35.56: a) There is one half-cycle phase shift, so for constructive interference:

$$2t = \left(m + \frac{1}{2}\right)\frac{\lambda_0}{n} \Rightarrow \lambda = \frac{2tn}{(m+\frac{1}{2})} = \frac{2(380\text{ nm})\,(1.45)}{(m+\frac{1}{2})} = \frac{1102\text{ nm}}{(m+\frac{1}{2})}.$$

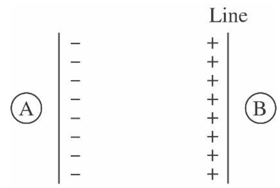
Therefore, we have constructive interference at $\lambda = 441\,\text{nm}\ (m = 2),$ which corresponds to blue-violet.

b) Beneath the water, looking for maximum intensity means that the reflected part of the wave at the wavelength must be weak, or have interfered destructively. So:

$$2t = \frac{m\lambda_0}{n} \Rightarrow \lambda_0 = \frac{2tn}{m} = \frac{2(380\text{ nm})\,(1.45)}{m} = \frac{1102\text{ nm}}{m}.$$

Therefore, the strongest transmitted wavelength (as measured in air) is $\lambda = 551\text{ nm}\ (m = 2),$ which corresponds to green.

22.34:



The α particle feels no force where the net electric field is zero. The fields can cancel only in regions A and B.

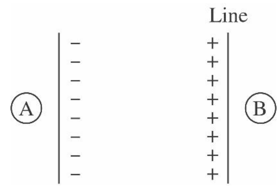
$$E_{line} = E_{sheet}$$

$$\frac{\lambda}{2\pi\varepsilon_0 r} = \frac{\sigma}{2\varepsilon_0}$$

$$r = \lambda/\pi\sigma = \frac{50\ \mu\text{C/m}}{\pi(100\ \mu\text{C/m}^2)} = 0.16\text{m} = 16\text{cm}$$

The fields cancel 16 cm from the line in regions A *and* B.

22.34:



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The fields cancel 16 cm from the line in regions A *and* B.

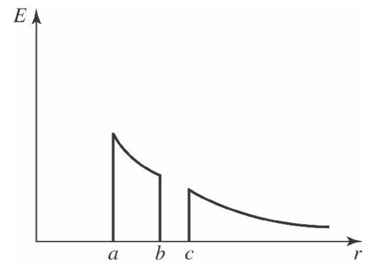
22.36: a) For $r < a$, $E = 0$, since no charge is enclosed.

For $a < r < b$, $E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$, since there is $+q$ inside a radius r.

For $b < r < c$, $E = 0$, since now the $-q$ cancels the inner $+q$.

For $r > c$, $E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$, since again the total charge enclosed is $+q$.

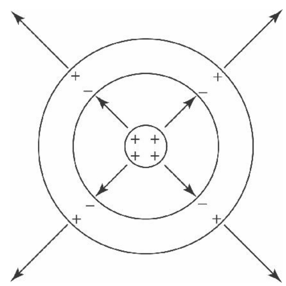
b)



c) Charge on inner shell surface is $-q$.

d) Charge on outer shell surface is $+q$.

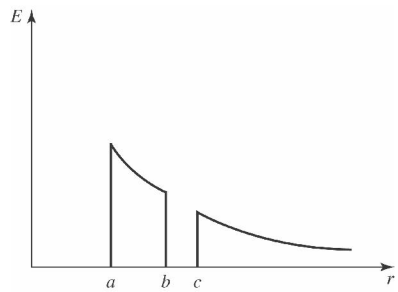
e)



22.45: a) $a < r < b,\ E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{2\lambda}{r},$ radially outward, as in **22.48 (b)**.

b) $r > c,\ E = \frac{1}{4\pi\varepsilon_0}\frac{2\lambda}{r},$ radially outward, since again the charge enclosed is the same as in part (a).

c)

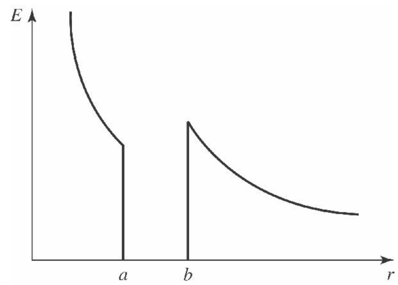


d) The inner and outer surfaces of the outer cylinder must have the same amount of charge on them: $\lambda l = -\lambda_{\text{inner}} l \Rightarrow \lambda_{\text{inner}} = -\lambda$, and $\lambda_{\text{outer}} = \lambda$.

22.46: a) (i) $r < a,\ E(2\pi rl) = \dfrac{q}{\varepsilon_0} = \dfrac{\alpha l}{\varepsilon_0} \Rightarrow E = \dfrac{\alpha}{2\pi\varepsilon_0 r}.$

(ii) $a < r < b,$ there is no net charge enclosed, so the electric field is zero.

(iii) $r > b,\ E(2\pi rl) = \dfrac{q}{\varepsilon_0} = \dfrac{2\alpha l}{\varepsilon_0} \Rightarrow E = \dfrac{\alpha}{\pi\varepsilon_0 r}.$

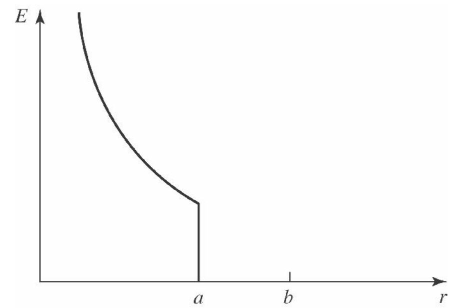


b) (i) Inner charge per unit length is $-\alpha$. (ii) Outer charge per length is $+2\alpha$.

22.47: a) (i) $r < a,\ E(2\pi rl) = \frac{q}{\varepsilon_0} = \frac{\alpha l}{\varepsilon_0} \Rightarrow E = \frac{\alpha}{2\pi\varepsilon_0 r}$, radially outward.

(ii) $a < r < b,$ there is not net charge enclosed, so the electric field is zero.

(iii) $r > b,$ there is no net charge enclosed, so the electric field is zero.



b) (i) Inner charge per unit length is $-\alpha$.

(ii) Outer charge per length is ZERO.

23.18: Initial energy equals final energy:

$$E_i = E_f \Rightarrow -\frac{keq_1}{r_{1i}} - \frac{keq_2}{r_{2i}} = -\frac{keq_1}{r_{1f}} - \frac{keq_2}{r_{2f}} + \frac{1}{2} m_e v_f{}^2$$

$$E_i = k(-1.60\times10^{-19}\ \text{C})\left(\frac{(3.00\times10^{-9}\ \text{C})}{0.25\ \text{m}} + \frac{(2.00\times10^{-9}\ \text{C})}{0.25\ \text{m}}\right) = -2.88\times10^{-17}\ \text{J}$$

$$E_f = k(-1.60\times10^{-19}\ \text{C})\left(\frac{(3.00\times10^{-9}\ \text{C})}{0.10\ \text{m}} + \frac{(2.00\times10^{-9}\ \text{C}}{0.40\ \text{m}}\right) + \frac{1}{2} m_e v_f^2$$

$$= -5.04\times10^{-17}\ \text{J} + \frac{1}{2} m_e v_f{}^2$$

$$\Rightarrow v_f = \sqrt{\frac{2}{9.11\times10^{-31}\ \text{kg}}(5.04\times10^{-17}\ \text{J} - 2.88\times10^{-17}\ \text{J})}$$

$$= 6.89\times10^{6}\ \text{m/s}.$$

23.56: $F_e = mg\ \tan\theta = (1.50\times10^{-3}\ \text{kg})\ (9.80\ \text{m/s}^2)\ \tan\ (30°) = 0.0085\ \text{N}$. (Balance forces in x and y directions.) But also:

$$F_e = Eq = \frac{Vq}{d} \Rightarrow V = \frac{Fd}{q} = \frac{(0.0085\ \text{N})\ (0.0500\ \text{m})}{8.90\times10^{-6}\ \text{C}} = 47.8\ \text{V}.$$

23.57: a) (i) $V = \dfrac{\lambda}{2\pi\varepsilon_0}(\ln(b/a) - \ln(b/b)) = \dfrac{\lambda}{2\pi\varepsilon_0}\ln(b/a).$

(ii) $V = \dfrac{\lambda}{2\pi\varepsilon_0}(\ln(b/r) - \ln(b/b)) = \dfrac{\lambda}{2\pi\varepsilon_0}\ln(b/r)\,.$

(iii) $V = 0.$

b) $V_{ab} = V\,(a) - V(b) = \dfrac{\lambda}{2\pi\varepsilon_0}\ln(b/a).$

c) Between the cylinders:

$$V = \frac{\lambda}{2\pi\varepsilon_0}\ln(b/r) = \frac{V_{ab}}{\ln(b/a)}\ln(b/r)$$

$$\therefore E = -\frac{\partial V}{\partial r} = -\frac{V_{ab}}{\ln(b/a)}\frac{\partial}{\partial r}(\ln(b/r)) = \frac{V_{ab}}{\ln(b/a)}\frac{1}{r}.$$

d) The potential difference between the two cylinders is identical to that in part (b) even if the outer cylinder has no charge.

23.58: Using the results of Problem 23.57, we can calculate the potential difference:

$$E = \frac{V_{ab}}{\ln(b/a)} \frac{1}{r} \Rightarrow V_{ab} = E \ln(b/a) r$$

$$\Rightarrow V_{ab} = (2.00 \times 10^{4}\ \mathrm{N/C})\ (\ln (0.018\ \mathrm{m}/145 \times 10^{-6}\ \mathrm{m}))\ 0.012\ \mathrm{m} = 1157\ \mathrm{V}.$$

23.59: a) $F = Eq = (1.10\times10^{3}\ \text{V/m})\ (1.60\times10^{-19}\ \text{C}) = 1.76\times10^{-16}\ \text{N}$, downward.

b) $a = F/m_e = (1.76\times10^{-16}\ \text{N})/(9.11\times10^{-31}\ \text{kg}) = 1.93\times10^{14}\ \text{m/s}^2$, downward.

c) $t = \dfrac{0.060\ \text{m}}{6.50\times10^{6}\ \text{m/s}} = 9.23\times10^{-9}\ \text{s}$, $y - y_0 = \dfrac{1}{2}at^2 = \dfrac{1}{2}(1.93\times10^{14}\ \text{m/s}^2)\ (9.23\times10^{-9}\ \text{s})^2$

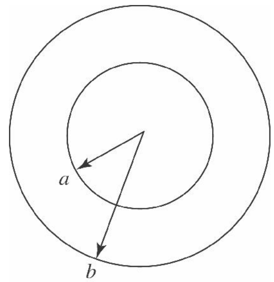
$= 8.22\times10^{-3}\ \text{m}$.

d) Angle $\theta = \arctan(v_y/v_x) = \arctan(at/v_x) = \arctan(1.78/6.50) = 15.3°$.

e) The distance below center of the screen is:

$$D = d_y + v_y t = 8.22\times10^{-3}\ \text{m} + (1.78\times10^{6}\ \text{m/s})\ \frac{0.120\ \text{m}}{6.50\times10^{6}\ \text{m/s}} = 0.0411\ \text{m}.$$

23.60:



(a) Use ΔV_{ab} to get $\lambda : \Delta V = \int_a^b E \cdot dl = \int_a^b \frac{\lambda}{2\pi\varepsilon_0} dr = \frac{\lambda}{2\pi\varepsilon_0} \ln \frac{b}{a}$

$$\lambda = \frac{2\pi\varepsilon_0 \Delta V}{\ln b/a}$$

$$E = \frac{\lambda}{2\pi\varepsilon_0 r} = \frac{2\pi\varepsilon_0 \Delta V / \ln b/a}{2\pi\varepsilon_0 r} = \frac{\Delta V}{r \ln b/a}$$

at outer surface of the wire, $r = a = \frac{0.127 \text{ mm}}{2}$

$$E = \frac{850 \text{ V}}{\left(\frac{0.000127 \text{ m}}{2}\right) \ln \left[\frac{1.00 \text{ cm}}{\left(\frac{0.0127 \text{ cm}}{2}\right)}\right]} = 2.65 \times 10^6 \text{ V/m}$$

(b) at the inner surface of the cylinder, $r = 1.00$ cm, which gives

$$E = 1.68 \times 10^4 \text{ V/m}$$

23.76: a) At $r = c : V = -\int_{\infty}^{c} \frac{kq}{r^2} dr = \frac{kq}{c}$.

b) At $r = b : V = -\int_{\infty}^{c} \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{r}} - \int_{c}^{b} \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{r}} = \frac{kq}{c} - 0 = \frac{kq}{c}$.

c) At $r = a : V = -\int_{\infty}^{c} \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{r}} - \int_{c}^{b} \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{r}} - \int_{b}^{a} \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{r}} = \frac{kq}{c} - kq \int_{b}^{a} \frac{dr}{r^2} = kq\left[\frac{1}{c} - \frac{1}{b} + \frac{1}{a}\right]$.

d) At $r = 0 : V = kq\left[\frac{1}{c} - \frac{1}{b} + \frac{1}{a}\right]$ since it is inside a metal sphere, and thus at the same potential as its surface.

24.9: a) $\dfrac{C}{L} = \dfrac{2\pi\varepsilon_0}{\ln(r_b/r_a)}$

$$C = \frac{(0.180\text{ m})2\pi\varepsilon_0}{\ln(5.00/0.50)} = 4.35\times10^{-12}\text{ F}$$

b) $V = Q/C = (10.0\times10^{-12}\text{ C})/(4.35\times10^{-12}\text{ F}) = 2.30\text{ V}$

24.13: a) $C = \frac{1}{k}\left(\frac{r_b r_a}{r_b - r_a}\right) = \frac{1}{k}\left(\frac{(0.148\text{ m})(0.125\text{ m})}{0.148\text{ m} - 0.125\text{ m}}\right) = 8.94 \times 10^{-11}\text{ F}.$

b) The electric field at a distance of 12.6 cm:

$$E = \frac{kQ}{r^2} = \frac{kCV}{r^2} = \frac{k(8.94\times 10^{-11}\text{ F})(120\text{ V})}{(0.126\text{ m})^2} = 6082\text{ N/C}.$$

c) The electric field at a distance of 14.7 cm:

$$E = \frac{kQ}{r^2} = \frac{kCV}{r^2} = \frac{k(8.94\times 10^{-11}\text{ F})(120\text{ V})}{(0.147\text{ m})^2} = 4468\text{ N/C}.$$

d) For a spherical capacitor, the electric field is not constant between the surfaces.

24.40: a) $E_0 = KE = (3.60)(1.20\times10^6 \text{ V/m}) = 4.32\times10^6 \text{ V/m} \Rightarrow \sigma = \varepsilon_0 E_0 =$ $3.82\times10^{-5} \text{ C/m}^2.$

b) $\sigma_i = \sigma\left(1-\dfrac{1}{K}\right) = (3.82\times10^{-5} \text{ C/m}^2)(1-1/3.60) = 2.76\times10^{-5} \text{ C/m}^2.$

c) $U = \frac{1}{2}CV^2 = uAd = \frac{1}{2}K\varepsilon_0 E^2 Ad$

$\Rightarrow U = \frac{1}{2}(3.60)\varepsilon_0(1.20\times10^6 \text{ V/m})^2(0.0018 \text{ m})(2.5\times10^{-4} \text{ m}^2) = 1.03\times10^{-5} \text{ J.}$

24.44: a) $\Delta Q = Q - Q_0 = (K-1)Q_0 = (K-1)C_0V_0 = (2.1)(2.5\times10^{-7}\ \text{F})(12\ \text{V}) =$ 6.3×10^{-6} C.

b) $Q_i = Q\left(1-\frac{1}{K}\right) = (9.3\times10^{-6}\ \text{C})(1-1/3.1) = 6.3\times10^{-6}$ C.

c) The addition of the mylar doesn't affect the electric field since the induced charge cancels the additional charge drawn to the plates.

25.76: a) $R_{steel} = \dfrac{\rho L}{A} = \dfrac{(2.0\times10^{-7}\,\Omega\cdot\text{m})\,(2.0\text{ m})}{(\pi/4)\,(0.018\text{ m})^2} = 1.57\times10^{-3}\ \Omega$

$$R_{Cu} = \frac{\rho L}{A} = \frac{(1.72\times10^{-8}\ \Omega\cdot\text{m})\,(35\text{ m})}{(\pi/4)\,(0.008\text{ m})^2} = 0.012\ \Omega$$

$$\Rightarrow V = IR = I\,(R_{steel} + R_{Cu}) = (15000\text{ A})\,(1.57\times10^{-3}\ \Omega + 0.012\ \Omega) = 204\text{ V}.$$

b) $E = Pt = I^2Rt = (15000\text{ A})^2\,(0.0136\,\Omega)\,(65\times10^{-6}\ \text{s}) = 199\text{ J}.$

26.69: a) When the switch is open, only the outer resistances have current through them. So the equivalent resistance of them is:

$$R_{\text{eq}} = \left(\frac{1}{6\ \Omega + 3\ \Omega} + \frac{1}{3\ \Omega + 6\ \Omega} \right)^{-1} = 4.50\ \Omega \Rightarrow I = \frac{V}{R_{\text{eq}}} = \frac{36.0\ \text{V}}{4.50\ \Omega} = 8.00\ \text{A}$$

$$\Rightarrow V_{ab} = \left(\frac{1}{2} 8.00\ \text{A} \right) (3.00\ \Omega) - \left(\frac{1}{2} 8.00\ \text{A} \right) (6.00\ \Omega) = -12.0\ \text{V}.$$

b) If the switch is closed, the circuit geometry and resistance ratios become identical to that of Problem 26.60 and the same analysis can be carried out. However, we can also use symmetry to infer the following:

$I_{6\Omega} = \frac{2}{3} I_{3\Omega}$, and $I_{\text{switch}} = \frac{1}{3} I_{3\Omega}$. From the left loop as in Problem 26.60:

$$36\ \text{V} - \left(\frac{2}{3} I_{3\Omega} \right) (6\ \Omega) - I_{3\Omega} (3\ \Omega) = 0 \Rightarrow I_{3\Omega} = 5.14\ \text{A} \Rightarrow I_{\text{switch}} = \frac{1}{3} I_{3\Omega} = 1.71\ \text{A}.$$

$$\text{(c)}\quad I_{\text{battery}} = \frac{2}{3} I_{3\Omega} + I_{3\Omega} = \frac{5}{3} I_{3\Omega} = 8.57\ \text{A} \Rightarrow R_{\text{eq}} \frac{\varepsilon}{I_{\text{battery}}} = \frac{36.0\ \text{V}}{8.57\ \text{A}} = 4.20\ \Omega.$$

26.70: a) With an open switch: $V_{ab} = \varepsilon = 18.0\ \text{V},$ since equilibrium has been reached.

b) Point "a" is at a higher potential since it is directly connected to the positive terminal of the battery.

c) When the switch is closed:

$$18.0\ \text{V} = I(6.00\ \Omega + 3.00\ \Omega) \Rightarrow I = 2.00\ \text{A} \Rightarrow V_b = (2.00\ \text{A})(3.00\ \Omega) = 6.00\ \text{V}.$$

d) Initially the capacitor's charges were:

$$Q_3 = CV = (3.00\times10^{-6}\ \text{F})(18.0\ \text{V}) = 5.40\times10^{-5}\ \text{C}.$$

$$Q_6 = CV = (6.00\times10^{-6}\ \text{F})(18.0\ \text{V}) = 1.08\times10^{-4}\ \text{C}.$$

After the switch is closed:

$$Q_3 = CV = (3.00\times10^{-6}\ \text{F})(18.0\ \text{V} - 12.0\ \text{V}) = 1.80\times10^{-5}\ \text{C}.$$

$$Q_6 = CV = (6.00\times10^{-6}\ \text{F})(18.0\ \text{V} - 6.0\ \text{V}) = 7.20\times10^{-5}\ \text{C}.$$

So both capacitors lose $3.60\times10^{-5}\ \text{C}.$

26.82: For a charged capacitor, connected into a circuit:

$$I_0 = \frac{Q_0}{RC} \Rightarrow Q_0 = I_0 RC = (0.620\ \text{A})(5.88\ \text{k}\Omega)(8.55\times10^{-10}\ \text{F}) = 3.12\times10^{-6}\ \text{C}.$$

26.83: $\varepsilon = I_0 R \Rightarrow R = \dfrac{\varepsilon}{I_0} = \dfrac{110 \text{ V}}{6.5 \times 10^{-5} \text{ A}} = 1.69 \times 10^{6} \ \Omega \Rightarrow$

$$C = \frac{\tau}{R} = \frac{6.2 \text{ s}}{1.69 \times 10^{6} \ \Omega} = 3.67 \times 10^{-6} \text{ F.}$$

27.17: $K_1 + U_1 = K_2 + U_2$

$U_1 = K_2 = 0,$ so $K_1 = U_2;\ \ \frac{1}{2}mv^2 = ke^2/r$

$$v = e\sqrt{\frac{2k}{mr}} = (1.602\times10^{-19}\ \text{C})\sqrt{\frac{2k}{(3.34\times10^{-27}\ \text{kg})(1.0\times10^{-15}\ \text{m})}} = 1.2\times10^{7}\ \text{m/s}$$

b) $\sum\vec{\boldsymbol{F}} = m\vec{\boldsymbol{a}}$ gives $qvB = mv^2/r$

$$B = \frac{mv}{qr} = \frac{(3.34\times10^{-27}\ \text{kg})(1.2\times10^{7}\,\text{m/s})}{(1.602\times10^{-19}\ \text{C})(2.50\ \text{m})} = 0.10\ \text{T}$$

27.19: $q = (4.00\times10^{8})(-1.602\times10^{-19}\ \text{C}) = 6.408\times10^{-11}\ \text{C}$

speed at bottom of shaft: $\frac{1}{2}mv^2 = mgy;\ v = \sqrt{2gy} = 49.5\ \text{m/s}$

$\vec{\boldsymbol{v}}$ is downward and $\vec{\boldsymbol{B}}$ is west, so $\vec{\boldsymbol{v}}\times\vec{\boldsymbol{B}}$ is north. Since $q < 0$, $\vec{\boldsymbol{F}}$ is south.

$F = qvB\sin\theta = (6.408\times10^{-11}\ \text{C})(49.5\ \text{m/s})(0.250\ \text{T})\sin 90° = 7.93\times10^{-10}\ \text{N}$

27.34: a) $F = Ilb = (1.20\ \text{A})\ (0.0100\ \text{m})\ (0.588\ \text{T}) = 7.06 \times 10^{-3}\ \text{N},$ and by the righthand rule, the easterly magnetic field results in a southerly force.

b) If the field is southerly, then the force is to the west, and of the same magnitude as part (a), $F = 7.06 \times 10^{-3}\ \text{N}.$

c) If the field is $30°$ south of west, the force is $30°$ west of north ($90°$ counterclockwise from the field) and still of the same magnitude, $F = 7.60 \times 10^{-6}\ \text{N}.$

27.39: a) $F_I = mg$ when bar is just ready to levitate.

$$IlB = mg, I = \frac{mg}{lB} = \frac{(0.750 \text{ kg})(9.80 \text{m/s}^2)}{(0.500 \text{ m})(0.450 \text{ T})} = 32.67 \text{ A}$$

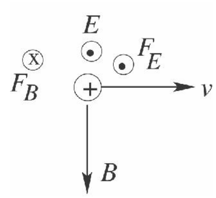
$$\varepsilon = IR = (32.67 \text{ A})(25.0 \ \Omega) = 817 \text{ V}$$

b) $R = 2.0 \ \Omega, I = \varepsilon / R = (816.7 \text{ V})/(2.0 \ \Omega) = 408 \text{ A}$

$F_I = IlB = 92 \text{ N}$

$a = (F_I - mg)/a = 113 \text{ m/s}^2$

27.55: The direction of $\vec{\boldsymbol{E}}$ is horizontal and perpendicular to $\vec{\boldsymbol{v}}$, as shown in the sketch:



$F_B = qvB,\ F_E = qE$

$F_B = F_E$ for no deflection, so $qvB = qE$

$E = vB = (14.0\ \text{m/s})(0.500\ \text{T}) = 7.00\ \text{V/m}$

We ignored the gravity force. If the target is 5.0 m from the rifle, it takes the bullet 0.36 s to reach the target and during this time the bullet moves downward $y - y_0 = \frac{1}{2}a_y t^2 = 0.62\ \text{m}.$ The magnetic and electric forces we considered are horizontal. A vertical electric field of $E = mg/q = 0.038\ \text{V/m}$ would be required to cancel the gravity force. Air resistance has also been neglected.

28.15: a) $B = \frac{\mu_0 I}{2\pi r} = \frac{\mu_0 (800 \text{ A})}{2\pi (5.50 \text{ m})} = 2.90 \times 10^{-5} \text{ T},$ to the east.

b) Since the magnitude of the earth's magnetic filed is 5.00×10^{-5} T, to the north, the total magnetic field is now 30° east of north with a magnitude of 5.78×10^{-5} T. This could be a problem!

28.22: a) $F = \dfrac{\mu_0 I_1 I_2 L}{2\pi r} = \dfrac{\mu_0 (5.00\ \text{A})\ (2.00\ \text{A})\ (1.20\ \text{m})}{2\pi (0.400\ \text{m})} = 6.00 \times 10^{-6}\ \text{N},$ and the force is repulsive since the currents are in opposite directions.

b) Doubling the currents makes the force increase by a factor of four to $F = 2.40 \times 10^{-5}\ \text{N}.$

28.32: Consider a coaxial cable where the currents run in OPPOSITE directions.

a) For $a < r < b, I_{encl} = I \Rightarrow \oint \vec{\boldsymbol{B}} \cdot d\boldsymbol{l} = \mu_0 I \Rightarrow B 2\pi r = \mu_0 I \Rightarrow B = \dfrac{\mu_0 I}{2\pi r}.$

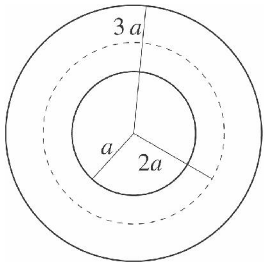
b) For $r > c,$ the enclosed current is zero, so the magnetic field is also zero.

28.37: a) $B = \dfrac{\mu_0 I}{2\pi r}$, so $I = \dfrac{Br}{(\mu_0/2\pi)} = 3.72 \times 10^6\ \text{A}$

b) $B_x = \dfrac{\mu_0 NI}{2a}$, so $I = \dfrac{2aB_x}{\mu_0 N} = 2.49 \times 10^5\ \text{A}$

c) $B = \mu_0 nI = \mu_0 (N/L) I$, so $I = BL/\mu_0 N = 237\ \text{A}$

28.73:



Apply Ampere's law to a circular path of radius 2*a*.

$$B(2\pi r) = \mu_0 I_{\text{encl}}$$

$$I_{\text{encl}} = I\left(\frac{(2a)^2 - a^2}{(3a)^2 - a^2}\right) = 3I/8$$

$B = \dfrac{3}{16}\dfrac{\mu_0 I}{2\pi a}$; this is the magnetic field inside the metal at a distance of $2a$ from the cylinder axis.

Outside the cylinder, $B = \dfrac{\mu_0 I}{2\pi r}$. The value of r where these two fields are equal is given by $1/r = 3/(16a)$ and $r = 16a/3$.

29.10: According to Faraday's law (assuming that the area vector points in the positive z-direction)

$$\varepsilon = -\frac{\Delta\Phi}{\Delta t} = -\frac{0-(1.5\ \text{T})\pi(0.120\ \text{m})^2}{2.0\times 10^{-3}\ \text{s}} = +34\ \text{V(counterclockwise)}$$

29.12: a)

$$|\varepsilon| = \frac{d\Phi_B}{dt} = \frac{d}{dt}(NBA\cos\omega t) = NBA\,\omega\sin\,\omega t \text{ and } 1200\text{ rev}/\text{min} = 20\text{ rev}/\text{s, so:}$$

$$\Rightarrow \varepsilon_{\max} = NBA\omega = (150)(0.060\text{ T})\pi(0.025\text{ m})^2(440\text{ rev}/\text{min})(1\text{ min}/60\text{sec})(2\pi\text{ rad}/\text{rev}) = 0.814\text{ V}.$$

b) Average $\varepsilon = \frac{2}{\pi}\varepsilon_{\max} = \frac{2}{\pi}0.814\text{ V} = 0.518\text{ V}.$

29.53: a) $\varepsilon = -\dfrac{\Delta\Phi_B}{\Delta t} = -B\dfrac{\Delta A}{\Delta t} = -B\dfrac{-\pi r^2}{\Delta t} = (0.950\ \text{T})\dfrac{\pi(0.0650/2\ \text{m})^2}{0.250\ \text{s}} = 0.0126\ \text{V}.$

b) Since the flux through the loop is decreasing, the induced current must produce a field that goes into the page. Therefore the current flows from point a through the resistor to point b.

29.56: The bar will experience a magnetic force due to the induced current in the loop. According to Example 29.6, the induced voltage in the loop has a magnitude BLv, which opposes the voltage of the battery, ε. Thus, the net current in the loop is $I = \frac{\varepsilon - BLv}{R}$. The acceleration of the bar is $a = \frac{F}{m} = \frac{ILB\sin(90°)}{m} = \frac{(\varepsilon - BLv)\,LB}{mR}$.

a) To find $v(t)$, set $\frac{dv}{dt} = a = \frac{(\varepsilon - BLv)LB}{mR}$ and solve for v using the method of separation of variables:

$$\int_0^v \frac{dv}{(\varepsilon - BLv)} = \int_0^t \frac{LB}{mR}\,dt \rightarrow v = \frac{\varepsilon}{BL}(1 - e^{-\frac{B^2L^2}{mR}t}) = (10\text{ m/s})\,(1 - e^{-\frac{t}{3.1\text{ s}}}).$$

Note that the graph of this function is similar in appearance to that of a charging capacitor.

b) $I = \varepsilon/R = 2.4$ A; $F = ILB = 2.88$ N; $a = F/m = 3.2\text{ m/s}^2$

c) When

$$v = 2.0\text{ m/s},\ a = \frac{[12\text{ V} - (1.5\text{ T})\,(0.8\text{ m})\,(2.0\text{ m/s})]\,(0.8\text{ m})\,(1.5\text{ T})}{(0.90\text{ kg})\,(5.0\Omega)} = 2.6\text{ m/s}^2$$

d) Note that as the velocity increases, the acceleration decreases. The velocity will asymptotically approach the terminal velocity $\frac{\varepsilon}{BL} = \frac{12\text{ V}}{(1.5\text{ T})\,(0.8\text{ m})} = 10\text{ m/s}$, which makes the acceleration zero.

30.65: a) Just after the switch is closed the voltage V_5 across the capacitor is zero and there is also no current through the inductor, so $V_3 = 0. V_2 + V_3 = V_4 = V_5$, and since $V_5 = 0$ and $V_3 = 0, V_4$ and V_2 are also zero. $V_4 = 0$ means V_3 reads zero.

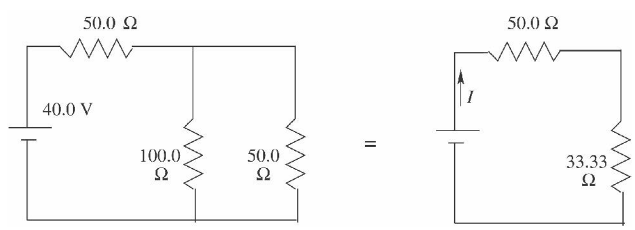
V_1 then must equal 40.0 V, and this means the current read by A_1 is $(40.0 \text{ V})/(50.0\ \Omega) = 0.800$ A.

$A_2 + A_3 + A_4 = A_1$, but $A_2 = A_3 = 0$ so $A_4 = A_1 = 0.800$ A.

$A_1 = A_4 = 0.800$ A; all other ammeters read zero.

$V_1 = 40.0$ V and all other voltmeters read zero.

b) After a long time the capacitor is fully charged so $A_4 = 0$. The current through the inductor isn't changing, so $V_2 = 0$. The currents can be calculated from the equivalent circuit that replaces the inductor by a short-circuit.:



$I = (40.0 \text{ V})/(83.33\ \Omega) = 0.480$ A; A_1 reads 0.480 A
$V_1 = I(50.0\ \Omega) = 24.0$ V

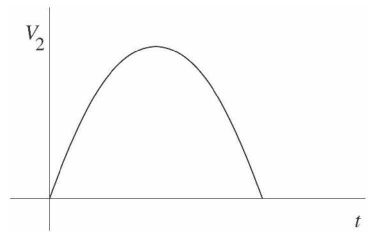
The voltage across each parallel branch is $40.0 \text{ V} - 24.0 \text{ V} = 16.0$ V

$V_2 = 0, V_3 = V_4 = V_5 = 16.0$ V

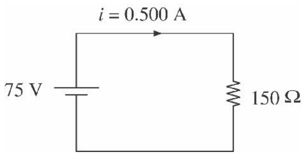
$V_3 = 16.0$ V means A_2 reads 0.160 A. $V_4 = 16.0$ V means A_3 reads 0.320 A. A_4 reads zero. Note that $A_2 + A_3 = A_1$.

c) $V_5 = 16.0$ V so $Q = CV = (12.0\ \mu\text{F})(16.0 \text{ V}) = 192\ \mu$C

d) At $t = 0$ and $t \to \infty, V_2 = 0$. As the current in this branch increases from zero to 0.160 A the voltage V_2 reflects the rate of change of current.


V_2
t

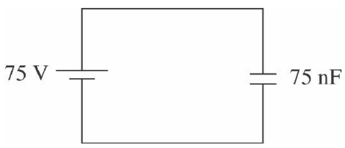
30.66: (a) Initially the capacitor behaves like a short circuit and the inductor like an open circuit. The simplified circuit becomes



$$i = \frac{\varepsilon}{R} = \frac{75\text{ V}}{150\ \Omega} = 0.500\text{ A}$$

$$V_1 = Ri = (50\ \Omega)(0.50\text{ A}) = 25.0\text{ V}$$
$$V_3 = 0, V_4 = (100\ \Omega)(0.50\text{ A}) = 50.0\text{ V}$$
$$V_2 = V_4 \text{ (in parallel)} = 50.0\text{ V}$$
$$A_1 = A_3 = 0.500\text{ A},\ A_2 = 0$$

(b) Long after S is closed, capacitor stops all current. Circuit becomes

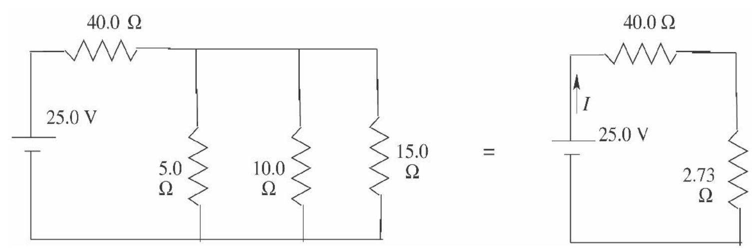


$V_3 = 75.0\text{ V}$ and all other meters read zero.

(c) $q = CV = (75\text{ nF})(75\text{ V}) = 5630\text{ nC},$ long after S is closed.

30.67: a) Just after the switch is closed there is no current through either inductor and they act like breaks in the circuit. The current is the same through the $40.0\ \Omega$ and $15.0\ \Omega$ resistors and is equal to $(25.0\ \text{V})/(40.0\ \Omega + 15.0\ \Omega) = 0.455\ \text{A}$. $A_1 = A_4 = 0.455\ \text{A}$; $A_2 = A_3 = 0$.

b) After a long time the currents are constant, there is no voltage across either inductor, and each inductor can be treated as a short-circuit . The circuit is equivalent to:



$I = (25.0\ \text{V})/(42.73\ \Omega) = 0.585\ \text{A}$

A_1 reads 0.585 A. The voltage across each parallel branch is $25.0\ \text{V} - (0.585\ \text{A})(40.0\ \Omega) =$ 1.60 V. A_2 reads $(1.60\ \text{V})/(5.0\ \Omega) = 0.320\ \text{A}$. A_3 reads $(1.60\ \text{V})/10.0\ \Omega) = 0.160\ \text{A}$. A_4 reads $(1.60\ \text{V})/(15.0\ \Omega) = 0.107\ \text{A}$.

32.7: a) $\lambda = \dfrac{c}{f} = \dfrac{3.00\times10^{8}\ \text{m/s}}{8.30\times10^{5}\ \text{Hz}} = 361\ \text{m}.$

b) $k = \dfrac{2\pi}{\lambda} = \dfrac{2\pi}{361\ \text{m}} = 0.0174\ \text{m}^{-1}$

c) $\omega = 2\pi f = 2\pi(8.30\times10^{5}\ \text{Hz}) = 5.21\times10^{6}\ \text{rad/s}.$

$E_{\text{max}} = cB_{\text{max}} = (3.00\times10^{8}\ \text{m/s})\ (4.82\times10^{-11}\ \text{T}) = 0.0145\ \text{V/m}.$

32.11: a) $\lambda = \dfrac{v}{f} = \dfrac{2.17 \times 10^{8}\ \text{m/s}}{5.70 \times 10^{14}\ \text{Hz}} = 3.81 \times 10^{-7}\ \text{m}.$

b) $\lambda_0 = \dfrac{c}{f} = \dfrac{3.00 \times 10^{8}\ \text{m/s}}{5.70 \times 10^{14}\ \text{Hz}} = 5.26 \times 10^{-7}\ \text{m}.$

c) $n = \dfrac{c}{v} = \dfrac{3.00 \times 10^{8}\ \text{m/s}}{2.17 \times 10^{8}\ \text{m/s}} = 1.38.$

d) $v = \dfrac{c}{\sqrt{K_E}} \Rightarrow K_E = \dfrac{c^2}{v^2} = n^2 = (1.38)^2 = 1.90.$

32.45: a) $E = \rho J = \frac{\rho I}{A} = \frac{\rho I}{\pi a^2}$, in the direction of the current.

b) $\oint \vec{\boldsymbol{B}} \cdot d\vec{\boldsymbol{l}} = \mu_0 I \Rightarrow B = \frac{\mu_0 I}{2\pi a}$, counterclockwise when looking into the current.

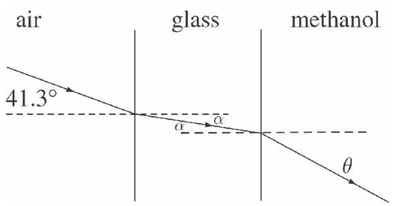
c) The direction of the Poynting vector $\hat{\boldsymbol{S}} = \hat{\boldsymbol{E}} \times \hat{\boldsymbol{B}} = \hat{\boldsymbol{k}} \times \hat{\boldsymbol{\phi}} = -\hat{\boldsymbol{\rho}}$, where we have used cylindrical coordinates, with the current in the z-direction.

Its magnitude is $S = \frac{EB}{\mu_0} = \frac{1}{\mu_0} \frac{\rho I}{\pi a^2} \frac{\mu_0 I}{2\pi a} = \frac{\rho I^2}{2\pi^2 a^3}$.

d) Over a length l, the rate of energy flowing in is $SA = \frac{\rho I^2}{2\pi^2 a^3} 2\pi a l = \frac{\rho l I^2}{\pi a^2}$.

The thermal power loss is $I^2 R = I^2 \frac{\rho l}{A} = \frac{\rho l I^2}{\pi a^2}$, which exactly equals the flow of electromagnetic energy.

33.8 (a)



Apply Snell's law at both interfaces.

At the air-glass interface:

$$(1.00)\sin 41.3° = n_{\text{glass}} \sin \alpha$$

At the glass-methanol interface:

$$n_{\text{glass}} \sin \alpha = (1.329)\sin \theta \qquad (2)$$

Combine (1) and (2):

$$\sin 41.3° = 1.329 \sin \theta$$
$$\theta = 29.8°$$

(b) Same figure as for (a), except $\theta = 20.2°$.

$$(1.00)\sin 41.3° = n \sin 20.2°$$
$$n = 1.91$$

33.20 : $\theta_{\text{crit}} = \arcsin\left(\dfrac{n_b}{n_a}\right) = \arcsin\left(\dfrac{1.00}{2.42}\right) = 24.4°.$

33.35: $\theta_b = 90° - \arcsin\left(\dfrac{n_a}{n_b}\right) = 90° - \arcsin\left(\dfrac{1.00}{1.38}\right) = 43.6°.$

But $n_a \sin\theta_a = n_b \sin\theta_b \Rightarrow \theta_a = \arcsin\left(\dfrac{n_b \sin\theta_b}{n_a}\right) = \arcsin\left(\dfrac{1.38 \sin(43.6°)}{1.00}\right) = 72.1°.$

33.41 $\theta_a = \arctan\left(\dfrac{8.0\text{ cm}}{16.0\text{ cm}}\right) = 27°$ and $\theta_b = \arctan\left(\dfrac{4.0\text{ cm}}{16.0\text{ cm}}\right) = 14°$.

So, $n_a \sin\theta_a = n_b \sin\theta_b \Rightarrow n_b = \left(\dfrac{n_a \sin\theta_a}{\sin\theta_b}\right) = \left(\dfrac{1.00 \sin 27°}{\sin 14°}\right) = 1.8.$

33.42: The beam of light will emerge at the same angle as it entered the fluid as seen by following what happens via Snell's Law at each of the interfaces. That is, the emergent beam is at $42.5°$ from the normal.

33.43: a) $\theta_i = \arcsin\left(\dfrac{n_a \sin 90°}{n_w}\right) = \arcsin\left(\dfrac{1.000}{1.333}\right) = 48.61°.$

The ice does not come into the calculation since $n_{\text{air}} \sin 90° = n_{\text{ice}} \sin\theta_c = n_w \sin\theta_i$.

b) Same as part (a).

35.8: a) For the number of antinodes we have:

$$\sin\theta = \frac{m\lambda}{d} = \frac{mc}{df} = \frac{m(3.00\times10^{8}\ \text{m/s})}{(12.0\ \text{m})(1.079\times10^{8}\ \text{Hz})} = 0.2317\ m, \text{ so, setting } \theta = 90°,$$

the maximum integer value is four. The angles are $\pm13.4°$, $\pm27.6°$, $\pm44.0°$, and $\pm67.9°$ for $m = 0, \pm1, \pm2, \pm3, \pm4.$

b) The nodes are given by $\sin\theta = \dfrac{(m+1/2)\lambda}{d} = 0.2317\ (m+1/2).$ So the angles are $\pm6.65°, \pm20.3°, \pm35.4°, 54.2°$ for $m = 0, \pm1, \pm2, \pm3.$

35.10: For bright fringes:

$$d = \frac{Rm\lambda}{y_m} = \frac{(1.20\ \text{m})(20)(5.02\times 10^{-7}\ \text{m})}{0.0106\ \text{m}} = 1.14\times 10^{-3}\ \text{m} = 1.14\ \text{mm}.$$

35.14: Using Eq.35.6 for small angles,

$$y_m = R\frac{m\lambda}{d},$$

we see that the distance between corresponding bright fringes is

$$\Delta_y = \frac{Rm}{d}\Delta\lambda = \frac{(5.00\ \text{m})(1)}{(0.300\times 10^{-3}\ \text{m})}(660-470)\times(10^{-9}\ \text{m}) = 3.17\ \text{mm}.$$

35.36: a) Since there is a half-cycle phase shift at just one of the interfaces, the minimum thickness for constructive interference is:

$$t = \frac{\lambda}{4} = \frac{\lambda_0}{4n} = \frac{550\ \text{nm}}{4(1.85)} = 74.3\ \text{nm}.$$

b) The next smallest thickness for constructive interference is with another half wavelength thickness added: $t = \dfrac{3\lambda}{4} = \dfrac{3\lambda_0}{4n} = \dfrac{3(550\ \text{nm})}{4(1.85)} = 223\ \text{nm}.$

35.41: a) Hearing minimum intensity sound means that the path lengths from the individual speakers to you differ by a half-cycle, and are hence out of phase by $180°$ at that position.

b) By moving the speakers toward you by 0.398 m, a maximum is heard, which means that you moved the speakers one-half wavelength from the min and the signals are back in phase. Therefore the wavelength of the signals is 0.796 m, and the frequency is

$$f = \frac{v}{\lambda} = \frac{340 \text{ m/s}}{0.796 \text{ m}} = 427 \text{ Hz.}$$

c) To reach the next maximum, one must move an additional distance of one wavelength, a distance of 0.796 m.

35.55: a) Intensified reflected light means we have constructive interference. There is one half-cycle phase shift, so:

$$2t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n} \Rightarrow \lambda = \frac{2tn}{(m + \frac{1}{2})} = \frac{2(485 \text{ nm})\,(1.53)}{(m + \frac{1}{2})} = \frac{1484 \text{ nm}}{(m + \frac{1}{2})}.$$

$$\Rightarrow \lambda = 593 \text{ nm}(m = 2), \text{ and } \lambda = 424 \text{ nm } (m = 3).$$

b) Intensified transmitted light means we have destructive interference at the upper surface. There is still a one half-cycle phase shift, so:

$$2t = \frac{m\lambda}{n} \Rightarrow \lambda = \frac{2tn}{m} = \frac{2(485 \text{ nm})\,(1.53)}{m} = \frac{1484 \text{ nm}}{m}.$$

$$\Rightarrow \lambda = 495 \text{ nm } (m = 3)$$

is the only wavelength of visible light that is intensified. We could also think of this as the result of internal reflections interfering with the outgoing ray *without* any extra phase shifts.