

INSTRUCTOR SOLUTIONS MANUAL

SEARS & ZEMANSKY'S

UNIVERSITY PHYSICS

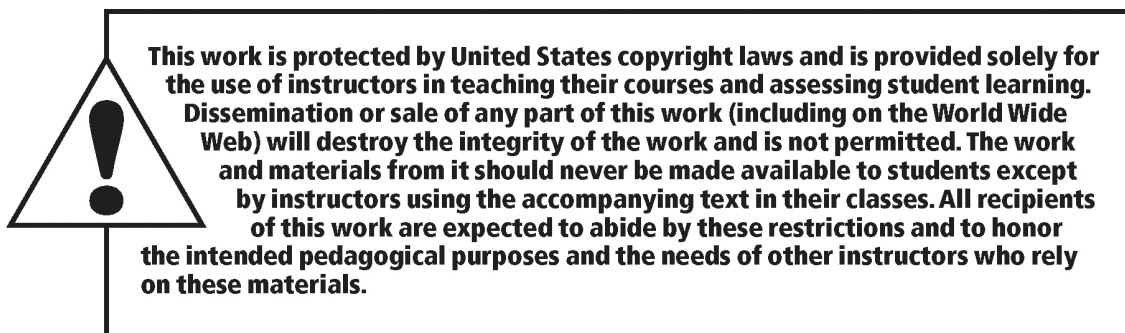
13TH EDITION

**A. LEWIS FORD
WAYNE ANDERSON**

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PREFACE

This Instructor Solutions Manual contains the solutions to all the problems and exercises in University Physics, Thirteenth Edition, by Hugh Young and Roger Freedman.

In preparing this manual, we assumed that its primary users would be college professors; thus the solutions are condensed, and some steps are not shown. Some calculations were carried out to more significant figures than demanded by the input data in order to allow for differences in calculator rounding. In many cases answers were then rounded off. Therefore, you may obtain slightly different results, especially when powers or trig functions are involved.

This edition was constructed from the previous editions authored by Craig Watkins and Mark Hollabaugh, and much of what is here is due to them.

Lewis Ford
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Sacramento, CA

1

UNITS, PHYSICAL QUANTITIES AND VECTORS

- 1.1. IDENTIFY:** Convert units from mi to km and from km to ft.

SET UP: 1 in. = 2.54 cm, 1 km = 1000 m, 12 in. = 1 ft, 1 mi = 5280 ft.

EXECUTE: (a) $1.00 \text{ mi} = (1.00 \text{ mi}) \left(\frac{5280 \text{ ft}}{1 \text{ mi}} \right) \left(\frac{12 \text{ in.}}{1 \text{ ft}} \right) \left(\frac{2.54 \text{ cm}}{1 \text{ in.}} \right) \left(\frac{1 \text{ m}}{10^2 \text{ cm}} \right) \left(\frac{1 \text{ km}}{10^3 \text{ m}} \right) = 1.61 \text{ km}$

(b) $1.00 \text{ km} = (1.00 \text{ km}) \left(\frac{10^3 \text{ m}}{1 \text{ km}} \right) \left(\frac{10^2 \text{ cm}}{1 \text{ m}} \right) \left(\frac{1 \text{ in.}}{2.54 \text{ cm}} \right) \left(\frac{1 \text{ ft}}{12 \text{ in.}} \right) = 3.28 \times 10^3 \text{ ft}$

EVALUATE: A mile is a greater distance than a kilometer. There are 5280 ft in a mile but only 3280 ft in a km.

- 1.2. IDENTIFY:** Convert volume units from L to in.³.

SET UP: 1 L = 1000 cm³, 1 in. = 2.54 cm

EXECUTE: $0.473 \text{ L} \times \left(\frac{1000 \text{ cm}^3}{1 \text{ L}} \right) \times \left(\frac{1 \text{ in.}}{2.54 \text{ cm}} \right)^3 = 28.9 \text{ in.}^3$

EVALUATE: 1 in.³ is greater than 1 cm³, so the volume in in.³ is a smaller number than the volume in cm³, which is 473 cm³.

- 1.3. IDENTIFY:** We know the speed of light in m/s. $t = d/v$. Convert 1.00 ft to m and t from s to ns.

SET UP: The speed of light is $v = 3.00 \times 10^8 \text{ m/s}$. 1 ft = 0.3048 m. 1 s = 10⁹ ns.

EXECUTE: $t = \frac{0.3048 \text{ m}}{3.00 \times 10^8 \text{ m/s}} = 1.02 \times 10^{-9} \text{ s} = 1.02 \text{ ns}$

EVALUATE: In 1.00 s light travels $3.00 \times 10^8 \text{ m} = 3.00 \times 10^5 \text{ km} = 1.86 \times 10^5 \text{ mi}$.

- 1.4. IDENTIFY:** Convert the units from g to kg and from cm³ to m³.

SET UP: 1 kg = 1000 g, 1 m = 1000 cm.

EXECUTE: $19.3 \frac{\text{g}}{\text{cm}^3} \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \times \left(\frac{100 \text{ cm}}{1 \text{ m}} \right)^3 = 1.93 \times 10^4 \frac{\text{kg}}{\text{m}^3}$

EVALUATE: The ratio that converts cm to m is cubed, because we need to convert cm³ to m³.

- 1.5. IDENTIFY:** Convert volume units from in.³ to L.

SET UP: 1 L = 1000 cm³, 1 in. = 2.54 cm.

EXECUTE: $(327 \text{ in.}^3) \times (2.54 \text{ cm/in.})^3 \times (1 \text{ L}/1000 \text{ cm}^3) = 5.36 \text{ L}$

EVALUATE: The volume is 5360 cm³. 1 cm³ is less than 1 in.³, so the volume in cm³ is a larger number than the volume in in.³.

- 1.6. IDENTIFY:** Convert ft² to m² and then to hectares.

SET UP: 1.00 hectare = 1.00 × 10⁴ m², 1 ft = 0.3048 m.

3-18 Chapter 3

3.37. IDENTIFY: Relative velocity problem in two dimensions.

(a) SET UP: $\vec{v}_{P/A}$ is the velocity of the plane relative to the air. The problem states that $\vec{v}_{P/A}$ has magnitude 35 m/s and direction south.

$\vec{v}_{A/E}$ is the velocity of the air relative to the earth. The problem states that $\vec{v}_{A/E}$ is to the southwest (45° S of W) and has magnitude 10 m/s.

The relative velocity equation is $\vec{v}_{P/E} = \vec{v}_{P/A} + \vec{v}_{A/E}$.

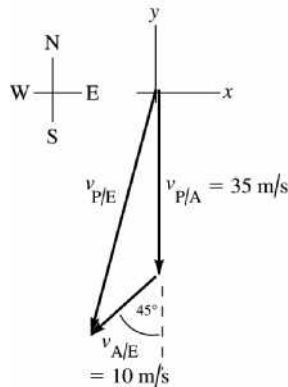


Figure 3.37a

EXECUTE: (b) $(v_{P/A})_x = 0$, $(v_{P/A})_y = -35$ m/s

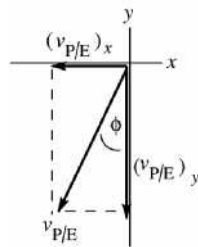
$$(v_{A/E})_x = -(10 \text{ m/s}) \cos 45^\circ = -7.07 \text{ m/s},$$

$$(v_{A/E})_y = -(10 \text{ m/s}) \sin 45^\circ = -7.07 \text{ m/s}$$

$$(v_{P/E})_x = (v_{P/A})_x + (v_{A/E})_x = 0 - 7.07 \text{ m/s} = -7.1 \text{ m/s}$$

$$(v_{P/E})_y = (v_{P/A})_y + (v_{A/E})_y = -35 \text{ m/s} - 7.07 \text{ m/s} = -42 \text{ m/s}$$

(c)



$$v_{P/E} = \sqrt{(v_{P/E})_x^2 + (v_{P/E})_y^2}$$

$$v_{P/E} = \sqrt{(-7.1 \text{ m/s})^2 + (-42 \text{ m/s})^2} = 43 \text{ m/s}$$

$$\tan \phi = \frac{(v_{P/E})_x}{(v_{P/E})_y} = \frac{-7.1}{-42} = 0.169$$

$$\phi = 9.6^\circ; (9.6^\circ \text{ west of south})$$

Figure 3.37b

EVALUATE: The relative velocity addition diagram does not form a right triangle so the vector addition must be done using components. The wind adds both southward and westward components to the velocity of the plane relative to the ground.

3.38. IDENTIFY: Use the relation that relates the relative velocities.

SET UP: The relative velocities are the velocity of the plane relative to the ground, $\vec{v}_{P/G}$, the velocity of the plane relative to the air, $\vec{v}_{P/A}$, and the velocity of the air relative to the ground, $\vec{v}_{A/G}$. $\vec{v}_{P/G}$ must due west and $\vec{v}_{A/G}$ must be south. $v_{A/G} = 80$ km/h and $v_{P/A} = 320$ km/h. $\vec{v}_{P/G} = \vec{v}_{P/A} + \vec{v}_{A/G}$. The relative velocity addition diagram is given in Figure 3.38.

EXECUTE: (a) $\sin \theta = \frac{v_{A/G}}{v_{P/A}} = \frac{80 \text{ km/h}}{320 \text{ km/h}}$ and $\theta = 14^\circ$, north of west.

$$(b) v_{P/G} = \sqrt{v_{P/A}^2 - v_{A/G}^2} = \sqrt{(320 \text{ km/h})^2 - (80.0 \text{ km/h})^2} = 310 \text{ km/h}.$$

cancel n gives $\frac{\sin \beta + \mu_s \cos \beta}{\cos \beta - \mu_s \sin \beta} = 2.25 \tan \beta$. Solving for μ_s and simplifying yields $\mu_s = \frac{1.25 \sin \beta \cos \beta}{1 + 1.25 \sin^2 \beta}$.

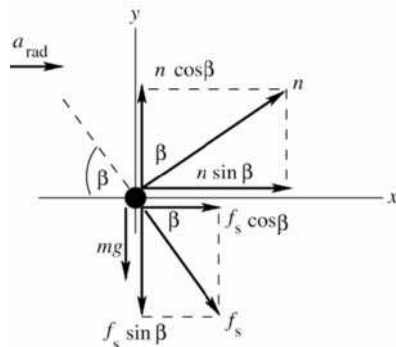
Using $\beta = \arctan \left(\frac{(20 \text{ m/s})^2}{(9.80 \text{ m/s}^2)(120 \text{ m})} \right) = 18.79^\circ$ gives $\mu_s = 0.34$.

EVALUATE: If μ_s is insufficient, the car skids away from the center of curvature of the roadway, so the friction is inward.

5.102. IDENTIFY: Apply $\Sigma \vec{F} = m\vec{a}$ to the car. The car moves in the arc of a horizontal circle, so $\vec{a} = \vec{a}_{\text{rad}}$, directed toward the center of curvature of the roadway. The target variable is the speed of the car. a_{rad} will be calculated from the forces and then v will be calculated from $a_{\text{rad}} = v^2/R$.

(a) To keep the car from sliding up the banking the static friction force is directed down the incline. At maximum speed the static friction force has its maximum value $f_s = \mu_s n$.

SET UP: The free-body diagram for the car is sketched in Figure 5.102a.



EXECUTE:

$$\Sigma F_y = ma_y$$

$$n \cos \beta - f_s \sin \beta - mg = 0$$

But $f_s = \mu_s n$, so

$$n \cos \beta - \mu_s n \sin \beta - mg = 0$$

$$n = \frac{mg}{\cos \beta - \mu_s \sin \beta}$$

Figure 5.102a

$$\Sigma F_x = ma_x$$

$$n \sin \beta + \mu_s n \cos \beta = ma_{\text{rad}}$$

$$n(\sin \beta + \mu_s \cos \beta) = ma_{\text{rad}}$$

Use the ΣF_y equation to replace n :

$$\left(\frac{mg}{\cos \beta - \mu_s \sin \beta} \right) (\sin \beta + \mu_s \cos \beta) = ma_{\text{rad}}$$

$$a_{\text{rad}} = \left(\frac{\sin \beta + \mu_s \cos \beta}{\cos \beta - \mu_s \sin \beta} \right) g = \left(\frac{\sin 25^\circ + (0.30) \cos 25^\circ}{\cos 25^\circ - (0.30) \sin 25^\circ} \right) (9.80 \text{ m/s}^2) = 8.73 \text{ m/s}^2$$

$$a_{\text{rad}} = v^2/R \text{ implies } v = \sqrt{a_{\text{rad}} R} = \sqrt{(8.73 \text{ m/s}^2)(50 \text{ m})} = 21 \text{ m/s}.$$

(b) **IDENTIFY:** To keep the car from sliding *down* the banking the static friction force is directed up the incline. At the minimum speed the static friction force has its maximum value $f_s = \mu_s n$.

SET UP: The free-body diagram for the car is sketched in Figure 5.102b.

(d) $P_x = Mv_{\text{cm}-x} = (3000 \text{ kg})(16.8 \text{ m/s}) = 5.04 \times 10^4 \text{ kg} \cdot \text{m/s}$, the same as in part (b).

EVALUATE: The total momentum can be calculated either as the vector sum of the momenta of the individual objects in the system, or as the total mass of the system times the velocity of the center of mass.

8.55. IDENTIFY: Use Eq. 8.28 to find the x and y coordinates of the center of mass of the machine part for each configuration of the part. In calculating the center of mass of the machine part, each uniform bar can be represented by a point mass at its geometrical center.

SET UP: Use coordinates with the axis at the hinge and the $+x$ and $+y$ axes along the horizontal and vertical bars in the figure in the problem. Let (x_i, y_i) and (x_f, y_f) be the coordinates of the bar before and after the vertical bar is pivoted. Let object 1 be the horizontal bar, object 2 be the vertical bar and 3 be the ball.

EXECUTE: $x_i = \frac{m_1 x_1 + m_2 x_2 + m_3 x_3}{m_1 + m_2 + m_3} = \frac{(4.00 \text{ kg})(0.750 \text{ m}) + 0 + 0}{4.00 \text{ kg} + 3.00 \text{ kg} + 2.00 \text{ kg}} = 0.333 \text{ m}.$

$$y_i = \frac{m_1 y_1 + m_2 y_2 + m_3 y_3}{m_1 + m_2 + m_3} = \frac{0 + (3.00 \text{ kg})(0.900 \text{ m}) + (2.00 \text{ kg})(1.80 \text{ m})}{9.00 \text{ kg}} = 0.700 \text{ m}.$$

$$x_f = \frac{(4.00 \text{ kg})(0.750 \text{ m}) + (3.00 \text{ kg})(-0.900 \text{ m}) + (2.00 \text{ kg})(-1.80 \text{ m})}{9.00 \text{ kg}} = -0.366 \text{ m}.$$

$y_f = 0$. $x_f - x_i = -0.700 \text{ m}$ and $y_f - y_i = -0.700 \text{ m}$. The center of mass moves 0.700 m to the right and 0.700 m upward.

EVALUATE: The vertical bar moves upward and to the right so it is sensible for the center of mass of the machine part to move in these directions.

8.56. IDENTIFY: Use Eq. 8.28.

SET UP: The target variable is m_1 .

EXECUTE: $x_{\text{cm}} = 2.0 \text{ m}$, $y_{\text{cm}} = 0$

$$x_{\text{cm}} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2} = \frac{m_1(0) + (0.10 \text{ kg})(8.0 \text{ m})}{m_1 + (0.10 \text{ kg})} = \frac{0.80 \text{ kg} \cdot \text{m}}{m_1 + 0.10 \text{ kg}}.$$

$$x_{\text{cm}} = 2.0 \text{ m} \text{ gives } 2.0 \text{ m} = \frac{0.80 \text{ kg} \cdot \text{m}}{m_1 + 0.10 \text{ kg}}.$$

$$m_1 + 0.10 \text{ kg} = \frac{0.80 \text{ kg} \cdot \text{m}}{2.0 \text{ m}} = 0.40 \text{ kg}.$$

$$m_1 = 0.30 \text{ kg}.$$

EVALUATE: The cm is closer to m_1 so its mass is larger than m_2 .

(b) **IDENTIFY:** Use Eq. 8.32 to calculate \vec{P} .

SET UP: $\vec{v}_{\text{cm}} (5.0 \text{ m/s}) \hat{i}$.

$$\vec{P} = M\vec{v}_{\text{cm}} = (0.10 \text{ kg} + 0.30 \text{ kg})(5.0 \text{ m/s}) \hat{i} = (2.0 \text{ kg} \cdot \text{m/s}) \hat{i}.$$

(c) **IDENTIFY:** Use Eq. 8.31.

SET UP: $\vec{v}_{\text{cm}} = \frac{m_1 \vec{v}_1 + m_2 \vec{v}_2}{m_1 + m_2}$. The target variable is \vec{v}_1 . Particle 2 at rest says $v_2 = 0$.

EXECUTE: $\vec{v}_1 = \left(\frac{m_1 + m_2}{m_1} \right) \vec{v}_{\text{cm}} = \left(\frac{0.30 \text{ kg} + 0.10 \text{ kg}}{0.30 \text{ kg}} \right) (5.00 \text{ m/s}) \hat{i} = (6.7 \text{ m/s}) \hat{i}.$

EVALUATE: Using the result of part (c) we can calculate \vec{p}_1 and \vec{p}_2 and show that \vec{P} as calculated in part (b) does equal $\vec{p}_1 + \vec{p}_2$.

8.57. IDENTIFY: There is no net external force on the system of James, Ramon and the rope and the momentum of the system is conserved and the velocity of its center of mass is constant. Initially there is no motion, and the velocity of the center of mass remains zero after Ramon has started to move.

(b) (i) $K_1 = \frac{1}{2}mv_1^2$, $K_2 = 0.100K_1$, $U_1 = -\frac{GMm}{R}$, $U_2 = -\frac{GMm}{r}$. $K_1 + U_1 = K_2 + U_2$ gives

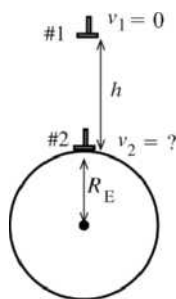
$$\frac{1}{2}mv_1^2 - \frac{GMm}{R} = (0.100)(\frac{1}{2}mv_1^2) - \frac{GMm}{r}$$

$$\frac{1}{r} = \frac{1}{R} - \frac{0.450v_1^2}{GM} = \frac{1}{4.5 \times 10^3 \text{ m}} - \frac{0.450(1.0 \text{ m/s})^2}{(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(3.37 \times 10^{13} \text{ kg})}$$

and $r = 45 \text{ km}$. (ii) The debris never loses all of its initial kinetic energy, but $K_2 \rightarrow 0$ as $r \rightarrow \infty$. The farther the debris are from the comet's center, the smaller is their kinetic energy.

EVALUATE: The debris will have lost 90.0% of their initial kinetic energy when they are at a distance from the comet's center of about ten times the radius of the comet.

- 13.65. IDENTIFY and SET UP:** Apply conservation of energy. Must use Eq. (13.9) for the gravitational potential energy since h is not small compared to R_E .



As indicated in Figure 13.65, take point 1 to be where the hammer is released and point 2 to be just above the surface of the earth, so $r_1 = R_E + h$ and $r_2 = R_E$.

Figure 13.65

EXECUTE: $K_1 + U_1 + W_{\text{other}} = K_2 + U_2$

Only gravity does work, so $W_{\text{other}} = 0$.

$$K_1 = 0, \quad K_2 = \frac{1}{2}mv_2^2$$

$$U_1 = -G\frac{mm_E}{r_1} = -G\frac{mm_E}{h + R_E}, \quad U_2 = -G\frac{mm_E}{r_2} = -G\frac{mm_E}{R_E}$$

$$\text{Thus, } -G\frac{mm_E}{h + R_E} = \frac{1}{2}mv_2^2 - G\frac{mm_E}{R_E}$$

$$v_2^2 = 2Gm_E \left(\frac{1}{R_E} - \frac{1}{R_E + h} \right) = \frac{2Gm_E}{R_E(R_E + h)} (R_E + h - R_E) = \frac{2Gm_E h}{R_E(R_E + h)}$$

$$v_2 = \sqrt{\frac{2Gm_E h}{R_E(R_E + h)}}$$

EVALUATE: If $h \rightarrow \infty$, $v_2 \rightarrow \sqrt{2Gm_E/R_E}$, which equals the escape speed. In this limit this event is the reverse of an object being projected upward from the surface with the escape speed. If $h \ll R_E$, then

$$v_2 = \sqrt{2Gm_E h/R_E^2} = \sqrt{2gh}, \text{ the same result if Eq. (7.2) used for } U.$$

- 13.66. IDENTIFY:** In orbit the total mechanical energy of the satellite is $E = -\frac{Gm_E m}{2R_E}$. $U = -G\frac{m_E m}{r}$.

$$W = E_2 - E_1.$$

SET UP: $U \rightarrow 0$ as $r \rightarrow \infty$.

(c) **IDENTIFY and SET UP:** Energy = (power) × (time); the energy is that calculated in part (a).

EXECUTE: $U = Pt, t = \frac{U}{P} = \frac{2.6 \times 10^6 \text{ J}}{450 \text{ W}} = 5800 \text{ s} = 97 \text{ min} = 1.6 \text{ h}.$

EVALUATE: The battery discharges at a rate of 720 W (for 60 A) and is charged at a rate of 450 W, so it takes longer to charge than to discharge.

25.48. IDENTIFY: The rate of conversion of chemical to electrical energy in an emf is $\mathcal{E}I$. The rate of dissipation of electrical energy in a resistor R is I^2R .

SET UP: Example 25.9 finds that $I = 1.2 \text{ A}$ for this circuit. In Example 25.8, $\mathcal{E}I = 24 \text{ W}$ and $I^2r = 8 \text{ W}$. In Example 25.9, $I^2R = 12 \text{ W}$, or 11.5 W if expressed to three significant figures.

EXECUTE: (a) $P = \mathcal{E}I = (12 \text{ V})(1.2 \text{ A}) = 14.4 \text{ W}$. This is less than the previous value of 24 W.

(b) The energy dissipated in the battery is $P = I^2r = (1.2 \text{ A})^2(2.0 \Omega) = 2.9 \text{ W}$. This is less than 8 W, the amount found in Example (25.8).

(c) The net power output of the battery is $14.4 \text{ W} - 2.9 \text{ W} = 11.5 \text{ W}$. This is the same as the power dissipated in the $8.0\text{-}\Omega$ resistor.

EVALUATE: With the larger circuit resistance the current is less and the power input and power consumption are less.

25.49. IDENTIFY: Some of the power generated by the internal emf of the battery is dissipated across the battery's internal resistance, so it is not available to the bulb.

SET UP: Use $P = I^2R$ and take the ratio of the power dissipated in the internal resistance r to the total power.

EXECUTE: $\frac{P_r}{P_{\text{Total}}} = \frac{I^2r}{I^2(r+R)} = \frac{r}{r+R} = \frac{3.5 \Omega}{28.5 \Omega} = 0.123 = 12.3\%$

EVALUATE: About 88% of the power of the battery goes to the bulb. The rest appears as heat in the internal resistance.

25.50. IDENTIFY: The voltmeter reads the terminal voltage of the battery, which is the potential difference across the appliance. The terminal voltage is less than 15.0 V because some potential is lost across the internal resistance of the battery.

(a) **SET UP:** $P = V^2/R$ gives the power dissipated by the appliance.

EXECUTE: $P = (11.3 \text{ V})^2/(75.0 \Omega) = 1.70 \text{ W}$

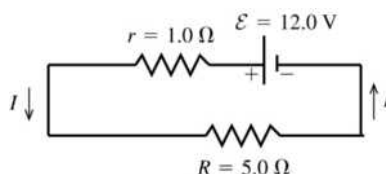
(b) **SET UP:** The drop in terminal voltage ($\mathcal{E} - V_{ab}$) is due to the potential drop across the internal resistance r . Use $Ir = \mathcal{E} - V_{ab}$ to find the internal resistance r , but first find the current using $P = IV$.

EXECUTE: $I = P/V = (1.70 \text{ W})/(11.3 \text{ V}) = 0.151 \text{ A}$. Then $Ir = \mathcal{E} - V_{ab}$ gives $(0.151 \text{ A})r = 15.0 \text{ V} - 11.3 \text{ V}$ and $r = 24.5 \Omega$.

EVALUATE: The full 15.0-V of the battery would be available only when no current (or a very small current) is flowing in the circuit. This would be the case if the appliance had a resistance much greater than 24.5Ω .

25.51. IDENTIFY: Solve for the current I in the circuit. Apply Eq. (25.17) to the specified circuit elements to find the rates of energy conversion.

SET UP: The circuit is sketched in Figure 25.51



EXECUTE: Compute I :

$$\mathcal{E} - Ir - IR = 0$$

$$I = \frac{\mathcal{E}}{r + R} = \frac{12.0 \text{ V}}{1.0 \Omega + 5.0 \Omega} = 2.00 \text{ A}$$

Figure 25.51

28.53. IDENTIFY: Example 28.10 shows that inside a toroidal solenoid, $B = \frac{\mu_0 NI}{2\pi r}$.

SET UP: $r = 0.070$ m

EXECUTE: $B = \frac{\mu_0 NI}{2\pi r} = \frac{\mu_0 (600)(0.650 \text{ A})}{2\pi (0.070 \text{ m})} = 1.11 \times 10^{-3} \text{ T}$.

EVALUATE: If the radial thickness of the torus is small compared to its mean diameter, B is approximately uniform inside its windings.

28.54. IDENTIFY: Use Eq. (28.24), with μ_0 replaced by $\mu = K_m \mu_0$, with $K_m = 80$.

SET UP: The contribution from atomic currents is the difference between B calculated with μ and B calculated with μ_0 .

EXECUTE: (a) $B = \frac{\mu NI}{2\pi r} = \frac{K_m \mu_0 NI}{2\pi r} = \frac{\mu_0 (80)(400)(0.25 \text{ A})}{2\pi (0.060 \text{ m})} = 0.0267 \text{ T}$.

(b) The amount due to atomic currents is $B' = \frac{79}{80} B = \frac{79}{80} (0.0267 \text{ T}) = 0.0263 \text{ T}$.

EVALUATE: The presence of the core greatly enhances the magnetic field produced by the solenoid.

28.55. IDENTIFY and SET UP: $B = \frac{K_m \mu_0 NI}{2\pi r}$ (Eq. 28.24, with μ_0 replaced by $K_m \mu_0$)

EXECUTE: (a) $K_m = 1400$

$I = \frac{2\pi r B}{\mu_0 K_m N} = \frac{(2.90 \times 10^{-2} \text{ m})(0.350 \text{ T})}{(2 \times 10^{-7} \text{ T} \cdot \text{m/A})(1400)(500)} = 0.0725 \text{ A}$

(b) $K_m = 5200$

$I = \frac{2\pi r B}{\mu_0 K_m N} = \frac{(2.90 \times 10^{-2} \text{ m})(0.350 \text{ T})}{(2 \times 10^{-7} \text{ T} \cdot \text{m/A})(5200)(500)} = 0.0195 \text{ A}$

EVALUATE: If the solenoid were air-filled instead, a much larger current would be required to produce the same magnetic field.

28.56. IDENTIFY: Apply $B = \frac{K_m \mu_0 NI}{2\pi r}$.

SET UP: K_m is the relative permeability and $\chi_m = K_m - 1$ is the magnetic susceptibility.

EXECUTE: (a) $K_m = \frac{2\pi r B}{\mu_0 NI} = \frac{2\pi (0.2500 \text{ m})(1.940 \text{ T})}{\mu_0 (500)(2.400 \text{ A})} = 2021$.

(b) $\chi_m = K_m - 1 = 2020$.

EVALUATE: Without the magnetic material the magnetic field inside the windings would be $B/2021 = 9.6 \times 10^{-4} \text{ T}$. The presence of the magnetic material greatly enhances the magnetic field inside the windings.

28.57. IDENTIFY: The magnetic field from the solenoid alone is $B_0 = \mu_0 nI$. The total magnetic field is

$B = K_m B_0$. M is given by Eq. (28.29).

SET UP: $n = 6000$ turns/m

EXECUTE: (a) (i) $B_0 = \mu_0 nI = \mu_0 (6000 \text{ m}^{-1})(0.15 \text{ A}) = 1.13 \times 10^{-3} \text{ T}$.

(ii) $M = \frac{K_m - 1}{\mu_0} B_0 = \frac{5199}{\mu_0} (1.13 \times 10^{-3} \text{ T}) = 4.68 \times 10^6 \text{ A/m}$.

(iii) $B = K_m B_0 = (5200)(1.13 \times 10^{-3} \text{ T}) = 5.88 \text{ T}$.

(b) The directions of \vec{B} , \vec{B}_0 and \vec{M} are shown in Figure 28.57. Silicon steel is paramagnetic and \vec{B}_0 and \vec{M} are in the same direction.

EVALUATE: The total magnetic field is much larger than the field due to the solenoid current alone.

$m=1$: $\lambda_{\text{air}} = 183 \text{ nm}$. All other λ_{air} values are shorter. For constructive interference, $2t = m \frac{\lambda_{\text{air}}}{n}$ and

$\lambda_{\text{air}} = \frac{2tn}{m} = \frac{275 \text{ nm}}{m}$. For $m=1$, $\lambda_{\text{air}} = 275 \text{ nm}$ and all other λ_{air} values are shorter.

EVALUATE: The only visible wavelength in air for which there is destructive interference is 550 nm. There are no visible wavelengths in air for which there is constructive interference.

- 35.40. IDENTIFY and SET UP:** Consider reflection from either side of the film. **(a)** At the front of the film, light in air ($n=1.00$) reflects off the film ($n=1.45$) and there is a 180° phase shift. At the back of the film, light in the film ($n=1.45$) reflects off the cornea ($n=1.38$) and there is no phase shift. The reflections produce a net 180° phase difference so the condition for constructive interference is $2t = (m + \frac{1}{2})\lambda$, where

$$\lambda = \frac{\lambda_{\text{air}}}{n}, \quad t = (m + \frac{1}{2}) \frac{\lambda_{\text{air}}}{2n}.$$

EXECUTE: The minimum thickness is for $m=0$, and is given by $t = \frac{\lambda_{\text{air}}}{4n} = \frac{600 \text{ nm}}{4(1.45)} = 103 \text{ nm}$ (103.4 nm with less rounding).

(b) $\lambda_{\text{air}} = \frac{2nt}{m + \frac{1}{2}} = \frac{2(1.45)(103.4 \text{ nm})}{m + \frac{1}{2}} = \frac{300 \text{ nm}}{m + \frac{1}{2}}$. For $m=0$, $\lambda_{\text{air}} = 600 \text{ nm}$. For $m=1$, $\lambda_{\text{air}} = 200 \text{ nm}$

and all other values are smaller. No other visible wavelengths are reinforced. The condition for destructive interference is $2t = m \frac{\lambda_{\text{air}}}{n}$. $\lambda = \frac{2tn}{m} = \frac{300 \text{ nm}}{m}$. For $m=1$, $\lambda_{\text{air}} = 300 \text{ nm}$ and all other values are shorter.

There are no visible wavelengths for which there is destructive interference.

(c) Now both rays have a 180° phase change on reflection and the reflections don't introduce any net phase shift. The expression for constructive interference in parts (a) and (b) now gives destructive interference and the expression in (a) and (b) for destructive interference now gives constructive interference. The only visible wavelength for which there will be destructive interference is 600 nm and there are no visible wavelengths for which there will be constructive interference.

EVALUATE: Changing the net phase shift due to the reflections can convert the interference for a particular thickness from constructive to destructive, and vice versa.

- 35.41. IDENTIFY:** The insertion of the metal foil produces a wedge of air, which is an air film of varying thickness. This film causes a path difference between light reflected off the top and bottom of this film. **SET UP:** The two sheets of glass are sketched in Figure 35.41. The thickness of the air wedge at a distance x from the line of contact is $t = x \tan \theta$. Consider rays 1 and 2 that are reflected from the top and bottom surfaces, respectively, of the air film. Ray 1 has no phase change when it reflects and ray 2 has a 180° phase change when it reflects, so the reflections introduce a net 180° phase difference. The path difference is $2t$ and the wavelength in the film is $\lambda = \lambda_{\text{air}}$.

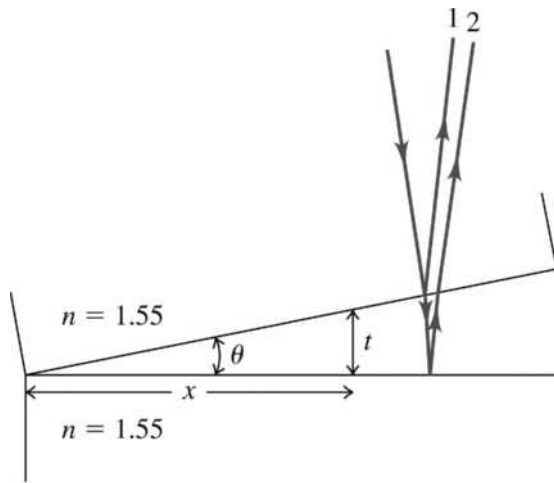


Figure 35.41