10^{-10}\,\text{T}$$

(c) The power radiated by the transmitter can be found from Eq. 38-28,

$$P = 4\pi r^2 I = 4\pi(11.3\text{ km})^2(7.83\mu\text{W/m}^2) = 12.6\text{ kW}.$$

E38-37 (a) $F = IA/c$, so

$$F = \frac{(1.38\times10^{3}\text{W/m}^2)\pi(6.37\times10^{6}\text{m})^2}{(3.00\times10^{8}\text{m/s})} = 5.86\times10^{8}\text{N}.$$

P38-5 (a) $\vec{\mathbf{E}} = E\hat{\mathbf{j}}$ and $\vec{\mathbf{B}} = B\hat{\mathbf{k}}$. Then $\vec{\mathbf{S}} = \vec{\mathbf{E}}\times\vec{\mathbf{B}}/\mu_0$, or

$$\vec{\mathbf{S}} = -EB/mu_0\,\hat{\mathbf{i}}.$$

Energy only passes through the yz faces; it goes in one face and out the other. The rate is $P = SA = EBa^2/mu_0$.

(b) The net change is zero.

P38-9 Eq. 38-14 requires

$$\begin{aligned}\frac{\partial E}{\partial x} &= -\frac{\partial B}{\partial t},\\ E_{\rm m}k\cos kx\sin\omega t &= B_{\rm m}\omega\cos kx\sin\omega t,\\ E_{\rm m}k &= B_{\rm m}\omega.\end{aligned}$$

Eq. 38-17 requires

$$\begin{aligned}\mu_0\epsilon_0\frac{\partial E}{\partial t} &= -\frac{\partial B}{\partial x},\\ \mu_0\epsilon_0 E_{\rm m}\omega\sin kx\cos\omega t &= B_{\rm m}k\sin kx\cos\omega t,\\ \mu_0\epsilon_0 E_{\rm m}\omega &= B_{\rm m}k.\end{aligned}$$

Dividing one expression by the other,

$$\mu_0\epsilon_0 k^2 = \omega^2,$$

or

$$\frac{\omega}{k} = c = \frac{1}{\sqrt{\mu_0\epsilon_0}}$$

.

Not only that, but $E_{\rm m} = cB_{\rm m}$. You've seen an expression similar to this before, and you'll see expressions similar to it again.

(b) We'll assume that Eq. 38-21 is applicable here. Then

$$\begin{aligned} S &= \frac{1}{\mu_0} = \frac{E_{\rm m}B_{\rm m}}{\mu_0}\sin kx \sin \omega t \cos kx \cos \omega t, \\ &= \frac{E_{\rm m}^2}{4\mu_0 c}\sin 2kx \sin 2\omega t \end{aligned}$$

is the magnitude of the instantaneous Poynting vector.

(c) The time averaged power flow across any surface is the value of

$$\frac{1}{T}\int_0^T \int \vec{\mathbf{S}} \cdot d\vec{\mathbf{A}}\, dt,$$

where T is the period of the oscillation. We'll just gloss over any concerns about direction, and assume that the $\vec{\mathbf{S}}$ will be constant in direction so that we will, at most, need to concern ourselves about a constant factor $\cos\theta$. We can then deal with a scalar, instead of vector, integral, and we can integrate it in any order we want. We want to do the t integration first, because an integral over $\sin\omega t$ for a period $T = 2\pi/\omega$ is zero. Then we are done!

(d) There is no energy flow; the energy remains inside the container.

P38-15 (a) $I = P/A = (5.00\times10^{-3}\mathrm{W})/\pi(1.05)^2(633\times10^{-9}\mathrm{m})^2 = 3.6\times10^9\mathrm{W/m^2}$.

(b) $p = I/c = (3.6\times10^9\mathrm{W/m^2})/(3.00\times10^8\mathrm{m/s}) = 12\,\mathrm{Pa}$

(c) $F = pA = P/c = (5.00\times10^{-3}\mathrm{W})/(3.00\times10^8\mathrm{m/s}) = 1.67\times10^{-11}\mathrm{N}$.

(d) $a = F/m = F/\rho V$, so

$$a = \frac{(1.67\times10^{-11}\mathrm{N})}{4(4880\,\mathrm{kg/m^3})(1.05)^3(633\times10^{-9})^3/3} = 2.9\times10^3\mathrm{m/s^2}.$$