# Physics and Measurement 

## CHAPTER OUTLINE

1.1 Standards of Length, Mass, and Time
1.2 Matter and Model-Building
1.3 Dimensional Analysis
1.4 Conversion of Units
1.5 Estimates and Order-of-

Magnitude Calculations
1.6 Significant Figures

## ANSWERS TO QUESTIONS

## * An asterisk indicates an item new to this edition.

Q1. 1 Density varies with temperature and pressure. It would be necessary to measure both mass and volume very accurately in order to use the density of water as a standard.

Q1.2 (a) 0.3 millimeters (b) 50 microseconds
(c) 7.2 kilograms
*Q1.3 In the base unit we have (a) 0.032 kg (b) 0.015 kg (c) 0.270 kg (d) 0.041 kg (e) 0.27 kg . Then the ranking is $\mathrm{c}=\mathrm{e}>\mathrm{d}>\mathrm{a}>\mathrm{b}$

Q1.4 No: A dimensionally correct equation need not be true. Example: 1 chimpanzee $=2$ chimpanzee is dimensionally correct.
Yes: If an equation is not dimensionally correct, it cannot be correct.
*Q1.5 The answer is yes for (a), (c), and (f). You cannot add or subtract a number of apples and a number of jokes. The answer is no for (b), (d), and (e). Consider the gauge of a sausage, $4 \mathrm{~kg} / 2 \mathrm{~m}$, or the volume of a cube, ( 2 m$)^{3}$. Thus we have (a) yes (b) no (c) yes (d) no (e) no (f) yes
*Q1.6 $41 € \approx 41 €(1 \mathrm{~L} / 1.3 €)(1 \mathrm{qt} / 1 \mathrm{~L})(1 \mathrm{gal} / 4 \mathrm{qt}) \approx(10 / 1.3) \mathrm{gal} \approx 8$ gallons, answer $(\mathrm{c})$
*Q1.7 The meterstick measurement, (a), and (b) can all be 4.31 cm . The meterstick measurement and (c) can both be 4.24 cm . Only (d) does not overlap. Thus (a) (b) and (c) all agree with the meterstick measurement.
*Q1.8 $\quad 0.02(1.365)=0.03$. The result is $(1.37 \pm 0.03) \times 10^{7} \mathrm{~kg}$. So (d) 3 digits are significant.

## SOLUTIONS TO PROBLEMS

## Section 1.1 Standards of Length, Mass, and Time

P1.1 Modeling the Earth as a sphere, we find its volume as $\frac{4}{3} \pi r^{3}=\frac{4}{3} \pi\left(6.37 \times 10^{6} \mathrm{~m}\right)^{3}=1.08 \times 10^{21} \mathrm{~m}^{3}$. Its density is then $\rho=\frac{m}{V}=\frac{5.98 \times 10^{24} \mathrm{~kg}}{1.08 \times 10^{21} \mathrm{~m}^{3}}=\frac{3}{5.52 \times 10^{3} \mathrm{~kg} / \mathrm{m}^{3}}$. This value is intermediate between the tabulated densities of aluminum and iron. Typical rocks have densities around 2000 to $3000 \mathrm{~kg} / \mathrm{m}^{3}$. The average density of the Earth is significantly higher, so higher-density material must be down below the surface.

P2.11 (a) Acceleration is constant over the first ten seconds, so at the end of this interval

$$
v_{f}=v_{i}+a t=0+\left(2.00 \mathrm{~m} / \mathrm{s}^{2}\right)(10.0 \mathrm{~s})=20.0 \mathrm{~m} / \mathrm{s} .
$$

Then $a=0$ so $v$ is constant from $t=10.0 \mathrm{~s}$ to $t=15.0 \mathrm{~s}$. And over the last five seconds the velocity changes to

$$
v_{f}=v_{i}+a t=20.0 \mathrm{~m} / \mathrm{s}+\left(-3.00 \mathrm{~m} / \mathrm{s}^{2}\right)(5.00 \mathrm{~s})=5.00 \mathrm{~m} / \mathrm{s}
$$

(b) In the first ten seconds,

$$
x_{f}=x_{i}+v_{i} t+\frac{1}{2} a t^{2}=0+0+\frac{1}{2}\left(2.00 \mathrm{~m} / \mathrm{s}^{2}\right)(10.0 \mathrm{~s})^{2}=100 \mathrm{~m}
$$

Over the next five seconds the position changes to

$$
x_{f}=x_{i}+v_{i} t+\frac{1}{2} a t^{2}=100 \mathrm{~m}+(20.0 \mathrm{~m} / \mathrm{s})(5.00 \mathrm{~s})+0=200 \mathrm{~m}
$$

And at $t=20.0 \mathrm{~s}$,

$$
x_{f}=x_{i}+v_{i} t+\frac{1}{2} a t^{2}=200 \mathrm{~m}+(20.0 \mathrm{~m} / \mathrm{s})(5.00 \mathrm{~s})+\frac{1}{2}\left(-3.00 \mathrm{~m} / \mathrm{s}^{2}\right)(5.00 \mathrm{~s})^{2}=262 \mathrm{~m}
$$

P2.12 (a) Acceleration is the slope of the graph of $v$ versus $t$.

For $0<t<5.00 \mathrm{~s}, a=0$.

For $15.0 \mathrm{~s}<t<20.0 \mathrm{~s}, a=0$.

For $5.0 \mathrm{~s}<t<15.0 \mathrm{~s}, a=\frac{v_{f}-v_{i}}{t_{f}-t_{i}}$.

$$
a=\frac{8.00-(-8.00)}{15.0-5.00}=1.60 \mathrm{~m} / \mathrm{s}^{2}
$$

We can plot $a(t)$ as shown.


FIG. P2.12
(b) $\quad a=\frac{v_{f}-v_{i}}{t_{f}-t_{i}}$
(i) For $5.00 \mathrm{~s}<t<15.0 \mathrm{~s}, t_{i}=5.00 \mathrm{~s}, v_{i}=-8.00 \mathrm{~m} / \mathrm{s}$,

$$
\begin{aligned}
t_{f} & =15.0 \mathrm{~s} \\
v_{f} & =8.00 \mathrm{~m} / \mathrm{s} \\
a & =\frac{v_{f}-v_{i}}{t_{f}-t_{i}}=\frac{8.00-(-8.00)}{15.0-5.00}=1.60 \mathrm{~m} / \mathrm{s}^{2} .
\end{aligned}
$$

(ii) $\quad t_{i}=0, v_{i}=-8.00 \mathrm{~m} / \mathrm{s}, t_{f}=20.0 \mathrm{~s}, v_{f}=8.00 \mathrm{~m} / \mathrm{s}$

$$
a=\frac{v_{f}-v_{i}}{t_{f}-t_{i}}=\frac{8.00-(-8.00)}{20.0-0}=0.800 \mathrm{~m} / \mathrm{s}^{2}
$$

P3.15 $A_{x}=-25.0$
$A_{y}=40.0$
$A=\sqrt{A_{x}^{2}+A_{y}^{2}}=\sqrt{(-25.0)^{2}+(40.0)^{2}}=47.2$ units
We observe that

$$
\tan \phi=\frac{\left|A_{y}\right|}{\left|A_{x}\right|}
$$



So

$$
\phi=\tan ^{-1}\left(\frac{A_{y}}{\left|A_{x}\right|}\right)=\tan \frac{40.0}{25.0}=\tan ^{-1}(1.60)=58.0^{\circ} .
$$

FIG. P3. 15

The diagram shows that the angle from the $+x$ axis can be found by subtracting from $180^{\circ}$ :

$$
\theta=180^{\circ}-58^{\circ}=122^{\circ} .
$$

P3.16 The person would have to walk $3.10 \sin \left(25.0^{\circ}\right)=1.31 \mathrm{~km}$ north , and

$$
3.10 \cos \left(25.0^{\circ}\right)=2.81 \mathrm{~km} \text { east. }
$$

*P3.17 Let $v$ represent the speed of the camper. The northward component of its velocity is $v \cos 8.5^{\circ}$. To avoid crowding the minivan we require $v \cos 8.5^{\circ} \geq 28 \mathrm{~m} / \mathrm{s}$.

We can satisfy this requirement simply by taking $v \geq(28 \mathrm{~m} / \mathrm{s}) / \cos 8.5^{\circ}=28.3 \mathrm{~m} / \mathrm{s}$.

P3.18 (a) Her net $x$ (east-west) displacement is $-3.00+0+6.00=+3.00$ blocks, while her net $y$ (north-south) displacement is $0+4.00+0=+4.00$ blocks. The magnitude of the resultant displacement is

$$
R=\sqrt{\left(x_{\text {net }}\right)^{2}+\left(y_{\text {net }}\right)^{2}}=\sqrt{(3.00)^{2}+(4.00)^{2}}=5.00 \text { blocks }
$$

and the angle the resultant makes with the $x$ axis (eastward direction) is

$$
\theta=\tan ^{-1}\left(\frac{4.00}{3.00}\right)=\tan ^{-1}(1.33)=53.1^{\circ} .
$$

The resultant displacement is then 5.00 blocks at $53.1^{\circ} \mathrm{N}$ of E.
(b) The total distance traveled is $3.00+4.00+6.00=13.0$ blocks.

P3.19 $x=r \cos \theta$ and $y=r \sin \theta$, therefore:
(a) $\quad x=12.8 \cos 150^{\circ}, y=12.8 \sin 150^{\circ}$, and $(x, y)=(-11.1 \hat{\mathbf{i}}+6.40 \hat{\mathbf{j}}) \mathrm{m}$
(b) $x=3.30 \cos 60.0^{\circ}, y=3.30 \sin 60.0^{\circ}$, and $(x, y)=(1.65 \hat{\mathbf{i}}+2.86 \hat{\mathbf{j}}) \mathrm{cm}$
(c) $x=22.0 \cos 215^{\circ}, y=22.0 \sin 215^{\circ}$, and $(x, y)=(-18.0 \hat{\mathbf{i}}-12.6 \hat{\mathbf{j}})$ in

P3.20 $x=d \cos \theta=(50.0 \mathrm{~m}) \cos (120)=-25.0 \mathrm{~m}$
$y=d \sin \theta=(50.0 \mathrm{~m}) \sin (120)=43.3 \mathrm{~m}$
$\overrightarrow{\mathbf{d}}=(-25.0 \mathrm{~m}) \hat{\mathbf{i}}+(43.3 \mathrm{~m}) \hat{\mathbf{j}}$

P3.57 $\quad \overrightarrow{\mathbf{d}}_{1}=100 \hat{\mathbf{i}}$
$\overrightarrow{\mathbf{d}}_{2}=-300 \hat{\mathbf{j}}$
$\overrightarrow{\mathbf{d}}_{3}=-150 \cos \left(30.0^{\circ}\right) \hat{\mathbf{i}}-150 \sin \left(30.0^{\circ}\right) \hat{\mathbf{j}}=-130 \hat{\mathbf{i}}-75.0 \hat{\mathbf{j}}$
$\overrightarrow{\mathbf{d}}_{4}=-200 \cos \left(60.0^{\circ}\right) \hat{\mathbf{i}}+200 \sin \left(60.0^{\circ}\right) \hat{\mathbf{j}}=-100 \hat{\mathbf{i}}+173 \hat{\mathbf{j}}$
$\overrightarrow{\mathbf{R}}=\overrightarrow{\mathbf{d}}_{1}+\overrightarrow{\mathbf{d}}_{2}+\overrightarrow{\mathbf{d}}_{3}+\overrightarrow{\mathbf{d}}_{4}=(-130 \hat{\mathbf{i}}-202 \hat{\mathbf{j}}) \mathrm{m}$
$|\overrightarrow{\mathbf{R}}|=\sqrt{(-130)^{2}+(-202)^{2}}=240 \mathrm{~m}$
$\phi=\tan ^{-1}\left(\frac{202}{130}\right)=57.2^{\circ}$
$\theta=180+\phi=237^{\circ}$


FIG. P3.57

P3.58 $\frac{d \overrightarrow{\mathbf{r}}}{d t}=\frac{d(4 \hat{\mathbf{i}}+3 \hat{\mathbf{j}}-2 \hat{\mathbf{t}})}{d t}=0+0-2 \hat{\mathbf{j}}=-(2.00 \mathrm{~m} / \mathrm{s}) \hat{\mathbf{j}}$
The position vector at $t=0$ is $4 \hat{\mathbf{i}}+3 \hat{\mathbf{j}}$. At $t=1 \mathrm{~s}$, the position is $4 \hat{\mathbf{i}}+1 \hat{\mathbf{j}}$, and so on. The object is moving straight downward at $2 \mathrm{~m} / \mathrm{s}$, so

$$
\frac{d \overrightarrow{\mathbf{r}}}{d t} \text { represents its velocity vector. }
$$

P3.59 (a) You start at point $A: \overrightarrow{\mathbf{r}}_{1}=\overrightarrow{\mathbf{r}}_{A}=(30.0 \hat{\mathbf{i}}-20.0 \hat{\mathbf{j}}) \mathrm{m}$.
The displacement to $B$ is

$$
\overrightarrow{\mathbf{r}}_{B}-\overrightarrow{\mathbf{r}}_{A}=60.0 \hat{\mathbf{i}}+80.0 \hat{\mathbf{j}}-30.0 \hat{\mathbf{i}}+20.0 \hat{\mathbf{j}}=30.0 \hat{\mathbf{i}}+100 \hat{\mathbf{j}}
$$

You cover half of this, $(15.0 \hat{\mathbf{i}}+50.0 \hat{\mathbf{j}})$ to move to

$$
\overrightarrow{\mathbf{r}}_{2}=30.0 \hat{\mathbf{i}}-20.0 \hat{\mathbf{j}}+15.0 \hat{\mathbf{i}}+50.0 \hat{\mathbf{j}}=45.0 \hat{\mathbf{i}}+30.0 \hat{\mathbf{j}} .
$$

Now the displacement from your current position to $C$ is

$$
\overrightarrow{\mathbf{r}}_{C}-\overrightarrow{\mathbf{r}}_{2}=-10.0 \hat{\mathbf{i}}-10.0 \hat{\mathbf{j}}-45.0 \hat{\mathbf{i}}-30.0 \hat{\mathbf{j}}=-55.0 \hat{\mathbf{i}}-40.0 \hat{\mathbf{j}} .
$$

You cover one-third, moving to

$$
\overrightarrow{\mathbf{r}}_{3}=\overrightarrow{\mathbf{r}}_{2}+\Delta \overrightarrow{\mathbf{r}}_{23}=45.0 \hat{\mathbf{i}}+30.0 \hat{\mathbf{j}}+\frac{1}{3}(-55.0 \hat{\mathbf{i}}-40.0 \hat{\mathbf{j}})=26.7 \hat{\mathbf{i}}+16.7 \hat{\mathbf{j}} .
$$

The displacement from where you are to $D$ is

$$
\overrightarrow{\mathbf{r}}_{D}-\overrightarrow{\mathbf{r}}_{3}=40.0 \hat{\mathbf{i}}-30.0 \hat{\mathbf{j}}-26.7 \hat{\mathbf{i}}-16.7 \hat{\mathbf{j}}=13.3 \hat{\mathbf{i}}-46.7 \hat{\mathbf{j}} .
$$

You traverse one-quarter of it, moving to

$$
\overrightarrow{\mathbf{r}}_{4}=\overrightarrow{\mathbf{r}}_{3}+\frac{1}{4}\left(\overrightarrow{\mathbf{r}}_{D}-\overrightarrow{\mathbf{r}}_{3}\right)=26.7 \hat{\mathbf{i}}+16.7 \hat{\mathbf{j}}+\frac{1}{4}(13.3 \hat{\mathbf{i}}-46.7 \hat{\mathbf{j}})=30.0 \hat{\mathbf{i}}+5.00 \hat{\mathbf{j}} .
$$

The displacement from your new location to $\mathbf{E}$ is

$$
\overrightarrow{\mathbf{r}}_{E}-\overrightarrow{\mathbf{r}}_{4}=-70.0 \hat{\mathbf{i}}+60.0 \hat{\mathbf{j}}-30.0 \hat{\mathbf{i}}-5.00 \hat{\mathbf{j}}=-100 \hat{\mathbf{i}}+55.0 \hat{\mathbf{j}}
$$

of which you cover one-fifth the distance, $-20.0 \hat{\mathbf{i}}+11.0 \hat{\mathbf{j}}$, moving to

$$
\overrightarrow{\mathbf{r}}_{4}+\Delta \overrightarrow{\mathbf{r}}_{45}=30.0 \hat{\mathbf{i}}+5.00 \hat{\mathbf{j}}-20.0 \hat{\mathbf{i}}+11.0 \hat{\mathbf{j}}=10.0 \hat{\mathbf{i}}+16.0 \hat{\mathbf{j}} .
$$

The treasure is at $(10.0 \mathrm{~m}, 16.0 \mathrm{~m})$.
continued on next page

P4.37 To guess the answer, think of $v$ just a little less than the speed $c$ of the river. Then poor Alan will spend most of his time paddling upstream making very little progress. His time-averaged speed will be low and Beth will win the race.

Now we calculate: For Alan, his speed downstream is $c+v$, while his speed upstream is $c-v$. Therefore, the total time for Alan is

$$
t_{1}=\frac{L}{c+v}+\frac{L}{c-v}=\frac{2 L / c}{1-v^{2} / c^{2}}
$$

For Beth, her cross-stream speed (both ways) is

$$
\sqrt{c^{2}-v^{2}}
$$

Thus, the total time for Beth is $t_{2}=\frac{2 L}{\sqrt{c^{2}-v^{2}}}=\sqrt{\frac{2 L / c}{\sqrt{1-v^{2} / c^{2}}}}$.
Since $1-\frac{v^{2}}{c^{2}}<1, t_{1}>t_{2}$, or Beth, who swims cross-stream, returns first.
*P4.38 We can find the time of flight of the can by considering its horizontal motion:
$16 \mathrm{~m}=(9.5 \mathrm{~m} / \mathrm{s}) t+0 \quad t=1.68 \mathrm{~s}$
(a) For the boy to catch the can at the same location on the truck bed, he must throw it straight up, at $0^{\circ}$ to the vertical.
(b) For the free fall of the can, $y_{f}=y_{i}+v_{y i} t+(1 / 2) a_{y} t^{2}$ :
$0=0+v_{y i}(1.68 \mathrm{~s})-(1 / 2)\left(9.8 \mathrm{~m} / \mathrm{s}^{2}\right)(1.68 \mathrm{~s})^{2} \quad v_{y i}=8.25 \mathrm{~m} / \mathrm{s}$
(c) The boy sees the can always over his head,
traversing a straight line segment upward and then downward.
(d) The ground observer sees the can move as a projectile on
a symmetric section of a parabola opening downward. Its initial velocity is
$\left(9.5^{2}+8.25^{2}\right)^{1 / 2} \mathrm{~m} / \mathrm{s}=12.6 \mathrm{~m} / \mathrm{s}$ north at $\tan ^{-1}(8.25 / 9.5)=41.0^{\circ}$ above the horizontal

P4.39 Identify the student as the $S^{\prime}$ observer and the professor as
the $S$ observer. For the initial motion in $S^{\prime}$, we have

$$
\frac{v_{y}^{\prime}}{v_{x}^{\prime}}=\tan 60.0^{\circ}=\sqrt{3}
$$

Let $u$ represent the speed of $S^{\prime}$ relative to $S$. Then because there is no $x$-motion in $S$, we can write $v_{x}=v_{x}^{\prime}+u=0$ so that $v_{x}^{\prime}=-u=-10.0 \mathrm{~m} / \mathrm{s}$. Hence the ball is thrown backwards in $S^{\prime}$. Then,


The motion of the ball as seen by the student in $S^{\prime}$ is shown in diagram (b). The view of the professor in $S$ is shown in diagram (c).

## Section 5.7 Some Applications of Newton's Laws

*P5.15 As the worker through the pole exerts on the lake bottom a force of 240 N downward at $35^{\circ}$ behind the vertical, the lake bottom through the pole exerts a force of 240 N upward at $35^{\circ}$ ahead of the vertical. With the $x$ axis horizontally forward, the pole force on the boat is

$$
240 \mathrm{~N} \cos 35^{\circ} \hat{\mathbf{j}}+240 \mathrm{~N} \sin 35^{\circ} \hat{\mathbf{i}}=138 \mathrm{~N} \hat{\mathbf{i}}+197 \mathrm{~N} \hat{\mathbf{j}}
$$



The gravitational force of the whole Earth on boat and worker is $F_{g}=m g=370 \mathrm{~kg}\left(9.8 \mathrm{~m} / \mathrm{s}^{2}\right)=3630 \mathrm{~N}$ down. The acceleration of the boat is purely horizontal, so
$\sum F_{y}=m a_{y}$ gives $+B+197 \mathrm{~N}-3630 \mathrm{~N}=0$.
(a) The buoyant force is $B=3.43 \times 10^{3} \mathrm{~N}$.
(b) The acceleration is given by $\sum F_{x}=m a_{x}: \quad+138 \mathrm{~N}-47.5 \mathrm{~N}=(370 \mathrm{~kg}) a$; $a=\frac{90.2 \mathrm{~N}}{370 \mathrm{~kg}}=0.244 \mathrm{~m} / \mathrm{s}^{2}$. According to the constant-acceleration model,

$$
\begin{aligned}
& v_{x f}=v_{x i}+a_{x} t=0.857 \mathrm{~m} / \mathrm{s}+\left(0.244 \mathrm{~m} / \mathrm{s}^{2}\right)(0.450 \mathrm{~s})=0.967 \mathrm{~m} / \mathrm{s} \\
& \overrightarrow{\mathbf{v}}_{f}=0.967 \hat{\mathbf{i}} \mathrm{~m} / \mathrm{s}
\end{aligned}
$$

$\mathbf{P 5 . 1 6} v_{x}=\frac{d x}{d t}=10 t, v_{y}=\frac{d y}{d t}=9 t^{2}$
$a_{x}=\frac{d v_{x}}{d t}=10, a_{y}=\frac{d v_{y}}{d t}=18 t$
At $t=2.00 \mathrm{~s}, a_{x}=10.0 \mathrm{~m} / \mathrm{s}^{2}, a_{y}=36.0 \mathrm{~m} / \mathrm{s}^{2}$
$\sum F_{x}=m a_{x}: \quad 3.00 \mathrm{~kg}\left(10.0 \mathrm{~m} / \mathrm{s}^{2}\right)=30.0 \mathrm{~N}$
$\sum F_{y}=m a_{y}: \quad 3.00 \mathrm{~kg}\left(36.0 \mathrm{~m} / \mathrm{s}^{2}\right)=108 \mathrm{~N}$

$$
\sum F=\sqrt{F_{x}^{2}+F_{y}^{2}}=112 \mathrm{~N}
$$

P5.17

$$
\begin{aligned}
m & =1.00 \mathrm{~kg} \\
m g & =9.80 \mathrm{~N} \\
\tan \alpha & =\frac{0.200 \mathrm{~m}}{25.0 \mathrm{~m}} \\
\alpha & =0.458^{\circ}
\end{aligned}
$$

Balance forces,

$$
\begin{aligned}
2 T \sin \alpha & =m g \\
T & =\frac{9.80 \mathrm{~N}}{2 \sin \alpha}=613 \mathrm{~N}
\end{aligned}
$$



FIG. P5.17

## Additional Problems

P11.44 First, we define the following symbols:
$I_{P}=$ moment of inertia due to mass of people on the equator
$I_{E}=$ moment of inertia of the Earth alone (without people)
$\omega=$ angular velocity of the Earth (due to rotation on its axis)
$T=\frac{2 \pi}{\omega}=$ rotational period of the Earth (length of the day)
$R=$ radius of the Earth
The initial angular momentum of the system (before people start running) is

$$
L_{i}=I_{P} \omega_{i}+I_{E} \omega_{i}=\left(I_{P}+I_{E}\right) \omega_{i}
$$

When the Earth has angular speed $\omega$, the tangential speed of a point on the equator is $v_{t}=R \omega$. Thus, when the people run eastward along the equator at speed $v$ relative to the surface of the Earth, their tangential speed is $v_{p}=v_{t}+v=R \omega+v$ and their angular speed is $\omega_{P}=\frac{v_{p}}{R}=\omega+\frac{v}{R}$.

The angular momentum of the system after the people begin to run is

$$
L_{f}=I_{P} \omega_{p}+I_{E} \omega=I_{P}\left(\omega+\frac{v}{R}\right)+I_{E} \omega=\left(I_{P}+I_{E}\right) \omega+\frac{I_{P} v}{R}
$$

Since no external torques have acted on the system, angular momentum is conserved $\left(L_{f}=L_{i}\right)$, giving $\left(I_{P}+I_{E}\right) \omega+\frac{I_{P} v}{R}=\left(I_{P}+I_{E}\right) \omega_{i}$. Thus, the final angular velocity of the Earth is $\omega=\omega_{i}-\frac{I_{P} v}{\left(I_{P}+I_{E}\right) R}=\omega_{i}(1-x)=$, where $x \equiv \frac{I_{P} v}{\left(I_{P}+I_{E}\right) R \omega_{i}}$

The new length of the day is $T=\frac{2 \pi}{\omega}=\frac{2 \pi}{\omega_{i}(1-x)}=\frac{T_{i}}{1-x} \approx T_{i}(1+x)$, so the increase in the length of the day is $\Delta T=T-T_{i} \approx T_{i} x=T_{i}\left[\frac{I_{P} v}{\left(I_{P}+I_{E}\right) R \omega_{i}}\right]$. Since $\omega_{i}=\frac{2 \pi}{T_{i}}$, this may be written as $\Delta T \approx \frac{T_{i}^{2} I_{P} v}{2 \pi\left(I_{P}+I_{E}\right) R}$

To obtain a numeric answer, we compute

$$
I_{P}=m_{p} R^{2}=\left[\left(7 \times 10^{9}\right)(70 \mathrm{~kg})\right]\left(6.37 \times 10^{6} \mathrm{~m}\right)^{2}=1.99 \times 10^{25} \mathrm{~kg} \cdot \mathrm{~m}^{2}
$$

and

$$
I_{E}=\frac{2}{5} m_{E} R^{2}=\frac{2}{5}\left(5.98 \times 10^{24} \mathrm{~kg}\right)\left(6.37 \times 10^{6} \mathrm{~m}\right)^{2}=9.71 \times 10^{37} \mathrm{~kg} \cdot \mathrm{~m}^{2}
$$

Thus,

$$
\Delta T \approx \frac{\left(8.64 \times 10^{4} \mathrm{~s}\right)^{2}\left(1.99 \times 10^{25} \mathrm{~kg} \cdot \mathrm{~m}^{2}\right)(2.5 \mathrm{~m} / \mathrm{s})}{2 \pi\left[\left(1.99 \times 10^{25}+9.71 \times 10^{37}\right) \mathrm{kg} \cdot \mathrm{~m}^{2}\right]\left(6.37 \times 10^{6} \mathrm{~m}\right)}=9.55 \times 10^{-11} \mathrm{~s}
$$

(d) $\quad v=-(0.299 \mathrm{~m})(1.09 / \mathrm{s}) \sin 255^{\circ}=+0.315 \mathrm{~m} / \mathrm{s}$


P15.9 $x=A \cos \omega t \quad A=0.05 \mathrm{~m} \quad v=-A \omega \sin \omega t \quad a=-A \omega^{2} \cos \omega t$
If $f=3600 \mathrm{rev} / \mathrm{min}=60 \mathrm{~Hz}$, then $\omega=120 \pi \mathrm{~s}^{-1}$

$$
v_{\max }=0.05(120 \pi) \mathrm{m} / \mathrm{s}=18.8 \mathrm{~m} / \mathrm{s} \quad a_{\text {max }}=0.05(120 \pi)^{2} \mathrm{~m} / \mathrm{s}^{2}=7.11 \mathrm{~km} / \mathrm{s}^{2}
$$

P15.10 $m=1.00 \mathrm{~kg}, k=25.0 \mathrm{~N} / \mathrm{m}$, and $A=3.00 \mathrm{~cm}$. At $t=0, x=-3.00 \mathrm{~cm}$
(a) $\quad \omega=\sqrt{\frac{k}{m}}=\sqrt{\frac{25.0}{1.00}}=5.00 \mathrm{rad} / \mathrm{s}$
so that, $\quad T=\frac{2 \pi}{\omega}=\frac{2 \pi}{5.00}=1.26 \mathrm{~s}$
(b) $v_{\text {max }}=A \omega=3.00 \times 10^{-2} \mathrm{~m}(5.00 \mathrm{rad} / \mathrm{s})=0.150 \mathrm{~m} / \mathrm{s}$
$a_{\text {max }}=A \omega^{2}=3.00 \times 10^{-2} \mathrm{~m}(5.00 \mathrm{rad} / \mathrm{s})^{2}=0.750 \mathrm{~m} / \mathrm{s}^{2}$
(c) Because $x=-3.00 \mathrm{~cm}$ and $v=0$ at $t=0$, the required solution is $x=-A \cos \omega t$

$$
\text { or } \begin{aligned}
& x=-3.00 \cos (5.00 t) \mathrm{cm} \\
& v=\frac{d x}{d t}=15.0 \sin (5.00 t) \mathrm{cm} / \mathrm{s} \\
& a=\frac{d v}{d t}=75.0 \cos (5.00 \mathrm{t}) \mathrm{cm} / \mathrm{s}^{2}
\end{aligned}
$$

P15.11 (a) $\omega=\sqrt{\frac{k}{m}}=\sqrt{\frac{8.00 \mathrm{~N} / \mathrm{m}}{0.500 \mathrm{~kg}}}=4.00 \mathrm{~s}^{-1} \quad$ so position is given by $\quad x=10.0 \sin (4.00 t) \mathrm{cm}$
From this we find that
$v=40.0 \cos (4.00 t) \mathrm{cm} / \mathrm{s} \quad v_{\text {max }}=40.0 \mathrm{~cm} / \mathrm{s}$
$a=-160 \sin (4.00 t) \mathrm{cm} / \mathrm{s}^{2} \quad a_{\text {max }}=160 \mathrm{~cm} / \mathrm{s}^{2}$
(b) $\quad t=\left(\frac{1}{4.00}\right) \sin ^{-1}\left(\frac{x}{10.0}\right)$ and when $\quad x=6.00 \mathrm{~cm}, t=0.161 \mathrm{~s}$.

We find
$v=40.0 \cos [4.00(0.161)]=32.0 \mathrm{~cm} / \mathrm{s}$
$a=-160 \sin [4.00(0.161)]=-96.0 \mathrm{~cm} / \mathrm{s}^{2}$
(c) Using $t=\left(\frac{1}{4.00}\right) \sin ^{-1}\left(\frac{x}{10.0}\right)$
when $x=0, t=0$ and when $\quad x=8.00 \mathrm{~cm}, t=0.232 \mathrm{~s}$
Therefore,
$\Delta t=0.232 \mathrm{~s}$

## Section 19.4 Thermal Expansion of Solids and Liquids

P19.5 The wire is 35.0 m long when $T_{C}=-20.0^{\circ} \mathrm{C}$.

$$
\begin{aligned}
& \Delta L=L_{i} \bar{\alpha}\left(T-T_{i}\right) \\
& \bar{\alpha}=\alpha\left(20.0^{\circ} \mathrm{C}\right)=1.70 \times 10^{-5}\left(\mathrm{C}^{\circ}\right)^{-1} \text { for } \mathrm{Cu} . \\
& \Delta L=(35.0 \mathrm{~m})\left(1.70 \times 10^{-5}\left(\mathrm{C}^{\circ}\right)^{-1}\right)\left(35.0^{\circ} \mathrm{C}-\left(-20.0^{\circ} \mathrm{C}\right)\right)=+3.27 \mathrm{~cm}
\end{aligned}
$$

P19.6 Each section can expand into the joint space to the north of it. We need think of only one section expanding. $\Delta L=L_{i} \alpha \Delta T=(25.0 \mathrm{~m})\left(12.0 \times 10^{-6} / \mathrm{C}^{\circ}\right)\left(40.0^{\circ} \mathrm{C}\right)=1.20 \mathrm{~cm}$

P19.7 (a) $\Delta L=\alpha L_{i} \Delta T=9.00 \times 10^{-6}{ }^{\circ} \mathrm{C}^{-1}(30.0 \mathrm{~cm})\left(65.0^{\circ} \mathrm{C}\right)=0.176 \mathrm{~mm}$
(b) $\quad L$ stands for any linear dimension.

$$
\Delta L=\alpha L_{i} \Delta T=9.00 \times 10^{-6}{ }^{\circ} \mathrm{C}^{-1}(1.50 \mathrm{~cm})\left(65.0^{\circ} \mathrm{C}\right)=8.78 \times 10^{-4} \mathrm{~cm}
$$

(c) $\quad \Delta V=3 \alpha V_{i} \Delta T=3\left(9.00 \times 10^{-6}{ }^{\circ} \mathrm{C}^{-1}\right)\left(\frac{30.0(\pi)(1.50)^{2}}{4} \mathrm{~cm}^{3}\right)\left(65.0^{\circ} \mathrm{C}\right)=0.0930 \mathrm{~cm}^{3}$

P19.8 The horizontal section expands according to $\Delta L=\alpha L_{i} \Delta T$.

$$
\Delta x=\left(17 \times 10^{-6}{ }^{\circ} \mathrm{C}^{-1}\right)(28.0 \mathrm{~cm})\left(46.5^{\circ} \mathrm{C}-18.0^{\circ} \mathrm{C}\right)=1.36 \times 10^{-2} \mathrm{~cm}
$$

The vertical section expands similarly by

$$
\Delta y=\left(17 \times 10^{-6}{ }^{\circ} \mathrm{C}^{-1}\right)(134 \mathrm{~cm})\left(28.5^{\circ} \mathrm{C}\right)=6.49 \times 10^{-2} \mathrm{~cm}
$$



FIG. P19.8

The vector displacement of the pipe elbow has magnitude

$$
\Delta r=\sqrt{\Delta x^{2}+\Delta y^{2}}=\sqrt{(0.136 \mathrm{~mm})^{2}+(0.649 \mathrm{~mm})^{2}}=0.663 \mathrm{~mm}
$$

and is directed to the right below the horizontal at angle

$$
\theta=\tan ^{-1}\left(\frac{\Delta y}{\Delta x}\right)=\tan ^{-1}\left(\frac{0.649 \mathrm{~mm}}{0.136 \mathrm{~mm}}\right)=78.2^{\circ}
$$

$\Delta r=0.663 \mathrm{~mm}$ to the right at $78.2^{\circ}$ below the horizontal
*P19.9 (a) $\quad L_{\text {Al }}\left(1+\alpha_{\text {Al }} \Delta T\right)=L_{\text {Brass }}\left(1+\alpha_{\text {Brass }} \Delta T\right)$
$\Delta T=\frac{L_{\mathrm{Al}}-L_{\text {Brass }}}{L_{\text {Brass }} \alpha_{\text {Brass }}-L_{\mathrm{Al}} \alpha_{\mathrm{Al}}}$
$\Delta T=\frac{(10.01-10.00)}{(10.00)\left(19.0 \times 10^{-6}\right)-(10.01)\left(24.0 \times 10^{-6}\right)}$
$\Delta T=-199^{\circ} \mathrm{C}$ so $T=-179^{\circ} \mathrm{C} . \begin{aligned} & \text { This is attainable, because it is above absolute zero }\end{aligned}$
(b) $\quad \Delta T=\frac{(10.02-10.00)}{(10.00)\left(19.0 \times 10^{-6}\right)-(10.02)\left(24.0 \times 10^{-6}\right)}$
$\Delta T=-396^{\circ} \mathrm{C}$ so
$T=-376^{\circ} \mathrm{C}$, which is below 0 K so it cannot be reached. The rod and ring cannot be separated by changing their temperatures together.

P38.63 (a) The E and O rays, in phase at the surface of the plate, will have a phase difference $\theta=\left(\frac{2 \pi}{\lambda}\right) \delta$
after traveling distance $d$ through the plate. Here $\delta$ is the difference in the optical path lengths of these rays. The optical path length between two points is the product of the actual path length $d$ and the index of refraction. Therefore,
$\delta=\left|d n_{O}-d n_{E}\right|$
The absolute value is used since $\underline{n_{O}}$ may be more or less than unity. Therefore,
$\theta=\left(\frac{2 \pi}{\lambda}\right)\left|d n_{O}-d n_{E}\right|=\left(\frac{2 \pi}{\lambda}\right) d\left|n_{O}-n_{E}\right|$
(b) $\quad d=\frac{\lambda \theta}{2 \pi\left|n_{O}-n_{E}\right|}=\frac{\left(550 \times 10^{-9} \mathrm{~m}\right)(\pi / 2)}{2 \pi|1.544-1.553|}=1.53 \times 10^{-5} \mathrm{~m}=15.3 \mu \mathrm{~m}$

P38.64 (a) From Equation 38.2, $\frac{I}{I_{\max }}=\left[\frac{\sin (\phi)}{\phi}\right]^{2}$
where we define $\quad \phi \equiv \frac{\pi a \sin \theta}{\lambda}$
Therefore, when $\quad \frac{I}{I_{\max }}=\frac{1}{2} \quad$ we must have $\quad \frac{\sin \phi}{\phi}=\frac{1}{\sqrt{2}}$, or $\sin \phi=\frac{\phi}{\sqrt{2}}$
(b) Let $y_{1}=\sin \phi$ and $y_{2}=\frac{\phi}{\sqrt{2}}$.

A plot of $y_{1}$ and $y_{2}$ in the range $1.00 \leq \phi \leq \frac{\pi}{2}$ is shown to the right.

The solution to the transcendental equation is found to
be $\phi=1.39 \mathrm{rad}$.


FIG. P38.64(b)
(c) $\frac{\pi a \sin \theta}{\lambda}=\phi$ gives $\sin \theta=\left(\frac{\phi}{\pi}\right) \frac{\lambda}{a}=0.443 \frac{\lambda}{a}$.

If $\frac{\lambda}{a}$ is small, then $\theta \approx 0.443 \frac{\lambda}{a}$.
This gives the half-width, measured away from the maximum at $\theta=0$. The pattern is symmetric, so the full width is given by
$\Delta \theta=0.443 \frac{\lambda}{a}-\left(-0.443 \frac{\lambda}{a}\right)=\frac{0.886 \lambda}{a}$

## Section 42.6 Physical Interpretation of the Quantum Numbers

Note: Problems 31 and 36 in Chapter 29 and Problem 62 in Chapter 30 can be assigned with this section.
P42.21 (a) In the $3 d$ subshell, $n=3$ and $\ell=2$,

$$
\begin{array}{c|rrrrrrrrrr}
\text { we have } n & 3 & 3 & 3 & 3 & 3 & 3 & 3 & 3 & 3 & 3 \\
\ell & 2 & 2 & 2 & 2 & 2 & 2 & 2 & 2 & 2 & 2 \\
m_{\ell} & +2 & +2 & +1 & +1 & 0 & 0 & -1 & -1 & -2 & -2 \\
m_{s} & +1 / 2 & -1 / 2 & +1 / 2 & -1 / 2 & +1 / 2 & -1 / 2 & +1 / 2 & -1 / 2 & +1 / 2 & -1 / 2
\end{array}
$$

(A total of 10 states)
(b) In the $3 p$ subshell, $n=3$ and $\ell=1$,
we have $\left.n \left\lvert\, \begin{array}{rrrrrr}3 & 3 & 3 & 3 & 3 & 3 \\ \ell & 1 & 1 & 1 & 1 & 1\end{array}\right.\right) 12$
(A total of 6 states)
P42.22
(a) For the $d$ state, $\ell=2$,
$L=\sqrt{6 \hbar}=2.58 \times 10^{-34} \mathrm{~J} \cdot \mathrm{~s}$
(b) For the $f$ state, $\ell=3$,

$$
L=\sqrt{\ell(\ell+1)} \hbar=\sqrt{12} \hbar=3.65 \times 10^{-34} \mathrm{~J} \cdot \mathrm{~s}
$$

*P42.23 (a) The problem: Find the orbital quantum number of a hydrogen atom in a state in which it has orbital angular momentum $4.714 \times 10^{-34} \mathrm{~J} \cdot \mathrm{~s}$.
(b) The solution: $L=\sqrt{\ell(\ell+1)} \hbar$

$$
\begin{aligned}
& \sqrt{\ell(\ell+1)} \hbar \quad 4.714 \times 10^{-34}=\sqrt{\ell(\ell+1)}\left(\frac{6.626 \times 10^{-34}}{2 \pi}\right) \\
& \ell(\ell+1)=\frac{\left(4.714 \times 10^{-34}\right)^{2}(2 \pi)^{2}}{\left(6.626 \times 10^{-34}\right)^{2}}=1.998 \times 10^{1} \approx 20=4(4+1)
\end{aligned}
$$

so the orbital quantum number is $\ell=4$.

P42.24 The 5th excited state has $n=6$, energy $\frac{-13.6 \mathrm{eV}}{36}=-0.378 \mathrm{eV}$.
The atom loses this much energy: $\quad \frac{h c}{\lambda}=\frac{\left(6.626 \times 10^{-34} \mathrm{~J} \cdot \mathrm{~s}\right)\left(3.00 \times 10^{8} \mathrm{~m} / \mathrm{s}\right)}{\left(1090 \times 10^{-9} \mathrm{~m}\right)\left(1.60 \times 10^{-19} \mathrm{~J} / \mathrm{eV}\right)}=1.14 \mathrm{eV}$
to end up with energy

$$
-0.378 \mathrm{eV}-1.14 \mathrm{eV}=-1.52 \mathrm{eV}
$$

which is the energy in state $3: \quad-\frac{13.6 \mathrm{eV}}{3^{3}}=-1.51 \mathrm{eV}$
While $n=3, \ell$ can be as large as 2 , giving angular momentum $\sqrt{\ell(\ell+1)} \hbar=\sqrt{6} \hbar$.

P46.23

| (a) $\mu^{-} \rightarrow \mathrm{e}^{-}+\gamma$ | $L_{e}:$ | $0 \rightarrow 1+0$, |
| :--- | :--- | :--- |
| and | $L_{\mu}:$ | $1 \rightarrow 0$ |
| (b) $\quad \mathrm{n} \rightarrow \mathrm{p}+\mathrm{e}^{-}+v_{e}$ | $L_{e}:$ | $0 \rightarrow 0+1+1$ |
| (c) $\Lambda^{0} \rightarrow \mathrm{p}+\pi^{0}$ | Strangeness: | $-1 \rightarrow 0+0$, |
|  | and | charge: |
| (d) | $\mathrm{p} \rightarrow \mathrm{e}^{+}+\pi^{0}$ | Baryon number: |
| (e) $\Xi^{0} \rightarrow \mathrm{n}+\pi^{0}$ | Strangeness: | $0 \rightarrow+1+0$ |
|  |  |  |

P46.24 (a) $\pi^{-}+\mathrm{p} \rightarrow 2 \eta$ violates conservation of baryon number as $0+1 \rightarrow 0, \quad$ not allowed .
(b) $\mathrm{K}^{-}+\mathrm{n} \rightarrow \Lambda^{0}+\pi^{-}$

Baryon number
$0+1 \rightarrow 1+0$
Charge, $\quad-1+0 \rightarrow 0-1$
Strangeness, $\quad-1+0 \rightarrow-1+0$
Lepton number, $\quad 0 \rightarrow 0$
The interaction may occur via the strong interaction since all are conserved.
(c) $\mathrm{K}^{-} \rightarrow \pi^{-}+\pi^{0}$

| Strangeness, | $-1 \rightarrow 0+0$ |
| :--- | :--- |
| Baryon number, | $0 \rightarrow 0$ |
| Lepton number, | $0 \rightarrow 0$ |
| Charge, | $-1 \rightarrow-1+0$ |

Strangeness conservation is violated by one unit, but everything else is conserved. Thus, the reaction can occur via the weak interaction, but not the strong or electromagnetic interaction.
(d) $\Omega^{-} \rightarrow \Xi^{-}+\pi^{0}$

| Baryon number, | $1 \rightarrow 1+0$ |
| :--- | :--- |
| Lepton number, | $0 \rightarrow 0$ |
| Charge, | $-1 \rightarrow-1+0$ |
| Strangeness, | $-3 \rightarrow-2+0$ |

May occur by weak interaction, but not by strong or electromagnetic.
(e) $\quad \eta \rightarrow 2 \gamma$

| Baryon number, | $0 \rightarrow 0$ |
| :--- | :--- |
| Lepton number, | $0 \rightarrow 0$ |
| Charge, | $0 \rightarrow 0$ |
| Strangeness, | $0 \rightarrow 0$ |

No conservation laws are violated, but photons are the mediators of the electromagnetic interaction. Also, the lifetime of the $\eta$ is consistent with the electromagnetic interaction.

