TABLE 32–8 Quarks and Antiquarks

		Quarks		Antiquarks	
Name	Rest Energy (MeV)	Symbol	Charge	Symbol	Charge
Up	360	u	$+\frac{2}{3}e$	$\bar{u}$	$-\frac{2}{3}e$
Down	360	d	$-\frac{1}{3}e$	$\bar{d}$	$+\frac{1}{3}e$
Charmed	1500	c	$+\frac{2}{3}e$	$\bar{c}$	$-\frac{2}{3}e$
Strange	540	s	$-\frac{1}{3}e$	$\bar{s}$	$+\frac{1}{3}e$
Top	173,000	t	$+\frac{2}{3}e$	$\bar{t}$	$-\frac{2}{3}e$
Bottom	5000	b	$-\frac{1}{3}e$	$\bar{b}$	$+\frac{1}{3}e$

hadrons are composed of a number of truly elementary particles that Gell-Mann dubbed quarks. Originally, it was proposed that there are three types of quarks, arbitrarily named up (u), down (d), and strange (s). Discoveries of new and more massive hadrons, such as the J/ψ particle discovered in 1974, have necessitated the addition of three more quarks. The equally whimsical names for these new quarks are charmed (c), top or truth (t), and bottom or beauty (b). Table 32–8 lists the six quarks, along with some of their more important properties.

The antiparticles to the quarks are also given in Table 32–8. Notice that antiquarks are indicated with a bar over the symbol for the corresponding quark. For example, the symbol for the up quark is u; the symbol for the corresponding antiquark is $\bar{u}$.

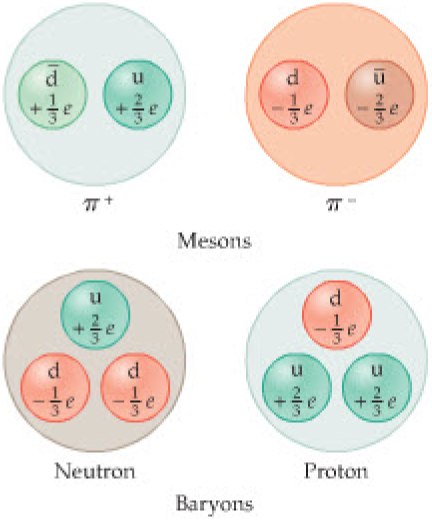
Quarks are unique among the elementary particles in a number of ways. For example, they all have charges that are fractions of the charge of the electron. As can be seen in Table 32–8, some quarks have a charge of $+(\frac{2}{3})e$ or $-(\frac{2}{3})e$; others have a charge of $+(\frac{1}{3})e$ or $-(\frac{1}{3})e$. No other particles are known to have charges that differ from integer multiples of the electron's charge.

Now it might seem that the fractional charge of a quark would make it easy to identify experimentally. In fact, a number of experiments have searched for quarks in just that way, by looking for particles with fractional charge. No such particle has ever been observed, however. It is now believed that a free, independent quark cannot exist; quarks must always be bound with other quarks. This concept is referred to as **quark confinement.** The physical reason behind confinement is that the force between two quarks increases with separation—like two particles connected by a spring. Hence, an infinite amount of energy is required to increase the separation between two quarks to infinity.

The smallest system of bound quarks that can be observed as an independent particle is a pair of quarks. In fact, mesons consist of bound pairs of quarks and antiquarks, as illustrated schematically in Figure 32–12. For example, the π^+ meson is composed of a $u\bar{d}$ pair of quarks. Note that this combination of quarks gives the π^+ meson a net charge of $+e$. The π^- meson, the antiparticle to the π^+ meson, consists of a $\bar{u}d$ pair with a charge of $-e$. Quarks are always bound in configurations that result in integer charges.

Baryons are bound systems consisting of three quarks, as shown in Figure 32–12. The proton, for example, has the composition uud, with a net charge of $+e$. The neutron, on the other hand, is formed from the combination udd, with a net charge of 0. A variety of hadrons and their corresponding quark compositions are given in Table 32–9.

Finally, not long after the quark model of elementary particles was introduced, it was found that some quark compositions implied a violation of the Pauli exclusion principle. To resolve these discrepancies, it was suggested that quarks must come in three different varieties, which were given the completely arbitrary but colorful names red, green, and blue. Though these quark "colors" have nothing to do with visible colors in the electromagnetic spectrum, they bring quarks into agreement with the exclusion principle and explain other experimental observations that were difficult to understand before the introduction of this new property. The



▲ **FIGURE 32–12 The quark composition of mesons and baryons**

Mesons and baryons are composed of various quark combinations—mesons always have a quark and an antiquark, baryons always have three quarks. Note that even though quarks have fractional charges (in units of the electron charge, *e*), the resulting mesons and baryons always have integer charges.

TABLE 32–9 Quark Composition of Some Hadrons

Particle	Quark Composition
MESONS	
π^+	$u\bar{d}$
π^-	$\bar{u}d$
K^+	$u\bar{s}$
K^-	$\bar{u}s$
K^0	$d\bar{s}$
BARYONS	
p	uud
n	udd
Σ^+	uus
Σ^0	uds
Σ^-	dds
Ξ^0	uss
Ξ^-	dss
Ω^-	sss

theory of how colored quarks interact with one another is called **quantum chromodynamics,** or QCD, in analogy with the theory describing interactions between charged particles, which is known as **quantum electrodynamics,** or QED.

32–9 Unified Forces and Cosmology

As discussed earlier, the universe as we see it today has four fundamental forces through which various particles interact with one another. This has not always been the case, however. Shortly after the Big Bang these four forces were combined into a single force sometimes referred to as the **unified force.** This situation lasted for only a brief interval of time. As the early universe expanded and cooled, it eventually underwent a type of "phase transition" in which the gravitational force took on a separate identity. This transition occurred at a time of approximately 10^{-43} s after the Big Bang, when the temperature of the universe was about 10^{32} K.

The phase transition just described was the first of three such transitions to occur in the early universe, as we see in **Figure 32–13**. At 10^{-35} s, when the temperature was 10^{28} K, the strong nuclear force became a separate force. Similarly, the weak nuclear force became a separate force at 10^{-10} s, when the temperature was 10^{15} K. From 10^{-10} s until the present, the situation has remained the same, even as the temperature of the universe has dipped to a chilly 2.7 K.

Let's look at these forces and the transitions between them more carefully. First, the electromagnetic force combines the forces associated with both electricity and magnetism. Although electricity and magnetism were originally thought to be separate forces, the work of Maxwell and others showed that these forces are simply different aspects of the same underlying force. For example, changing electric fields generate magnetic fields, and changing magnetic fields generate electric fields. In fact, the theory of electromagnetism can be thought of as the first *unified field theory*, in which seemingly different forces are combined into one all-encompassing theory.

At times earlier than 10^{-10} s the weak nuclear force was indistinguishable from the electromagnetic force. Thus, even though these forces seem very different today, we can recognize them as different aspects of the same underlying force—much like the two faces of a coin look very different but are part of the same physical object. The theory that encompasses the weak nuclear force and the electromagnetic force is called the **electroweak theory.** It was developed by Sheldon Glashow, Abdus Salam, and Steven Weinberg.

Going further back in time, the strong nuclear force was indistinguishable from the electroweak force before 10^{-35} s. Although no one has yet succeeded in producing a theory combining the electroweak force and the strong nuclear force, most physicists feel confident that such a theory exists. This hypothetical theory is referred to as the **grand unified theory,** or GUT.

Finally, a theory that encompasses gravity along with the other forces of nature is one of the ultimate goals of physics. Many physicists, including Einstein in his later years, have worked long and hard toward such an end, but so far with little success.

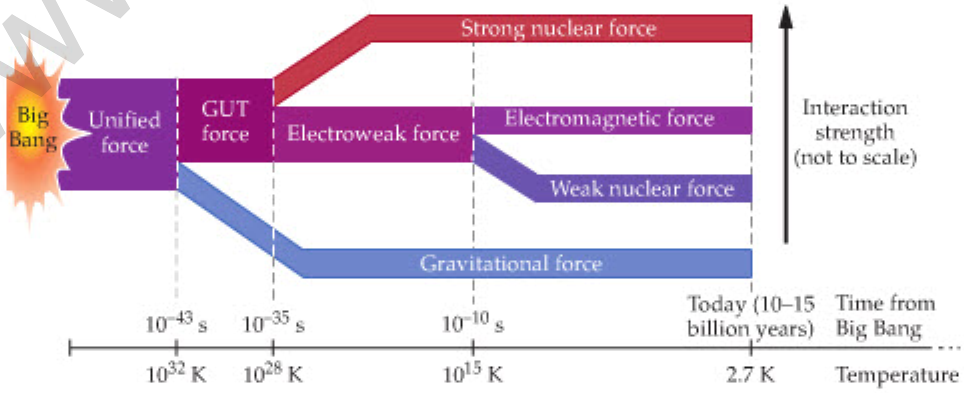


FIGURE 32–13 The evolution of the four fundamental forces

The four forces we observe in today's universe began as a single unified force at the time of the Big Bang. As the universe cooled, the unified force evolved through a series of "transitions" in which the various forces took on different characteristics.

THE BIG PICTURE PUTTING PHYSICS IN CONTEXT

LOOKING BACK

In this, our final chapter, we've discussed some of the frontiers of modern physics, like fundamental forces, elementary particles, and the evolution of the universe. And yet, no matter how advanced or esoteric the topic, the fundamental principles of physics still form the basis for our understanding. A few examples from this chapter are as follows:

In considering the decay of a nucleus, we used the concept of electrostatic repulsion, momentum conservation, and energy conservation. For example, we compared the kinetic energies of nuclear decay products in Conceptual Checkpoint 32–2 with exactly the same methods used to study air carts in Chapter 9.

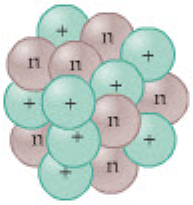
The most famous equation in physics, $E = mc^2$, plays a key role in nuclear reactions. In general, the mass of nuclear decay products does not add up to the mass of the initial nucleus—instead, the mass difference appears as energy given off during the decay. $E = mc^2$ also occurs in the study of matter/antimatter annihilation.

Finally, the evolution of the universe has been marked by a series of phase transitions as it cooled after the Big Bang. These phase transitions are similar to those studied in Chapter 17, and have resulted in a single force splitting into the four distinct types of forces we see in the universe today.

CHAPTER SUMMARY

32–1 THE CONSTITUENTS AND STRUCTURE OF NUCLEI

Nuclei are composed of just two types of particles: protons and neutrons. These particles are referred to collectively as nucleons.



Atomic Number, Z; Neutron Number, N; Mass Number, A

The atomic number, Z, is equal to the number of protons in a nucleus. The neutron number, N, is the number of neutrons in a nucleus. The mass number of a nucleus, A, is the total number of nucleons it contains. Thus, $A = N + Z$.

Designation of Nuclei

A nucleus with atomic number Z and mass number A is designated as follows:

$$^{A}_{Z}X$$

Isotopes

Isotopes are nuclei with the same atomic number but different neutron number.

Atomic Mass Unit, u

A convenient mass unit for nucleons and nuclei is the atomic mass unit, u, which is defined so that the mass of $^{12}_{6}\text{C}$ is exactly 12 u. The value of u is as follows:

$$1\ \text{u} = 1.660540 \times 10^{-27}\ \text{kg} \tag{32–2}$$

Neutrons and protons have masses slightly greater than 1 u, with the neutron slightly more massive than the proton.

Energy/Mass Equivalence

The atomic mass unit can be expressed in terms of energy (MeV) as follows:

$$1\ \text{u} = 931.5\ \text{MeV}/c^2 \tag{32–3}$$

Nuclear Size and Density

The approximate radius of a nucleus of mass number A is given by

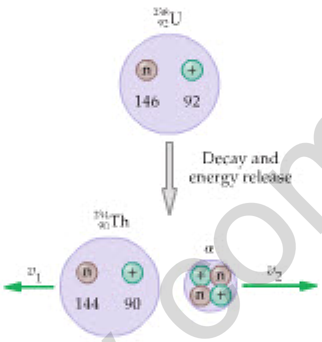
$$r = (1.2 \times 10^{-15}\ \text{m})A^{1/3} \tag{32–4}$$

All nuclei have roughly the same density, regardless of their mass number.

Nuclear Forces and Stability

Nuclei are held together by the strong nuclear force. This force is attractive between all nucleons and has a range of only a few fermis.

32–2 RADIOACTIVITY



Radioactivity refers to the emissions observed when an unstable nucleus changes its composition or when an excited nucleus decays to a lower-energy state.

Alpha Decay
An α particle (the nucleus of a helium atom) consists of two protons and two neutrons. A nucleus that emits an α particle decreases its mass number by 4 and its atomic number by 2:

$$^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

where X is the parent nucleus and Y is the daughter nucleus.

Beta Decay
Beta decay refers to the emission of an electron, as when a neutron decays into a proton, an electron, and an antineutrino:

$$^{1}_{0}n \longrightarrow {}^{1}_{1}p + e^{-} + \overline{\nu}$$

This type of decay, which increases the atomic number by 1 but leaves the mass number unchanged, is referred to as β^- decay. If a positron and a neutrino are given off instead, we refer to the process as β^+ decay.

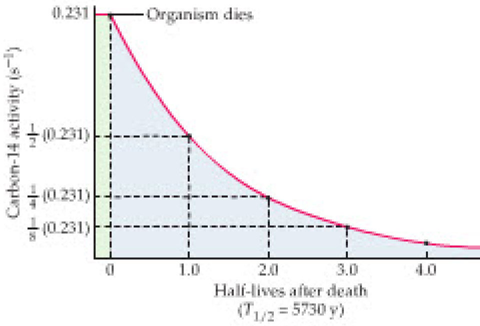
Gamma Decay
Gamma decay occurs when an excited nucleus drops to a lower-energy state and emits a photon. In this case, neither the mass number nor the atomic number is changed.

Activity
The activity of a radioactive sample is equal to the number of decays per second. The units of activity are the curie (Ci) and the becquerel (Bq):

$$1 \text{ curie} = 1 \text{ Ci} = 3.7 \times 10^{10} \text{ decays/s} \qquad 32\text{–}6$$

$$1 \text{ becquerel} = 1 \text{ Bq} = 1 \text{ decay/s} \qquad 32\text{–}7$$

32–3 HALF-LIFE AND RADIOACTIVE DATING



Radioactive nuclei decay with time in a well-defined way. As a result, many radioactive nuclei can be used as a type of "nuclear clock."

Nuclei as a Function of Time and the Decay Constant, λ
If the number of radioactive nuclei in a sample at time $t = 0$ is N_0, the number, N, at a later time is

$$N = N_0 e^{-\lambda t} \qquad 32\text{–}9$$

The constant, λ, in this expression is referred to as the decay constant.

Half-life, $T_{1/2}$
The half-life of a radioactive material is the time required for half of its nuclei to decay. In terms of the decay constant, the half-life is

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda} \qquad 32\text{–}10$$

Decay Rate, or Activity, R
The rate at which radioactive nuclei decay is proportional to the number of nuclei present at any given time, and to the decay constant:

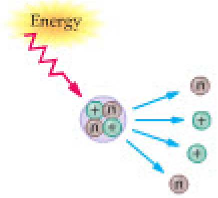
$$R = \left|\frac{\Delta N}{\Delta t}\right| = \lambda N = \lambda N_0 e^{-\lambda t} = R_0 e^{-\lambda t} \qquad 32\text{–}11, 32\text{–}12$$

Carbon-14 Dating
Carbon-14 can be used to date organic materials with ages up to about 15,000 y. The age can be found using

$$t = -\frac{1}{\lambda}\ln\frac{R}{R_0} = \frac{1}{\lambda}\ln\frac{R_0}{R} \qquad 32\text{–}13$$

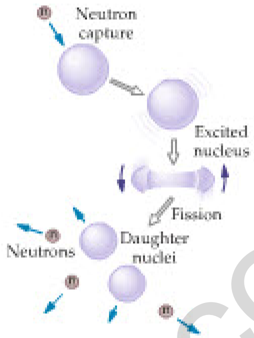
where $R_0 = 0.231$ is the initial activity, R is the present activity, and $\lambda = 1.21 \times 10^{-4}\ \text{y}^{-1}$.

32–4 NUCLEAR BINDING ENERGY



The binding energy of a nucleus is the energy that must be supplied to separate it into its component nucleons.

32–5 NUCLEAR FISSION



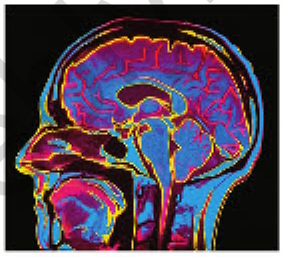
Nuclear fission is the process in which a large nucleus captures a neutron and then divides into two smaller "daughter" nuclei. Typical fission reactions emit two or three neutrons along with the daughter nuclei.

Chain Reactions
When neutrons given off by one fission reaction initiate additional fission reactions, we refer to the process as a chain reaction.

32–6 NUCLEAR FUSION

Nuclear fusion occurs when two small nuclei merge to form a larger nucleus. To initiate a fusion reaction, it is necessary to give the small nuclei enough energy to overcome their mutual Coulomb repulsion.

32–7 PRACTICAL APPLICATIONS OF NUCLEAR PHYSICS



Nuclear radiation can have both harmful and useful effects. An important way to characterize exposure to radiation is in terms of dosage, which can be defined in a number of ways.

Roentgen, R
The first unit of radiation, the roentgen, is related to the amount of ionization charge produced by 200-keV X-rays in 1 kg of dry air at STP:

$$1\ \mathrm{R} = 2.58 \times 10^{-4}\ \mathrm{C/kg} \quad \text{(X-rays or } \gamma \text{ rays in dry air at STP)} \qquad 32\text{–}15$$

Radiation Absorbed Dose (rad)
The rad is a measure of the amount of energy absorbed by an irradiated material, regardless of the type of radiation:

$$1\ \mathrm{rad} = 0.01\ \mathrm{J/kg} \quad \text{(any type of radiation)} \qquad 32\text{–}16$$

Relative Biological Effectiveness (RBE)
The RBE takes into account that different types of radiation produce different amounts of biological damage. It is defined as follows:

$$\mathrm{RBE} = \frac{\begin{array}{c}\text{the dose of 200-keV X-rays necessary to}\\ \text{produce a given biological effect}\end{array}}{\begin{array}{c}\text{the dose of a particular type of radiation}\\ \text{necessary to produce the same biological effect}\end{array}} \qquad 32\text{–}17$$

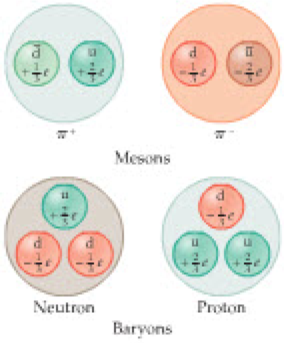
Roentgen Equivalent in Man (rem)
Combining the rad and the RBE yields the rem:

$$\text{dose in rem} = \text{dose in rad} \times \mathrm{RBE} \qquad 32\text{–}18$$

A dose of 1 rem of any type of radiation causes the same amount of biological damage.

32–8 ELEMENTARY PARTICLES

Elementary particles are the fundamental building blocks of all matter.



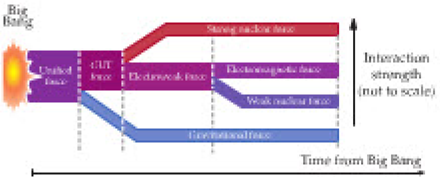
The Fundamental Forces of Nature
There are just four fundamental forces in nature. In order of decreasing strength, they are the strong nuclear force, the electromagnetic force, the weak nuclear force, and the gravitational force.

Leptons
Leptons are elementary particles that experience the weak nuclear force but not the strong nuclear force.

Hadrons
Hadrons are composite particles that experience both the weak and the strong nuclear force.

Quarks
Quarks are elementary particles that combine to form hadrons. Mesons are formed from quark-antiquark pairs; baryons are formed from combinations of three quarks.

32–9 UNIFIED FORCES AND COSMOLOGY



The four fundamental forces observed in the universe today began as a single force at the time of the Big Bang. As the universe expanded and cooled, the single force split into four different forces with different characteristics.

PROBLEM-SOLVING SUMMARY

Type of Problem	Relevant Physical Concepts	Related Examples
Identify a missing term in a nuclear reaction.	The number of protons and neutrons must be the same before and after an alpha decay. In a β^- decay, the number of neutrons after the decay is decreased by 1, and the number of protons is increased by 1.	Examples 32–3, 32–4, 32–7
Find the energy released in a nuclear reaction.	Calculate the difference in mass before and after the reaction. Multiply the difference in mass by the speed of light squared.	Examples 32–3, 32–4, 32–6, 32–7 Active Example 32–4
Determine the number of radioactive nuclei as a function of time.	The number of nuclei decreases exponentially with time according to the relation $N = N_0 e^{-\lambda t}$.	Active Example 32–2
Determine the activity of radioactive nuclei as a function of time.	Activity, which is the rate of decay, is the decay constant times the number of nuclei present at a given time	Active Example 32–3
Find the age of an organic sample using carbon-14 decay.	The age can be found using $t = \frac{1}{\lambda}\ln\frac{R_0}{R}$, where the initial activity of a 1-g sample of carbon-14 is $R_0 = 0.231$ Bq, and $\lambda = 1.21 \times 10^{-4}\ \mathrm{y}^{-1}$.	Example 32–5

For instructor-assigned homework, go to www.masteringphysics.com

CONCEPTUAL QUESTIONS

(Answers to odd-numbered Conceptual Questions can be found in the back of the book.)

1. Nucleus A and nucleus B have different numbers of protons and different numbers of neutrons. Explain how it is still possible for these nuclei to have equal radii.
2. When α particles are emitted in a nuclear decay, they have well-defined energies. In contrast, β particles are found to be emitted with a range of energies. Explain this difference.
3. Is it possible for a form of heavy hydrogen to decay by emitting an α particle? Explain.
4. Which is more likely to expose film kept in a cardboard box, α particles or β particles? Explain.
5. It is not possible for a stable nucleus to contain more than one proton without also having at least one neutron. Explain why neutrons are necessary in a stable, multiparticle nucleus.
6. Different isotopes of a given element have different masses, but they have the same chemical properties. Explain why chemical properties are unaffected by a change of isotope.
7. **(a)** Give three examples of objects for which carbon-14 dating would give useful results. **(b)** Give three examples of objects for which carbon-14 dating would not be useful.
8. Explain why the large, stable nuclei in Figure 32–1 are found to lie above the $N = Z$ line, rather than below the line.
9. Suppose each of the following items is about 10,000 years old: a feather, a tooth, an obsidian arrowhead, a deer hide moccasin. Which of these items cannot be dated with carbon-14? Explain.
10. Can carbon-14 dating give the age of fossil dinosaur skeletons? Explain.
11. Two different samples contain the same radioactive isotope. Is it possible for these samples to have different activities? Explain.
12. Two samples contain different radioactive isotopes. Is it possible for these samples to have the same activity? Explain.
13. Two different types of radiation deliver the same amount of energy to a sample of tissue. Does it follow that each of these types of radiation has the same RBE? Explain.

PROBLEMS AND CONCEPTUAL EXERCISES

Note: Answers to odd-numbered Problems and Conceptual Exercises can be found in the back of the book. **IP** *denotes an integrated problem, with both conceptual and numerical parts;* **BIO** *identifies problems of biological or medical interest;* **CE** *indicates a conceptual exercise.* **Predict/Explain** *problems ask for two responses:* **(a)** *your prediction of a physical outcome, and* **(b)** *the best explanation among three provided. On all problems, red bullets (•, ••, •••) are used to indicate the level of difficulty.*

Refer to Appendix F for the masses and half-lives of relevant isotopes. Remember that the masses in Appendix F include the mass of the electrons associated with the neutral atoms.

SECTION 32–1 THE CONSTITUENTS AND STRUCTURE OF NUCLEI

1. • Identify Z, N, and A for the following isotopes: **(a)** $^{238}_{92}\mathrm{U}$, **(b)** $^{239}_{94}\mathrm{Pu}$, **(c)** $^{144}_{60}\mathrm{Nd}$.
2. • Identify Z, N, and A for the following isotopes: **(a)** $^{202}_{80}\mathrm{Hg}$, **(b)** $^{220}_{86}\mathrm{Rn}$, **(c)** $^{93}_{41}\mathrm{Nb}$.
3. • What are the nuclear radii of **(a)** $^{197}_{79}\mathrm{Au}$ and (b) $^{60}_{27}\mathrm{Co}$?
4. • A certain chlorine nucleus has a radius of approximately 4.0×10^{-15} m. How many neutrons are in this nucleus?
5. •• **IP** (a) What is the nuclear density of $^{228}_{90}\mathrm{Th}$? **(b)** Do you expect the nuclear density of an alpha particle to be greater than,

less than, or the same as that of ${}^{228}_{90}\text{Th}$? Explain. **(c)** Calculate the nuclear density of an alpha particle.

6. •• **IP** (a) What initial kinetic energy must an alpha particle have if it is to approach a stationary gold nucleus to within a distance of 22.5 fm? **(b)** If the initial speed of the alpha particle is reduced by a factor of 2, by what factor is the distance of closest approach changed? Explain.

7. •• **IP** An α particle with a kinetic energy of 0.85 MeV approaches a stationary gold nucleus. **(a)** What is the speed of the α particle? **(b)** What is the distance of closest approach between the α particle and the gold nucleus? **(c)** If this same α particle were fired at a copper nucleus instead, would its distance of closest approach be greater than, less than, or the same as that found in part (b)? Explain. (To obtain the mass of an alpha particle, refer to Appendix F and subtract the mass of two electrons from the mass of ${}^{4}_{2}\text{He}$.)

8. •• Suppose a marble with a radius of 1.5 cm has the density of a nucleus, as given in Example 32–2. **(a)** What is the mass of this marble? **(b)** How many of these marbles would be required to have a mass equal to the mass of Earth?

9. •• **IP** (a) Find the nuclear radius of ${}^{30}_{15}\text{P}$. **(b)** What mass number would be required for a nucleus to have twice the radius found in part (a)? **(c)** Verify your answer to part (b) with an explicit calculation.

10. •• **IP** An alpha particle is the nucleus of a ${}^{4}_{2}\text{He}$ atom. **(a)** How many nucleons are in a nucleus with twice the radius of an alpha particle? Explain. **(b)** Write the symbol for a phosphorus nucleus that has twice the radius of an alpha particle.

11. •• **IP** Suppose a uranium-236 nucleus undergoes fission by splitting into two smaller nuclei of equal size. **(a)** Is the radius of each of the smaller nuclei one-half, more than one-half, or less than one-half the radius of the uranium-236 nucleus? Explain. **(b)** Calculate the radius of the uranium-236 nucleus. **(c)** Calculate the radii of the two smaller nuclei.

12. •• A hypothetical nucleus weighs 1 lb. **(a)** How many nucleons are in this nucleus? **(b)** What is the radius of this nucleus?

SECTION 32–2 RADIOACTIVITY

13. • **CE Predict/Explain** Consider a nucleus that undergoes α decay. **(a)** Is the radius of the resulting daughter nucleus greater than, less than, or equal to the radius of the original nucleus? **(b)** Choose the *best explanation* from among the following:
    I. The decay adds an alpha particle to the nucleus, causing its radius to increase.
    II. When the nucleus undergoes decay it ejects two neutrons and two protons. This decreases the number of nucleons in the nucleus, and therefore its radius will decrease.
    III. An α decay leaves the number of nucleons unchanged. As a result, the radius of the nucleus stays the same.

14. • **CE Predict/Explain** Consider a nucleus that undergoes β decay. **(a)** Is the radius of the resulting daughter nucleus greater than, less than, or the same as that of the original nucleus? **(b)** Choose the *best explanation* from among the following:
    I. Capturing a β particle will cause the radius of a nucleus to increase. Therefore, the daughter nucleus has the greater radius.
    II. The original nucleus emits a β particle, and anytime a particle is emitted from a nucleus the result is a smaller radius. Therefore, the radius of the daughter nucleus is less than the radius of the original nucleus.
    III. When a nucleus emits a β particle a neutron is converted to a proton, but the number of nucleons is unchanged. As a result, the radius of the daughter nucleus is the same as that of the original nucleus.

15. • **CE** Which of the three decay processes (α, β or γ) results in a new element? Explain.

16. • Complete the following nuclear reaction:

$$ {}^{7}_{3}\text{Li} + {}^{1}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + ? $$

17. • Complete the following nuclear reaction:

$$ {}^{234}_{90}\text{Th} \rightarrow {}^{230}_{88}\text{Ra} + ? $$

18. • Complete the following nuclear reaction:

$$? \rightarrow {}^{14}_{7}\text{N} + e^{-} + \overline{\nu} $$

19. •• **CE** One possible decay series for ${}^{238}_{92}\text{U}$ is ${}^{234}_{90}\text{Th}$, ${}^{234}_{91}\text{Pa}$, ${}^{234}_{92}\text{U}$, ${}^{230}_{90}\text{Th}$, ${}^{226}_{88}\text{Ra}$, ${}^{222}_{86}\text{Rn}$, ${}^{218}_{84}\text{Po}$, ${}^{218}_{85}\text{At}$, ${}^{218}_{86}\text{Rn}$, ${}^{214}_{84}\text{Po}$, ${}^{210}_{82}\text{Pb}$, ${}^{210}_{83}\text{Bi}$, ${}^{206}_{81}\text{Tl}$, and ${}^{206}_{82}\text{Pb}$. Identify, in the order given, each of the 14 decays that occur in this series.

20. •• Complete the following nuclear reaction and determine the amount of energy it releases:

$$ {}^{3}_{1}\text{H} \rightarrow {}^{3}_{2}\text{He} + ? + ? $$

Be sure to take into account the mass of the electrons associated with the neutral atoms.

21. •• The following nuclei are observed to decay by emitting an α particle: **(a)** ${}^{212}_{84}\text{Po}$ and **(b)** ${}^{239}_{94}\text{Pu}$. Write out the decay process for each of these nuclei, and determine the energy released in each reaction. Be sure to take into account the mass of the electrons associated with the neutral atoms.

22. •• The following nuclei are observed to decay by emitting a β^{-} particle: **(a)** ${}^{35}_{16}\text{S}$ and **(b)** ${}^{212}_{82}\text{Pb}$. Write out the decay process for each of these nuclei, and determine the energy released in each reaction. Be sure to take into account the mass of the electrons associated with the neutral atoms.

23. •• The following nuclei are observed to decay by emitting a β^{+} particle: **(a)** ${}^{18}_{9}\text{F}$ and **(b)** ${}^{22}_{11}\text{Na}$. Write out the decay process for each of these nuclei, and determine the energy released in each reaction. Be sure to take into account the mass of the electrons associated with the neutral atoms.

24. •• Find the energy released when ${}^{211}_{82}\text{Pb}$ undergoes β^{-} decay to become ${}^{211}_{83}\text{Bi}$. Be sure to take into account the mass of the electrons associated with the neutral atoms.

25. ••• It is observed that ${}^{66}_{28}\text{Ni}$, with an atomic mass of 65.9291 u, decays by β^{-} emission. **(a)** Identify the nucleus that results from this decay. **(b)** If the nucleus found in part (a) has an atomic mass of 65.9289 u, what is the maximum kinetic energy of the emitted electron?

SECTION 32–3 HALF-LIFE AND RADIOACTIVE DATING

26. • **CE** The half-life of carbon-14 is 5730 y. **(a)** Is it possible for a particular nucleus in a sample of carbon-14 to decay after only 1 s has passed? Explain. **(b)** Is it possible for a particular nucleus to decay after 10,000 y? Explain.

27. • **CE** Suppose we were to discover that the ratio of carbon-14 to carbon-12 in the atmosphere was significantly smaller 10,000 years ago than it is today. How would this affect the ages we have assigned to objects on the basis of carbon-14 dating? In particular, would the true age of an object be greater than or less than the age we had previously assigned to it? Explain.

28. • **CE** A radioactive sample is placed in a closed container. Two days later only one-quarter of the sample is still radioactive. What is the half-life of this sample?

29. • Radon gas has a half-life of 3.82 d. What is the decay constant for radon?

30. • A radioactive substance has a decay constant equal to $8.9 \times 10^{-3}\ \text{s}^{-1}$. What is the half-life of this substance?

31. • The number of radioactive nuclei in a particular sample decreases over a period of 18 d to one-sixteenth the original number. What is the half-life of these nuclei?

32. • The half-life of ${}^{15}_{8}\text{O}$ is 122 s. How long does it take for the number of ${}^{15}_{8}\text{O}$ nuclei in a given sample to decrease by a factor of 10^{-4}?

33. •• **BIO** **A Radioactive Tag** A drug prepared for a patient is tagged with ${}^{99}_{43}\text{Tc}$, which has a half-life of 6.05 h. **(a)** What is the decay constant of this isotope? **(b)** How many ${}^{99}_{43}\text{Tc}$ nuclei are required to give an activity of 1.50 μCi ?

34. •• **BIO** Referring to Problem 33, suppose the drug containing ${}^{99}_{43}\text{Tc}$ with an activity of 1.50 μCi is injected into the patient 2.05 h after it is prepared. What is its activity at the time it is injected?

35. •• An archeologist on a dig finds a fragment of an ancient basket woven from grass. Later, it is determined that the carbon-14 content of the grass in the basket is 9.25% that of an equal carbon sample from present-day grass. What is the age of the basket?

36. •• The bones of a saber-toothed tiger are found to have an activity per gram of carbon that is 15.0% of what would be found in a similar live animal. How old are these bones?

37. •• Charcoal from an ancient fire pit is found to have a carbon-14 content that is only 17.5% that of an equivalent sample of carbon from a living tree. What is the age of the fire pit?

38. •• One of the many isotopes used in cancer treatment is ${}^{198}_{79}\text{Au}$, with a half-life of 2.70 d. Determine the mass of this isotope that is required to give an activity of 225 Ci.

39. •• **Smoke Detectors** The radioactive isotope ${}^{241}_{95}\text{Am}$, with a half-life of 432 y, is the active element in many smoke detectors. Suppose such a detector will no longer function if the activity of the ${}^{241}_{95}\text{Am}$ it contains drops below $\frac{1}{525}$ of its initial activity. How long will this smoke detector work?

40. •• **BIO** **Radioactivity in the Bones** Because of its chemical similarity to calcium, ${}^{90}_{38}\text{Sr}$ can collect in the bones and present a health risk. What percentage of ${}^{90}_{38}\text{Sr}$ present initially still exists after a period of **(a)** 50.0 y, **(b)** 60.0 y, and **(c)** 70.0 y?

SECTION 32–4 NUCLEAR BINDING ENERGY

41. • The atomic mass of gold-197 is 196.96654 u. How much energy is required to completely separate the nucleons in a gold-197 nucleus?

42. • The atomic mass of lithium-7 is 7.016003 u. How much energy is required to completely separate the nucleons in a lithium-7 nucleus?

43. •• Calculate the average binding energy per nucleon of **(a)** ${}^{56}_{26}\text{Fe}$ and **(b)** ${}^{238}_{92}\text{U}$.

44. •• Calculate the average binding energy per nucleon of **(a)** ${}^{4}_{2}\text{He}$ and **(b)** ${}^{64}_{30}\text{Zn}$.

45. •• Find the energy required to remove one neutron from ${}^{16}_{8}\text{O}$.

46. ••• **IP** **(a)** Consider the following nuclear process, in which a proton is removed from an oxygen nucleus:

$${}^{16}_{8}\text{O} + \text{energy} \rightarrow {}^{15}_{7}\text{N} + {}^{1}_{1}\text{H}$$

Find the energy required for this process to occur. **(b)** Now consider a process in which a neutron is removed from an oxygen nucleus:

$${}^{16}_{8}\text{O} + \text{energy} \rightarrow {}^{15}_{8}\text{O} + {}^{1}_{0}\text{n}$$

Find the energy required for this process to occur. **(c)** Which particle, the proton or the neutron, do you expect to be more tightly bound in the oxygen nucleus? Verify your answer.

SECTION 32–5 NUCLEAR FISSION

47. • Find the number of neutrons released by the following fission reaction:

$${}^{1}_{0}\text{n} + {}^{235}_{92}\text{U} \rightarrow {}^{132}_{50}\text{Sn} + {}^{101}_{42}\text{Mo} + (?)\ \text{neutrons}$$

48. •• Complete the following fission reaction and determine the amount of energy it releases:

$${}^{1}_{0}\text{n} + {}^{235}_{92}\text{U} \rightarrow {}^{133}_{51}\text{Sb} + ? + 5{}^{1}_{0}\text{n}$$

49. •• Complete the following fission reaction and determine the amount of energy it releases:

$${}^{1}_{0}\text{n} + {}^{235}_{92}\text{U} \rightarrow {}^{88}_{38}\text{Sr} + {}^{136}_{54}\text{Xe} + (?)\ \text{neutrons}$$

50. •• A gallon of gasoline releases about 2.0×10^{8} J of energy when it is burned. How many gallons of gas must be burned to release the same amount of energy as is released when 1.0 lb of ${}^{235}_{92}\text{U}$ undergoes fission. (Assume that each fission reaction in ${}^{235}_{92}\text{U}$ releases 173 MeV.)

51. •• Assuming a release of 173 MeV per fission reaction, determine the minimum mass of ${}^{235}_{92}\text{U}$ that must undergo fission to supply the annual energy needs of the United States. (The amount of energy consumed in the United States each year is 8.4×10^{19} J.)

52. •• Assuming a release of 173 MeV per fission reaction, calculate how many reactions must occur per second to produce a power output of 150 MW.

SECTION 32–6 NUCLEAR FUSION

53. • Consider a fusion reaction in which two deuterium nuclei fuse to form a tritium nucleus and a proton. How much energy is released in this reaction?

54. • Consider a fusion reaction in which a proton fuses with a neutron to form a deuterium nucleus. How much energy is released in this reaction?

55. • Find the energy released in the following fusion reaction:

$${}^{1}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{3}_{2}\text{He} + \gamma$$

56. •• **(a)** Complete the following fusion reaction and determine the energy it releases:

$${}^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \rightarrow ? + {}^{1}_{0}\text{n}$$

(b) How many of these reactions must occur per second to produce a power output of 25 MW?

57. ••• **The Evaporating Sun** The Sun radiates energy at the prodigious rate of 3.90×10^{26} W. **(a)** At what rate, in kilograms per second, does the Sun convert mass into energy? **(b)** Assuming that the Sun has radiated at this same rate for its entire lifetime of 4.50×10^{9} y, and that the current mass of the Sun is 2.00×10^{30} kg, what percentage of its original mass has been converted to energy?

SECTION 32–7 PRACTICAL APPLICATIONS OF NUCLEAR PHYSICS

58. • **BIO** **Radiation Damage** A sample of tissue absorbs a 55-rad dose of α particles (RBE = 20). How many rad of protons (RBE = 10) cause the same amount of damage to the tissue?

59. • **BIO** **X-ray Damage** How many rad of 200-keV X-rays cause the same amount of biological damage as 50 rad of heavy ions?

60. •• **IP** **BIO** **(a)** Find the energy absorbed by a 78-kg person who is exposed to 52 mrem of α particles with an RBE of 15. **(b)** If the RBE of the α particles is increased, does the energy absorbed increase, decrease, or stay the same? Explain.

61. •• **BIO** A patient undergoing radiation therapy for cancer receives a 225-rad dose of radiation. **(a)** Assuming the cancerous growth has a mass of 0.17 kg, calculate how much energy it absorbs. **(b)** Assuming the growth to have the specific heat of water, determine its increase in temperature.

62. •• **BIO** Alpha particles with an RBE of 13 deliver a 32-mrad whole-body radiation dose to a 72-kg patient. **(a)** What dosage, in rem, does the patient receive? **(b)** How much energy is absorbed by the patient?

63. ••• **BIO** **A Radioactive Pharmaceutical** As part of a treatment program, a patient ingests a radioactive pharmaceutical containing $^{32}_{15}\mathrm{P}$, which emits β rays with an RBE of 1.50. The half-life of $^{32}_{15}\mathrm{P}$ is 14.28 d, and the initial activity of the medication is 1.34 MBq. **(a)** How many electrons are emitted over the period of 7.00 d? **(b)** If the β rays have an energy of 705 keV, what is the total amount of energy absorbed by the patient's body in 7.00 d? **(c)** Find the absorbed dosage in rem, assuming the radiation is absorbed by 125 g of tissue.

GENERAL PROBLEMS

64. • **CE** An α particle (charge $+2e$) and a β particle (charge $-e$) deflect in opposite directions when they pass through a magnetic field. Which particle deflects by a greater amount, given that both particles have the same speed? Explain.

65. • **CE** Radioactive samples A and B have equal half-lives. The initial activity of sample A is twice that of sample B. What is the ratio of the activity of sample A to that of sample B after two half-lives have elapsed?

66. • **CE** The initial activity of sample A is twice that of sample B. After two half-lives of sample A have elapsed, the two samples have the same activity. What is the ratio of the half-life of B to the half-life of A?

67. • **CE** To produce a given amount of electrical energy, is the amount of coal burned in a coal-burning power plant greater than, less than, or the same as the amount of $^{235}_{92}\mathrm{U}$ consumed in a nuclear power plant? Explain.

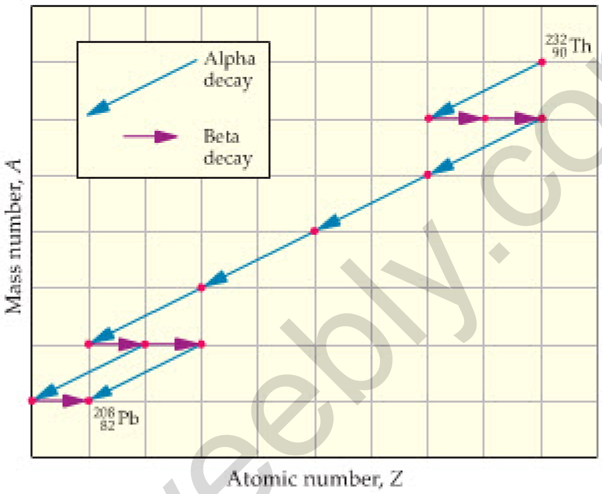
68. • Determine the number of neutrons and protons in **(a)** $^{232}_{90}\mathrm{Th}$, **(b)** $^{211}_{82}\mathrm{Pb}$, and **(c)** $^{60}_{27}\mathrm{Co}$.

69. • Identify the daughter nucleus that results when **(a)** $^{210}_{82}\mathrm{Pb}$ undergoes α decay, **(b)** $^{239}_{92}\mathrm{U}$ undergoes β^- decay, and **(c)** $^{11}_{6}\mathrm{C}$ undergoes β^+ decay.

70. • Suppose it is desired to give a cancerous tumor a dose of 3800 rem. How many rads are needed if the tumor is exposed to alpha radiation?

71. • A patient is exposed to 260 rad of gamma rays. What is the dose the patient receives in rem?

72. • **CE** The two radioactive decay series that begin with $^{232}_{90}\mathrm{Th}$ and end with $^{208}_{82}\mathrm{Pb}$ are shown in **Figure 32–14**. Identify the ten intermediary nuclei that appear in these series.



▲ **FIGURE 32–14** Problem 72

73. •• **Moon Rocks** In one of the rocks brought back from the Moon, it is found that 80.5% of the initial potassium-40 in the rock has decayed to argon-40. **(a)** If the half-life for this decay is 1.20×10^9 years, how old is the rock? **(b)** How much longer will it take before only 10.0% of the original potassium-40 is still present in the rock?

74. •• **IP** **Mantles in Gas Lanterns** Gas lanterns used on camping trips have mantles (small lacy bags that give off light) made from a rayon mesh impregnated with thorium and other materials. Thorium is used, even though it is radioactive, because it forms an oxide that can withstand being incandescent for long periods of time. Almost all natural thorium is $^{232}_{90}\mathrm{Th}$, which has a half-life of 1.405×10^{10} y. **(a)** A typical mantle contains 325 mg of thorium. What is the activity of the mantle? **(b)** If the half-life of thorium had been double its actual value, by what factor would the activity of a mantle be changed? Explain.

The glowing mantle of a gas lantern. (Problem 74)

75. •• Identify the nucleus whose β^- decay produces the same nucleus as that produced by the α decay of $^{214}_{84}\mathrm{Po}$.

76\. •• An α particle fired head-on at a stationary nickel nucleus approaches to a radius of 15 fm before being turned around. **(a)** What is the maximum Coulomb force exerted on the α particle? **(b)** What is the electric potential energy of the α particle at its point of closest approach? **(c)** Find the initial kinetic energy of the α particle.

77\. •• Calculate the number of disintegrations per second that one would expect from a 1.7-g sample of $^{226}_{88}\text{Ra}$. What is the activity of this sample in curies?

78\. •• **IP** Initially, a sample of radioactive nuclei of type A contains four times as many nuclei as a sample of radioactive nuclei of type B. Two days later (2.00 d) the two samples contain the same number of nuclei. **(a)** Which type of nucleus has the longer half-life? Explain. **(b)** Determine the half-life of type B nuclei if the half-life of type A nuclei is known to be 0.500 d.

79\. •• Stable nuclei have mass numbers that range from a minimum of 1 to a maximum of 209. **(a)** Find the corresponding range in nuclear radii. **(b)** Assuming all nuclei to be spherical, determine the ratio of the surface area of the largest stable nucleus to the surface area of the smallest nucleus. **(c)** Repeat part (b), only this time find the ratio of the volumes.

80\. •• **Radius of a Neutron Star** Neutron stars are so named because they are composed of neutrons and have a density the same as that of a nucleus. Referring to Example 32–2 for the nuclear density, find the radius of a neutron star whose mass is 0.50 that of the Sun.

81\. •• A specimen taken from the wrappings of a mummy contains 7.82 g of carbon and has an activity of 1.38 Bq. How old is the mummy? (Refer to pages 1132 and 1133 for relevant information regarding the isotopes of carbon.)

82\. •• **(a)** How many fission reactions are required to light a 120-W lightbulb for 2.5 d? Assume an energy release of 212 MeV per fission reaction and a 32% conversion efficiency. **(b)** What mass of $^{235}_{92}\text{U}$ corresponds to the number of fission reactions found in part (a)?

83\. •• **IP** Energy is released when three α particles fuse to form carbon-12. **(a)** Is the mass of carbon-12 greater than, less than, or the same as the mass of three α particles? Explain. **(b)** Calculate the energy given off in this fusion reaction.

84\. •• Find the dose of γ rays that must be absorbed by a block of ice at 0 °C to convert it to water at 0 °C. Give the dosage in rad.

85\. •• **IP** (a) What dosage (in rad) must a 1.0-kg sample of water absorb to increase its temperature by 1.0 C°? **(b)** If the mass of the water sample is increased, does the dosage found in part (a) increase, decrease, or stay the same? Explain.

86\. •• **BIO Chest X-rays** A typical chest X-ray uses X-rays with an RBE of 0.85. If the radiation dosage is 35 mrem, find the energy absorbed by a 72-kg patient, assuming one-quarter of the patient's body is exposed to the X-rays.

87\. ••• A γ ray photon emitted by $^{226}_{88}\text{Ra}$ has an energy of 0.186 MeV. Use conservation of linear momentum to calculate the recoil speed of a $^{226}_{88}\text{Ra}$ nucleus after such a γ ray is emitted. Assume that the nucleus is at rest initially, and that relativistic effects can be ignored.

88\. ••• The energy released by α decay in a 50.0-g sample of $^{239}_{94}\text{Pu}$ is to be used to heat 4.75 kg of water. Assuming all the energy released by the radioactive decay goes into heating the water, find how much the temperature of the water increases in 1.00 h.

89\. ••• Consider a solid sphere of $^{235}_{92}\text{U}$ with a radius of 2.25 cm in a room with a temperature of 293 K. Assume that all the energy released by α decay goes into heating the sphere, and that the sphere radiates heat to its surroundings as a blackbody. What is the change in temperature of the sphere as a result of the α decay? (*Note*: The density of uranium is 18.95 g/cm^3.)

PASSAGE PROBLEMS

BIO Treating a Hyperactive Thyroid

Of the many endocrine glands in the body, the thyroid is one of the most important. Weighing only an ounce and situated just below the "Adam's apple, " the thyroid produces hormones that regulate the metabolic rate of every cell in the body. To produce these hormones the thyroid uses iodine from the food we eat—in fact, the thyroid specializes in absorbing iodine.

The central role played by the thyroid is evidenced by the symptoms produced when it ceases to function properly. For example, a person experiencing hyperthyroidism (an overactive thyroid) presents the internist with a wide range of indicators, including weight loss, ravenous appetite, anxiety, fatigue, hyperactivity, apathy, palpitations, arrhythmias, and nausea, just to mention a few.

The most common treatment for hyperthyroidism is to destroy the overactive thyroid tissues with radioactive iodine-131. This treatment takes advantage of the fact that only thyroid cells absorb and concentrate iodine. To begin the treatment, a patient swallows a single, small capsule containing iodine-131. The radioactive isotope quickly enters the bloodstream and is taken up by the overactive thyroid cells, which are destroyed as the iodine-131 decays with a half-life of 8.04 d. Other cells in the body experience very little radiation damage, which minimizes side effects. In one or two months the thyroid activity is reduced to an acceptable level. Sometimes too much—or even all—of the thyroid is killed, which can result in hypothyroidism, or underactive thyroid. This is easily treated, however, with dietary supplements to replace the missing thyroid hormones.

90\. • What is the decay constant, λ, for iodine-131?

A. $9.98 \times 10^{-7}\ \text{s}^{-1}$ **B.** $1.44 \times 10^{-6}\ \text{s}^{-1}$

C. $2.39 \times 10^{-5}\ \text{s}^{-1}$ **D.** $5.99 \text{ x } 10^{-5}\ \text{s}^{-1}$

91\. • If a sample of iodine-131 contains 4.5×10^{16} nuclei, what is the activity of the sample? Express your answer in curies.

A. 0.27 Ci **B.** 1.2 Ci

C. 1.7 Ci **D.** 4.5 Ci

92\. • If the half-life of iodine-131 were only half of its actual value, would the activity of the sample in Problem 91 be increased or decreased?

Appendix A Basic mathematical tools

This text is designed for students with a working knowledge of basic algebra and trigonometry. Even so, it is useful to review some of the mathematical tools that are of particular importance in the study of physics. In this Appendix we cover a number of topics related to mathematical notation, trigonometry, algebra, mathematical expansions, and vector multiplication.

MATHEMATICAL NOTATION

Common mathematical symbols

In Table A–1 we present some of the more common mathematical symbols, along with a translation into English. Though these symbols are probably completely familiar, it is worthwhile to be sure we all interpret them in the same way.

TABLE A–1 Mathematical Symbols

$=$	is equal to
$\neq$	is not equal to
$\approx$	is approximately equal to
$\propto$	is proportional to
$>$	is greater than
$\geq$	is greater than or equal to
$\gg$	is much greater than
$<$	is less than
$\leq$	is less than or equal to
$\ll$	is much less than
$\pm$	plus or minus
$\mp$	minus or plus
x_{av} or $\overline{x}$	average value of x
Δx	change in $x (x_f - x_i)$
$\lvert x \rvert$	absolute value of x
Σ	sum of
$\rightarrow 0$	approaches 0
∞	infinity

A couple of the symbols in Table A–1 warrant further discussion. First, Δx, which means "change in x," is used frequently, and in many different contexts. Pronounced "delta x," it is defined as the final value of x, x_f, minus the initial value of x, x_i:

$$\Delta x = x_f - x_i \qquad \text{A–1}$$

Thus, Δx is not Δ times x; it is a shorthand way of writing $x_f - x_i$. The same delta notation can be applied to any quantity—it does not have to be x. In general, we can say that

$$\Delta(\textit{anything}) = (\textit{anything})_f - (\textit{anything})_i$$

For example, $\Delta t = t_f - t_i$ is the change in time, $\Delta\vec{v} = \vec{v}_f - \vec{v}_i$ is the change in velocity, and so on. Throughout this text, we use the delta notation whenever we want to indicate the change in a given quantity.

Second, the Greek letter Σ (capital sigma) is also encountered frequently. In general, Σ is shorthand for "sum." For example, suppose we have a system comprised of nine masses, m_1 through m_9. The total mass of the system, M, is simply

$$M = m_1 + m_2 + m_3 + m_4 + m_5 + m_6 + m_7 + m_8 + m_9$$

This is a rather tedious way to write M, however, and would be even more so if the number of masses were larger. To simplify our equation, we use the Σ notation:

$$M = \sum_{i=1}^{9} m_i \qquad \text{A–2}$$

With this notation we could sum over any number of masses, simply by changing the upper limit of the sum.

In addition, Σ is often used to designate a general summation, where the number of terms in the sum may not be known, or may vary from one system to another. In a case like this we would simply write Σ without specific upper and lower limits. Thus, a general way of writing the total mass of a system is as follows:

$$M = \sum m \qquad \text{A–3}$$

Vector notation

When we draw a vector to represent a physical quantity, we typically use an arrow whose length is proportional to the magnitude of the quantity, and whose direction is the direction of the quantity. (This and other aspects of vector notation are discussed in Chapter 3.) A slight problem arises, however, when a physical quantity points into or out of the page. In such a case, we use the conventions illustrated in **Figure A–1.**

Figure A–1 (a) shows a vector pointing out of the page. Note that we see only the tip. Below, we show the corresponding convention, which is a dot set off by a circle. The dot represents the point of the vector's arrow coming out of the page toward you.

A similar convention is employed in Figure A–1 (b) for a vector pointing into the page. In this case, the arrow moves directly away from you, giving a view of its "tail feathers." The feathers are placed in an X-shaped pattern, so we represent the vector as an X set off by a circle.

These conventions are used in Chapter 22 to represent the magnetic field vector, $\vec{\mathbf{B}}$, and in other locations in the text as well.

▲ **FIGURE A–1 Vectors pointing out of and into the page**

(a) A vector pointing out of the page is represented by a dot in a circle. The dot indicates the tip of the vector's arrow. **(b)** A vector pointing into the page is represented by an X in a circle. The X indicates the "tail feathers" of the vector's arrow.

Scientific notation

In physics, the numerical value of a physical quantity can cover an enormous range, from the astronomically large to the microscopically small. For example, the mass of the Earth is roughly

$$M_{\mathrm{E}} = 5970000000000000000000000 \text{ kg}$$

In contrast, the mass of a hydrogen atom is approximately

$$M_{\text{hydrogen}} = 0.00000000000000000000000000167 \text{ kg}$$

Clearly, representing such large and small numbers with a long string of zeros is clumsy and prone to error.

The preferred method for handling such numbers is to replace the zeros with the appropriate power of ten. For example, the mass of the Earth can be written as follows:

$$M_{\mathrm{E}} = 5.97 \times 10^{24} \text{ kg}$$

The factor of 10^{24} simply means that the decimal point for the mass of the Earth is 24 places to the right of its location in 5.97. Similarly, the mass of a hydrogen atom is

$$M_{\text{hydrogen}} = 1.67 \times 10^{-27} \text{ kg}$$

In this case, the correct location of the decimal point is 27 places to the left of its location in 1.67. This type of representation, using powers of ten, is referred to as **scientific notation.**

Scientific notation also simplifies various mathematical operations, such as multiplication and division. For example, the product of the mass of the Earth and the mass of a hydrogen atom is

$$\begin{aligned} M_{\mathrm{E}}M_{\text{hydrogen}} &= (5.97 \times 10^{24} \text{ kg})(1.67 \times 10^{-27} \text{ kg}) \\ &= (5.97 \times 1.67)(10^{24} \times 10^{-27}) \text{ kg}^2 \\ &= 9.99 \times 10^{24-27} \text{ kg}^2 \\ &= 9.99 \times 10^{-3} \text{ kg}^2 \end{aligned}$$

Similarly, the mass of a hydrogen atom divided by the mass of the Earth is

$$\begin{aligned} \frac{M_{\text{hydrogen}}}{M_{\mathrm{E}}} &= \frac{1.67 \times 10^{-27} \text{ kg}}{5.97 \times 10^{24} \text{ kg}} = \frac{1.67}{5.97} \times \frac{10^{-27}}{10^{24}} \\ &= 0.280 \times 10^{-27-24} \\ &= 0.280 \times 10^{-51} = 2.80 \times 10^{-52} \end{aligned}$$

Note the change in location of the decimal point in the last two expressions, and the corresponding change in the power of ten.

Exponents and their manipulation are discussed in greater detail later in this Appendix.

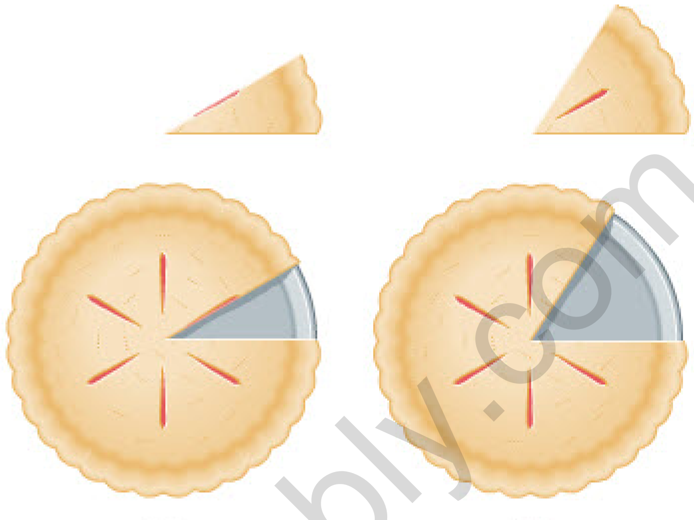
TRIGONOMETRY

Degrees and radians

We all know the definition of a degree; there are 360 degrees in a circle. The definition of a radian is somewhat less well known; there are 2π radians in a circle. An equivalent definition of the radian is the following:

> A radian is the angle for which the corresponding arc length is equal to the radius.

To visualize this definition, consider a pie with a piece cut out, as shown in **Figure A–2 (a)**. Note that a piece of pie has three sides—two radial lines from the center, and an arc of crust. If a piece of pie is cut with an angle of one radian, all three sides are equal in length, as shown in **Figure A–2 (b)**. Since a radian is about 57.3°, this amounts to a fairly good-sized piece of pie. Thus, if you want a healthy helping of pie, just tell the server, “One radian, please.”


(a) (b)

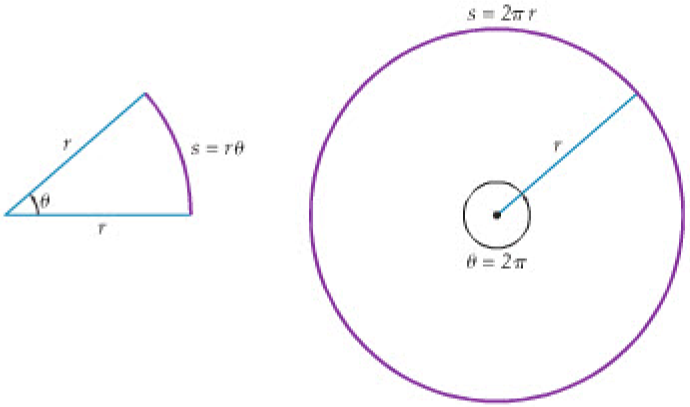
▲ **FIGURE A–2 The definition of a radian**

(a) This piece of pie is cut with an angle less than a radian. Thus, the two radial sides (coming out from the center) are longer than the arc of crust. **(b)** The angle for this piece of pie is equal to one radian (about 57.3°). Thus, all three sides of the piece are of equal length.

Now, radians are particularly convenient when we are interested in the length of an arc. In **Figure A–3** we show a circular arc corresponding to the radius r and the angle θ. *If the angle θ is measured in radians*, the length of the arc, s, is given by

$$s = r\theta \qquad \text{A–4}$$

Note that this simple relation is *not valid* when θ is measured in degrees. For a full circle, in which case $\theta = 2\pi$, the length of the arc (which is the circumference of the circle) is $2\pi r$, as expected.



▲ **FIGURE A–3 The Length of an arc**

The arc created by a radius r rotated through an angle θ has a length $s = r\theta$. If the radius is rotated through a full circle, the angle is $\theta = 2\pi$, and the arc length is the circumference of a circle, $s = 2\pi r$.

Trigonometric functions and the Pythagorean theorem

Next, we consider some of the more important and frequently used results from trigonometry. We start with the right triangle, shown in **Figure A–4**, and the basic **trigonometric functions,** sin θ (sine theta), cos θ (cosine theta), and tan θ (tangent theta). The cosine of an angle θ is defined to be the side adjacent to the angle divided by the hypotenuse; $\cos\theta = x/r$. Similarly, the sine is defined to be the opposite side divided by the hypotenuse, $\sin\theta = y/r$, and the tangent is the opposite side divided by the adjacent side, $\tan\theta = y/x$. These relations are summarized in the following equations:

$$\cos\theta = \frac{x}{r}$$

$$\sin\theta = \frac{y}{r} \qquad \text{A–5}$$

$$\tan\theta = \frac{y}{x} = \frac{\sin\theta}{\cos\theta}$$

Note that each of the trigonometric functions is the ratio of two lengths, and hence is dimensionless.

According to the **Pythagorean theorem,** the sides of the right triangle in Figure A–4 are related as follows:

$$x^2 + y^2 = r^2 \qquad \text{A–6}$$

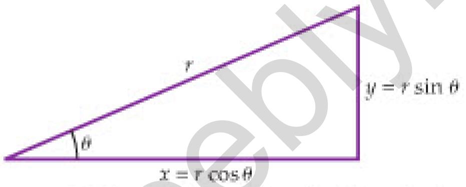
Dividing by r^2 yields

$$\frac{x^2}{r^2} + \frac{y^2}{r^2} = 1$$

This can be re-written in terms of sine and cosine to give

$$\sin^2\theta + \cos^2\theta = 1$$

Figure A–4 also shows how sine and cosine are used in a typical calculation. In many cases, the hypotenuse of a triangle, r, and one of its angles, θ, are given. To find the short sides of the triangle we rearrange the relations given in Equation A–5. For example, in Figure A–4 we see that $x = r\cos\theta$ is the length of the short side adjacent to the angle, θ, and $y = r\sin\theta$ is the length of the short side opposite the angle. The following Example applies this type of calculation to the case of an inclined roadway.



▲ **FIGURE A–4 Relating the short sides of a right triangle to its hypotenuse**

The trigonometric functions sin θ and cos θ and the Pythagorean theorem are useful in relating the lengths of the short sides of a right triangle to the length of its hypotenuse.

EXAMPLE A–1 HIGHWAY TO HEAVEN

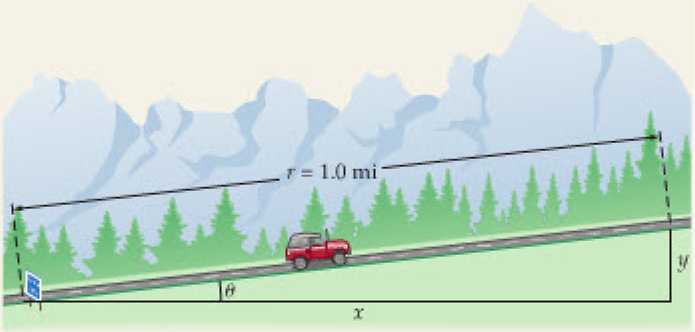
You are driving on a long straight road that slopes uphill at an angle of 6.4° above the horizontal. At one point you notice a sign that reads, "Elevation 1500 feet." What is your elevation after you have driven another 1.0 mi?

PICTURE THE PROBLEM

From our sketch, we see that the car is moving along the hypotenuse of a right triangle. The length of the hypotenuse is one mile.

STRATEGY

The elevation gain is the vertical side of the triangle, y. We find y by multiplying the hypotenuse, r, by the sine of theta. That is, since $\sin\theta = y/r$ it follows that $y = r\sin\theta$.



SOLUTION

1. Calculate the elevation gain, y: $y = r\sin\theta = (1.0\text{ mi})\sin 6.4° = (1.0\text{ mi})(0.11) = 0.11\text{ mi}$
2. Convert y from miles to feet: $y = (0.11\text{ mi})\left(\frac{5280\text{ ft}}{1\text{ mi}}\right) = 580\text{ ft}$
3. Add the elevation gain to the original elevation to obtain the new elevation: elevation = 1500 ft + 580 ft = 2100 ft

INSIGHT

As surprising as it may seem, the horizontal distance covered by the car is $r\cos\theta = (5280\text{ ft})\cos 6.4° = 5200$ ft, only about 80 ft less than the total distance driven by the car. At the same time, the car rises a distance of 580 ft.

PRACTICE PROBLEM

How far up the road from the first sign should the road crew put another sign reading "Elevation 3500 ft"? [**Answer:** 18,000 ft = 3.4 mi]

In some problems, the sides of a triangle (x and y) are given and it is desired to find the corresponding hypotenuse, r, and angle, θ. For example, suppose that $x = 5.0$ m and $y = 2.0$ m. Using the Pythagorean theorem, we find $r = \sqrt{x^2 + y^2} = \sqrt{(5.0\text{ m})^2 + (2.0\text{ m})^2} = 5.4$ m. Similarly, to find the angle we use the definition of tangent: $\tan\theta = y/x$. The inverse of this relation is $\theta = \tan^{-1}(y/x) = \tan^{-1}(2.0\text{ m}/5.0\text{ m}) = \tan^{-1}(0.40)$. Note that the expression $\tan^{-1}$ is the *inverse tangent function*—it does not mean 1 divided by tangent, but rather "the angle whose tangent is——." Your calculator should have a button on it labeled $\tan^{-1}$. If you enter 0.40 and then press $\tan^{-1}$, you should get 22° (to two significant figures), which means that $\tan 22° = 0.40$. Inverse sine and cosine functions work in the same way.

Trigonometric identities

In addition to the basic definitions of sine, cosine, and tangent just given, there are a number of useful relationships involving these functions referred to as **trigonometric identities.** First, consider changing the sign of an angle. This corresponds to flipping the triangle in Figure A–4 upside-down, which changes the sign of y but leaves x unaffected. The result is that sine changes its sign, but cosine does not. Specifically, for a general angle A we find the following:

$$\begin{aligned}\sin(-A) &= -\sin A\\ \cos(-A) &= \cos A\end{aligned}\tag{A–7}$$

Next, we consider trigonometric identities relating to the sum or difference of two angles. For example, consider two general angles A and B. The sine and cosine of the sum of these angles, $A + B$, are given below:

$$\begin{aligned}\sin(A + B) &= \sin A\cos B + \sin B\cos A\\ \cos(A + B) &= \cos A\cos B - \sin A\sin B\end{aligned}\tag{A–8}$$

By changing the sign of B, and using the results given in Equation A–7, we obtain the corresponding results for the difference between two angles:

$$\begin{aligned}\sin(A - B) &= \sin A\cos B - \sin B\cos A\\ \cos(A - B) &= \cos A\cos B + \sin A\sin B\end{aligned}\tag{A–9}$$

Applications of these relations can be found in Chapters 4, 14, 23, and 24.

To see how one might use a relation like $\sin(A + B) = \sin A\cos B + \sin B\cos A$, consider the case where $A = B = \theta$. With this substitution we find

$$\sin(\theta + \theta) = \sin\theta\cos\theta + \sin\theta\cos\theta$$

Simplifying somewhat yields the commonly used double-angle formula

$$\sin 2\theta = 2\sin\theta\cos\theta\tag{A–10}$$

This expression is used in deriving Equation 4–16.

As a final example of using trigonometric identities, let $A = 90°$ and $B = \theta$. Making these substitutions in Equations A–9 yields

$$\begin{aligned}\sin(90° - \theta) &= \sin 90°\cos\theta - \sin\theta\cos 90° = \cos\theta\\ \cos(90° - \theta) &= \cos 90°\cos\theta + \sin 90°\sin\theta = \sin\theta\end{aligned}\tag{A–11}$$

ALGEBRA

The quadratic equation

A well-known result that finds many uses in physics is the solution to the **quadratic equation**

$$\mathrm{a}x^2 + \mathrm{b}x + \mathrm{c} = 0\tag{A–12}$$

In this equation, a, b, and c are constants and x is a variable. When we refer to the solution of the quadratic equation, we mean the values of x that satisfy Equation A–12. These values are given by the following expression:

Solutions to the Quadratic Equation

$$x = \frac{-\mathrm{b} \pm \sqrt{\mathrm{b}^2 - 4\mathrm{ac}}}{2\mathrm{a}}\tag{A–13}$$

Note that there are two solutions to the quadratic equation, in general, corresponding to the plus and minus sign in front of the square root. In the special case that the quantity under the square root vanishes, there will be only a single solution. If the quantity under the square root is negative the result for x is not physical, which means a mistake has probably been made in the calculation.

To illustrate the use of the quadratic equation and its solution, we consider a standard one-dimensional kinematics problem, such as one might encounter in Chapter 2:

> A ball is thrown straight upward with an initial speed of 11 m/s. How long does it take for the ball to first reach a height of 4.5 m above its launch point?

The first step in solving this problem is to write the equation giving the height of the ball, y, as a function of time. Referring to Equation 2–11, we have

$$y = y_0 + v_0 t - \tfrac{1}{2}gt^2$$

To make this look more like a quadratic equation, we move all the terms onto the left-hand side, which yields

$$\tfrac{1}{2}gt^2 - v_0 t + y - y_0 = 0$$

This is the same as Equation A–12 if we make the following identifications: $x = t$; $\mathrm{a} = \frac{1}{2}g$; $\mathrm{b} = -v_0$; $\mathrm{c} = y - y_0$. The desired solution, then, is given by making these substitutions in Equation A–13:

$$t = \frac{v_0 \pm \sqrt{v_0{}^2 - 2g(y - y_0)}}{g}$$

The final step is to use the appropriate numerical values; $g = 9.81\text{ m/s}^2$, $v_0 = 11$ m/s, $y - y_0 = 4.5$ m. Straightforward calculation gives $t = 0.54$ s and $t = 1.7$ s. Therefore, the time it takes to first reach a height of 4.5 m is 0.54 s; the second solution is the time when the ball is again at a height of 4.5 m, this time on its way down.

Two equations in two unknowns

In some problems, two unknown quantities are determined by two interlinked equations. In such cases it often seems at first that you have not been given enough information to obtain a solution. By patiently writing out what is known, however, you can generally use straightforward algebra to solve the problem.

As an example, consider the following problem: A father and daughter share the same birthday. On one birthday the father announces to his daughter, "Today I am four times older than you, but in 5 years I will be only three times older." How old are the father and daughter now?

You might be able to solve this problem by guessing, but here's how to approach it systematically. First, write what is given in the form of equations. Letting F be the father's age in years, and D the daughter's age in years, we know that on this birthday

$$F = 4D \qquad \text{A–14}$$

In 5 years, the father's age will be $F + 5$, the daughter's age will be $D + 5$, and the following will be true:

$$F + 5 = 3(D + 5)$$

Multiplying through the parenthesis gives

$$F + 5 = 3D + 15 \qquad \text{A–15}$$

Now if we subtract Equation A–15 from Equation A–14 we can eliminate one of the unknowns, F:

$$\begin{array}{rl} F &= 4D \\ -\;F + 5 &= 3D + 15 \\ \hline -5 &= \;\;D - 15 \end{array}$$

The solution to this new equation is clearly $D = 10$, and thus the father's age is $F = 4D = 40$.

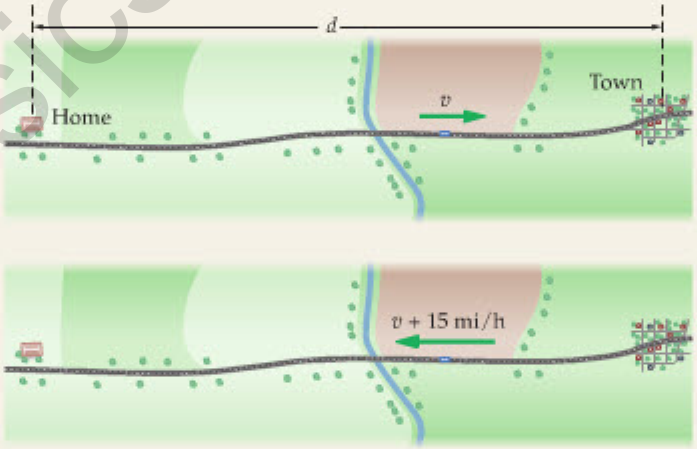
The following Example investigates a similar problem. In this case, we use the fact that if you drive with a speed v for a time t the distance covered is $d = vt$.

EXAMPLE A–2 HIT THE ROAD

It takes 1.50 h to drive with a speed v from home to a nearby town, a distance d away. Later, on the way back, the traffic is lighter, and you are able to increase your speed by 15 mi/h. With this higher speed, you get home in just 1.00 h. Find your initial speed v, and the distance to the town, d.

PICTURE THE PROBLEM

Our sketch shows home and the town, separated by a distance d. Going to town the speed is v, returning home the speed is v + 15 mi/h.



STRATEGY

To determine the two unknowns, v and d, we need two separate equations. One equation corresponds to what we know about the trip to the town, the second equation corresponds to what we know about the return trip.

SOLUTION

1. Write an equation for the trip to the town. Recall that this trip takes one and a half hours:

$$d = vt = v(1.50\text{ h})$$

2. Write an equation for the trip home. This trip takes one hour, and covers the same distance d:

$$d = (v + 15\text{ mi/h})t = (v + 15\text{ mi/h})(1.00\text{ h})$$

3. Subtract these two equations to eliminate d:

$$\begin{array}{rl} d &= v(1.50\text{ h}) \\ -\quad d &= (v + 15\text{ mi/h})(1.00\text{ h}) \\ \hline 0 &= v(1.50\text{ h}) - v(1.00\text{ h}) - (15\text{ mi/h})(1.00\text{ h}) \end{array}$$

4. Solve this new equation for v:

$$0 = v(1.50\text{ h}) - v(1.00\text{ h}) - (15\text{ mi/h})(1.00\text{ h})$$

$$0 = v(0.50\text{ h}) - (15\text{ mi/h})(1.00\text{ h})$$

$$v = \frac{(15\text{ mi/h})(1.00\text{ h})}{(0.50\text{ h})} = 30\text{ mi/h}$$

5. Use the first equation to solve for d:

$$d = vt = (30\text{ mi/h})(1.50\text{ h}) = 45\text{ mi}$$

INSIGHT

We could also use the second equation to solve for d. The algebra is a bit messier, but it provides a good double check on our results: $d = (30\ \text{mi/h} + 15\ \text{mi/h})(1.00\ \text{h}) = (45\ \text{mi/h})(1.00\ \text{h}) = 45\ \text{mi}$.

PRACTICE PROBLEM

Suppose the speed going home is 12 mi/h faster than the speed on the way to town, but the times are the same as above. What are v and d in this case? [**Answer:** $v = 24\ \text{mi/h}$, $d = 36\ \text{mi}$]

Exponents and logarithms

An **exponent** is the power to which a number is raised. For example, in the expression 10^3, we say that the exponent of 10 is 3. To evaluate 10^3 we simply multiply 10 by itself three times:

$$10^3 = 10 \times 10 \times 10 = 1000$$

Similarly, a negative exponent implies an inverse, as in the relation $10^{-1} = 1/10$. Thus, to evaluate a number like 10^{-4}, for example, we multiply 1/10 by itself four times:

$$10^{-4} = \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} = \frac{1}{10{,}000} = 0.0001$$

The relations just given apply not just to powers of 10, of course, but to any number at all. Thus, x^4 is

$$x^4 = x \times x \times x \times x$$

and x^{-3} is

$$x^{-3} = \frac{1}{x} \times \frac{1}{x} \times \frac{1}{x} = \frac{1}{x^3}$$

Using these basic rules, it follows that exponents add when two or more numbers are multiplied together:

$$\begin{aligned} x^2x^3 &= (x \times x)(x \times x \times x) \\ &= x \times x \times x \times x \times x = x^5 = x^{2+3} \end{aligned}$$

On the other hand, exponents multiply when a number is raised to a power:

$$\begin{aligned} (x^2)^3 &= (x \times x) \times (x \times x) \times (x \times x) \\ &= x \times x \times x \times x \times x \times x = x^6 = x^{2\times 3} \end{aligned}$$

In general, the rules obeyed by exponents can be summarized as follows:

$$\begin{aligned} x^nx^m &= x^{n+m} \\ x^{-n} &= \frac{1}{x^n} \\ \frac{x^n}{x^m} &= x^{n-m} \qquad \text{A–16} \\ (xy)^n &= x^ny^n \\ (x^n)^m &= x^{nm} \end{aligned}$$

Fractional exponents, such as $1/n$, indicate the nth root of a number. Specifically, the square root of x is written as

$$\sqrt{x} = x^{1/2}$$

For n greater than 2 we write the nth root in the following form:

$$\sqrt[n]{x} = x^{1/n} \qquad \text{A–17}$$

Thus, the nth root of a number, x, is the value that gives x when multiplied by itself n times: $(x^{1/n})^n = x^{n/n} = x^1 = x$.

A general method for calculating the exponent of a number is provided by the **logarithm.** For example, suppose x is equal to 10 raised to the power n:

$$x = 10^n$$

In this expression, 10 is referred to as the *base*. The exponent, n, is equal to the logarithm (log) of x:

$$n = \log x$$

The notation "log" is known as the *common logarithm*, and it refers specifically to base 10.

As an example, suppose that $x = 1000 = 10^n$. Clearly, we can write x as 10^3, which means that the exponent of x is 3:

$$\log x = \log 1000 = \log 10^3 = 3$$

When dealing with a number this simple, the exponent can be determined without a calculator. Suppose, however, that $x = 1205 = 10^n$. To find the exponent for this value of x we use the "log" button on a calculator. The result is

$$n = \log 1205 = 3.081$$

Thus, 10 raised to the 3.081 power gives 1205.

Another base that is frequently used for calculating exponents is $e = 2.718\ldots$. To represent $x = 1205$ in this base we write

$$x = 1205 = e^m$$

The logarithm to base e is known as the *natural logarithm*, and it is represented by the notation "ln." Using the "ln" button on a calculator, we find

$$m = \ln 1205 = 7.094$$

Thus, e raised to the 7.094 power gives 1205. The connection between the common and natural logarithms is as follows:

$$\ln x = 2.3026 \log x \qquad \text{A–18}$$

In the example just given, we have $\ln 1205 = 7.094 = 2.3026 \log 1205 = 2.3026(3.081)$.

The basic rules obeyed by logarithms follow directly from the rules given for exponents in Equation A–16. In particular,

$$\begin{aligned} \ln(xy) &= \ln x + \ln y \\ \ln\left(\frac{x}{y}\right) &= \ln x - \ln y \qquad \text{A–19} \\ \ln x^n &= n \ln x \end{aligned}$$

Though these rules are stated in terms of natural logarithms, they are satisfied by logarithms with any base.

MATHEMATICAL EXPANSIONS

We conclude with a brief consideration of small quantities in mathematics. Consider the following equation:

$$(1 + x)^3 = 1 + 3x + 3x^2 + x^3$$

This expression is valid for all values of x. However, if x is much smaller than one, $x \ll 1$, we can say to a good approximation that

$$(1 + x)^3 \approx 1 + 3x$$

Now, just how good is this approximation? After all, it ignores two terms that would need to be included to produce an equality. In the case $x = 0.001$, for example, the two terms that are neglected, $3x^2$ and x^3, have a combined contribution of only about 3 ten-thousandths of a percent! Clearly, then, little error is made in the approximation $(1 + 0.001)^3 \sim 1 + 3(0.001) = 1.003$. This can be seen visually in **Figure A–5 (a)**, where we plot $(1 + x)^3$ and $1 + 3x$ for x ranging from 0 to 1. Note that there is little difference in the two expressions for x less than about 0.1.

This is just one example of a general result in mathematics that can be derived from the **binomial expansion.** In general, we can say that the following approximation is valid for $x \ll 1$:

$$(1 + x)^n \approx 1 + nx \qquad \text{A–20}$$

This result holds for arbitrary n, not just for the case of $n = 3$. For example, if $n = -1$ we have

$$(1 + x)^{-1} = \frac{1}{1 + x} \approx 1 - x$$

We plot $(1 + x)^{-1}$ and $1 - x$ in **Figure A–5 (b)**, and again we see that the results are in good agreement for x less than about 0.1.

An example of an expansion that arises in the study of relativity concerns the following quotient:

$$\frac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}}$$

In this expression v is the speed of an object and c is the speed of light. Since objects we encounter generally have speeds much less than the speed of light, the ratio v/c is much less than one, and v^2/c^2 is even smaller than v/c. Thus, if we let $x = v^2/c^2$ we have

$$\frac{1}{\sqrt{1 - x}}$$

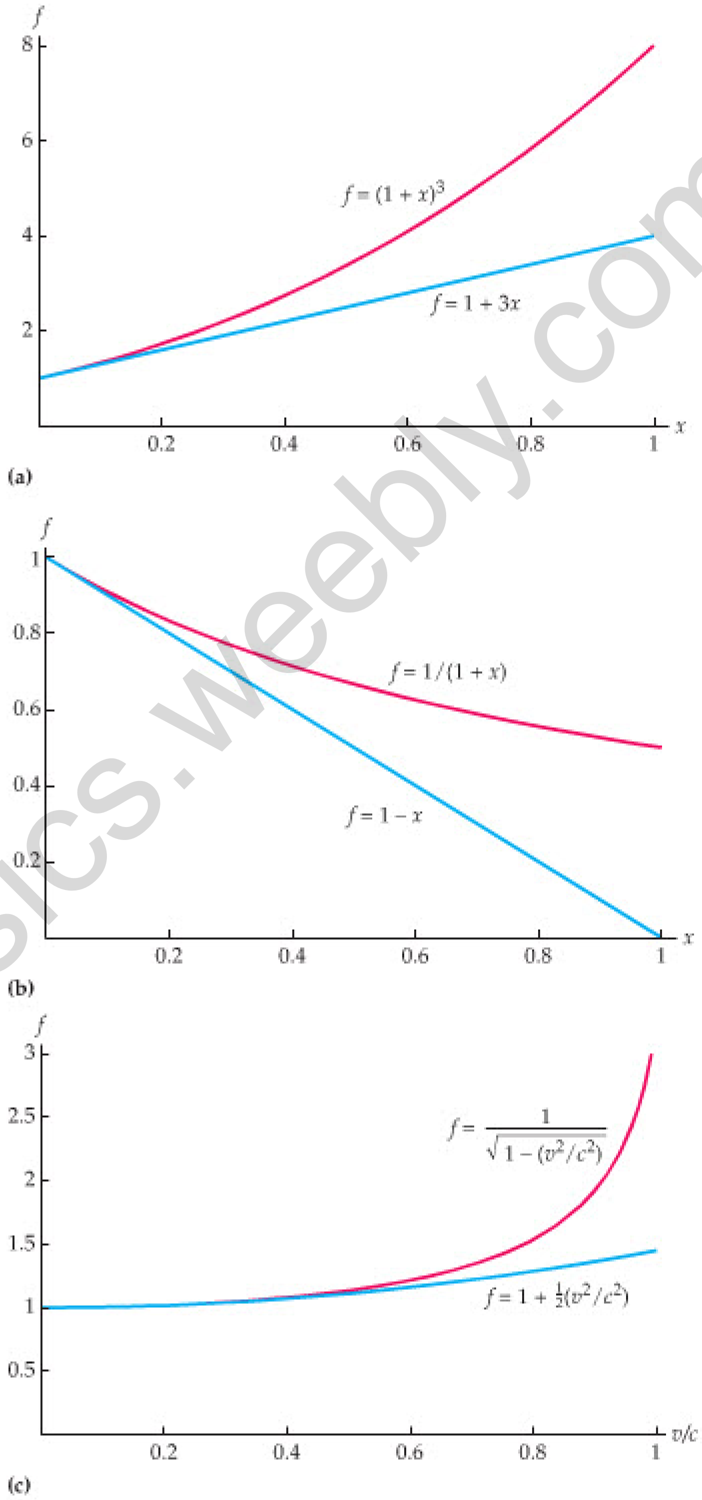
We can apply the binomial expansion to this result if we replace n with $-1/2$ and x with $-x$ in Equation A–20. This yields

$$\frac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}} \approx 1 + \frac{1}{2}\frac{v^2}{c^2}$$

The two sides of this approximate equality are plotted in **Figure A–5 (c)**, showing the accuracy of the approximation for small v/c.

Another type of mathematical expansion leads to the following useful results:

$$\begin{aligned} \sin\theta &\approx \theta \\ \cos\theta &\approx 1 - \tfrac{1}{2}\theta^2 \end{aligned} \qquad \text{A–21}$$



▲ **FIGURE A–5 Examples of mathematical expansions**

(a) A comparison between $(1 + x)^3$ and the result obtained from the binomial expansion, $1 + 3x$. **(b)** A comparison between $1/(1 + x)$ and the result obtained from the binomial expansion, $1 - x$. **(c)** A comparison between $1/\sqrt{1 - (v^2/c^2)}$ and the result obtained from the binomial expansion, $1 + \frac{1}{2}(v^2/c^2)$.

These expansions are valid for small angles θ measured in radians. Note that the result $\sin\theta \approx \theta$ is used to derive Equations 6–13 and 13–19. (See Table 6–2, p. 170, and Figure 13–15, p. 435, for more details on this expansion.)

VECTOR MULTIPLICATION

There are two distinct ways to multiply vectors, referred to as the **dot product** and the **cross product.** The difference between these two types of multiplication is that the dot product yields a scalar (a number) as its result, whereas the cross product results in a vector. Both types of product have important applications in physics. In what follows, we present the basic techniques associated with dot and cross products, and point out places in the text where they are used.

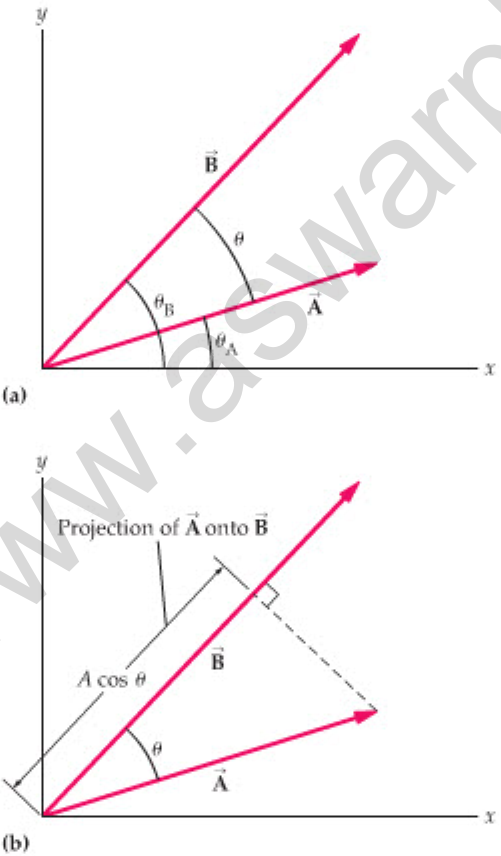
The dot product

Consider two vectors, $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$, as shown in **Figure A–6 (a)**. The magnitudes of these vectors are A and B, respectively, and the angle between them is θ. We define the dot product of $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ as follows:

$$\vec{\mathbf{A}} \cdot \vec{\mathbf{B}} = AB\cos\theta \qquad \text{A–22}$$

In words, the dot product of two vectors is a scalar equal to the magnitude of one vector times the magnitude of the second vector times the cosine of the angle between them.

A geometric interpretation of the dot product is presented in **Figure A–6 (b).** We begin by projecting the vector $\vec{\mathbf{A}}$ onto the direction of vector $\vec{\mathbf{B}}$. This is done by dropping a perpendicular from the tip of $\vec{\mathbf{A}}$ onto the line that passes through $\vec{\mathbf{B}}$, as shown in **Figure A–6 (b)**. Note that the projection of $\vec{\mathbf{A}}$ on the direction of $\vec{\mathbf{B}}$ has a length given by $A\cos\theta$. It follows that the dot product is simply the projection of $\vec{\mathbf{A}}$ onto $\vec{\mathbf{B}}$ times the magnitude of $\vec{\mathbf{B}}$; that is, $(A\cos\theta)B = AB\cos\theta = \vec{\mathbf{A}} \cdot \vec{\mathbf{B}}$. Equivalently, the dot product can be thought of as the projection of $\vec{\mathbf{B}}$ onto $\vec{\mathbf{A}}$ times the magnitude of $\vec{\mathbf{A}}$.



▲ **FIGURE A–6 The dot product between vectors $\vec{A}$ and $\vec{B}$.**

A few special cases will help to clarify the dot product. Suppose, for example, that $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ are parallel. In this case, $\theta = 0$ and $\vec{\mathbf{A}} \cdot \vec{\mathbf{B}} = AB$. Therefore, when vectors are parallel, the dot product is simply the product of their magnitudes. On the other hand, suppose $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ point in opposite directions. Now we have $\theta = 180$, and therefore $\vec{\mathbf{A}} \cdot \vec{\mathbf{B}} = -AB$. In general, the sign of $\vec{\mathbf{A}} \cdot \vec{\mathbf{B}}$ is positive if the angle between $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ is less than 90°, and is negative if the angle between them is greater than 90°. Finally, if $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ are perpendicular to one another—that is, if $\theta = 90°$—we see that $\vec{\mathbf{A}} \cdot \vec{\mathbf{B}} = AB\cos 90° = 0$. In this case, neither vector has a nonzero projection onto the other vector.

Dot products have a particularly simple form when applied to unit vectors. Recall, for example, that $\hat{\mathbf{x}}$ and $\hat{\mathbf{y}}$ have unit magnitude and are perpendicular to one another. It follows that

$$\hat{\mathbf{x}} \cdot \hat{\mathbf{x}} = 1, \quad \hat{\mathbf{x}} \cdot \hat{\mathbf{y}} = \hat{\mathbf{y}} \cdot \hat{\mathbf{x}} = 0, \quad \hat{\mathbf{y}} \cdot \hat{\mathbf{y}} = 1 \qquad \text{A–23}$$

These results can be applied to the general two-dimensional vectors $\vec{\mathbf{A}} = A_x\hat{\mathbf{x}} + A_y\hat{\mathbf{y}}$ and $\vec{\mathbf{B}} = B_x\hat{\mathbf{x}} + B_y\hat{\mathbf{y}}$ to give

$$\begin{aligned} \vec{\mathbf{A}} \cdot \vec{\mathbf{B}} &= (A_x\hat{\mathbf{x}} + A_y\hat{\mathbf{y}}) \cdot (B_x\hat{\mathbf{x}} + B_y\hat{\mathbf{y}}) \\ &= A_xB_x\hat{\mathbf{x}} \cdot \hat{\mathbf{x}} + A_xB_y\hat{\mathbf{x}} \cdot \hat{\mathbf{y}} + A_yB_x\hat{\mathbf{y}} \cdot \hat{\mathbf{x}} + A_yB_y\hat{\mathbf{y}} \cdot \hat{\mathbf{y}} \qquad \text{A–24} \\ &= A_xB_x + A_yB_y \end{aligned}$$

Thus, the dot product of two-dimensional vectors is simply the product of their x components plus the product of their y components.

At first glance the result $\vec{\mathbf{A}} \cdot \vec{\mathbf{B}} = AB\cos\theta$ looks quite different from the result $\vec{\mathbf{A}} \cdot \vec{\mathbf{B}} = A_xB_x + A_yB_y$. They are identical, however, as we now show. Suppose that $\vec{\mathbf{A}}$ is at an angle θ_A to the positive x axis, and that $\vec{\mathbf{B}}$ is at an angle $\theta_B > \theta_A$ to the x axis, from which it follows that the angle between $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ is $\theta = \theta_B - \theta_A$. Noting that $A_x = A\cos\theta_A$ and $A_y = A\sin\theta_A$, and similarly for B_x and B_y, we have

$$\vec{\mathbf{A}} \cdot \vec{\mathbf{B}} = AB(\cos\theta_A\cos\theta_B + \sin\theta_A\sin\theta_B)$$

The second trigonometric identity in Equation A–9 can be applied to the quantity in brackets, with the result that $\vec{\mathbf{A}} \cdot \vec{\mathbf{B}} = A_xB_x + A_yB_y = AB\cos(\theta_B - \theta_A) = AB\cos\theta$, as desired.

The most prominent application of dot products in this text is in Chapter 7, where in Equation 7–3 we define the work to be $W = Fd\cos\theta$, with θ the angle between $\vec{\mathbf{F}}$ and $\vec{\mathbf{d}}$. Clearly, this is simply a statement that work is the dot product of force and displacement:

$$W = \vec{\mathbf{F}} \cdot \vec{\mathbf{d}} = Fd\cos\theta$$

Later in the text, in Equation 19–11, we define the electric flux to be $\Phi = EA\cos\theta$. If we let $\vec{\mathbf{A}}$ represent a vector that has a magnitude equal to the area, A, and points in the direction of the normal to the area, we can write the electric flux as a dot product:

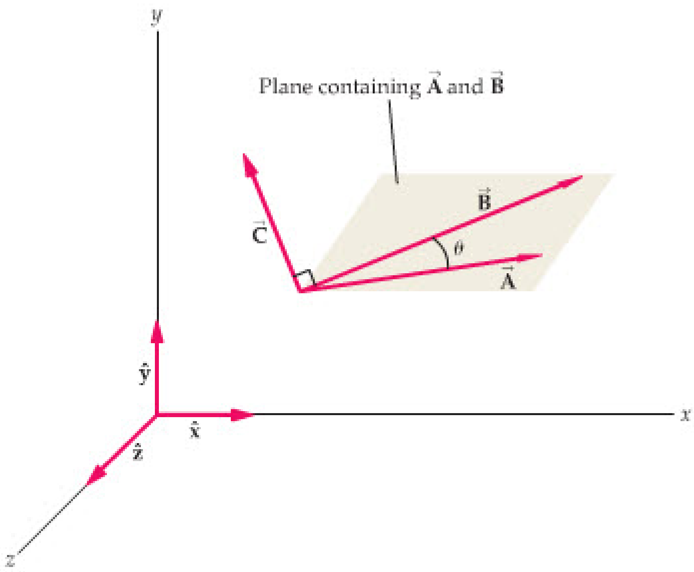
$$\Phi = \vec{\mathbf{E}} \cdot \vec{\mathbf{A}} = EA\cos\theta$$

Similar remarks apply to the magnetic flux, defined in Equation 23–1.

The cross product

When two vectors are multiplied with the cross product, the result is a third vector that is perpendicular to both original vectors. An example is shown in **Figure A–7**, where we see a vector $\vec{\mathbf{A}}$, a vector $\vec{\mathbf{B}}$, and their cross product, $\vec{\mathbf{C}}$:

$$\vec{\mathbf{C}} = \vec{\mathbf{A}} \times \vec{\mathbf{B}} \qquad \text{A–25}$$



▲ **FIGURE A–7 The vector cross product of $\vec{A}$ and $\vec{B}$.**

Notice that $\vec{C}$ is perpendicular to the plane formed by the vectors $\vec{A}$ and $\vec{B}$. In addition, the direction of $\vec{C}$ is given by the following right-hand rule:

> To find the direction of $\vec{C} = \vec{A} \times \vec{B}$, point the fingers of your right hand in the direction of $\vec{A}$ and curl them toward $\vec{B}$. Your thumb is now pointing in the direction of $\vec{C}$.

It is clear from this rule that if $\vec{A} \times \vec{B} = \vec{C}$, then $\vec{B} \times \vec{A} = -\vec{C}$.

The magnitude of $\vec{C} = \vec{A} \times \vec{B}$ depends on the magnitudes of the vectors $\vec{A}$ and $\vec{B}$, and on the angle θ between them. In particular,

$$C = AB\sin\theta \tag{A–26}$$

Comparing with Equation A–22, we see that the cross product involves a $\sin\theta$, whereas the dot product depends on $\cos\theta$. As a result, it follows that the cross product has zero magnitude when $\vec{A}$ and $\vec{B}$ point in the same direction ($\theta = 0°$) or in opposite directions ($\theta = 180°$). On the other hand, the cross product has its greatest magnitude, $C = AB$, when $\vec{A}$ and $\vec{B}$ are perpendicular to one another ($\theta = 90°$).

When we apply these rules to unit vectors, which are at right angles to one another and of unit magnitude, the results are particularly simple. For example, consider the cross product $\hat{x} \times \hat{y}$. Referring to Figure A–7, we see that this cross product points in the positive z direction. In addition, the magnitude of $\hat{x} \times \hat{y}$ is $(1)(1)\sin 90° = 1$. It follows, therefore, that $\hat{x} \times \hat{y} = \hat{z}$. On the other hand, $\hat{x} \times \hat{x} = \hat{y} \times \hat{y} = \hat{z} \times \hat{z} = 0$ because $\theta = 0°$ in each of these cases. To summarize:

$$\begin{array}{lll} \hat{x} \times \hat{y} = \hat{z}, & \hat{y} \times \hat{z} = \hat{x}, & \hat{z} \times \hat{x} = \hat{y} \\ \hat{y} \times \hat{x} = -\hat{z}, & \hat{z} \times \hat{y} = -\hat{x}, & \hat{x} \times \hat{z} = -\hat{y} \\ \hat{x} \times \hat{x} = 0, & \hat{y} \times \hat{y} = 0, & \hat{z} \times \hat{z} = 0 \end{array} \tag{A–27}$$

As an example of how to use these unit-vector results, consider the cross product of the two-dimensional vectors shown in Figure A–6, $\vec{A} = A_x\hat{x} + A_y\hat{y}$ and $\vec{B} = B_x\hat{x} + B_y\hat{y}$. Straightforward application of Equation A–27 yields

$$\begin{aligned} \vec{C} = \vec{A} \times \vec{B} &= (A_x\hat{x} + A_y\hat{y}) \times (B_x\hat{x} + B_y\hat{y}) \\ &= A_xB_x(\hat{x} \times \hat{x}) + A_xB_y(\hat{x} \times \hat{y}) \\ &\quad + A_yB_x(\hat{y} \times \hat{x}) + A_yB_y(\hat{y} \times \hat{y}) \\ &= (A_xB_y - A_yB_x)\hat{z} \end{aligned} \tag{A–28}$$

Notice that $\vec{C}$ is perpendicular to both $\vec{A}$ and $\vec{B}$, as required for a cross product. In addition, the magnitude of $\vec{C}$ is

$$A_xB_y - A_yB_x = AB(\cos\theta_A \sin\theta_B - \sin\theta_A \cos\theta_B)$$

If we now apply the first trigonometric identity in Equation A–9, we recover the result given in Equation A–26:

$$\begin{aligned} C &= AB(\cos\theta_A \sin\theta_B - \sin\theta_A \cos\theta_B) \\ &= AB\sin(\theta_B - \theta_A) = AB\sin\theta \end{aligned}$$

The first application of cross products in this text is torque, which is discussed in Chapter 11. In fact, Equation 11–2 defines the magnitude of the torque, τ, as follows: $\tau = r(F\sin\theta)$. As one might expect by referring to Equations A–25 and A–26, the torque vector, $\vec{\tau}$, can be written as the following cross product:

$$\vec{\tau} = \vec{r} \times \vec{F}$$

Similarly, the angular momentum vector, $\vec{L}$, whose magnitude is given in Equation 11–13, is simply

$$\vec{L} = \vec{r} \times \vec{p}$$

Finally, the cross product appears again in magnetism. In fact, the magnitude of the magnetic force on a charge q with a velocity $\vec{v}$ in a magnetic field $\vec{B}$ is $F = qvB\sin\theta$, as given in Equation 22–1. As one might guess, the vector form of this force is

$$\vec{F} = q\vec{v} \times \vec{B}$$

The advantage of a cross product expression like this is that it contains both the direction and magnitude of a vector in one compact equation. In fact, we can now see the origin of the right-hand rule for magnetic forces given in Section 22–2.

Appendix B Typical values

Mass

Sun	2.00×10^{30} kg
Earth	5.97×10^{24} kg
Moon	7.35×10^{22} kg
747 airliner (maximum takeoff weight)	3.5×10^{5} kg
blue whale	178,000 kg = 197 tons
elephant	5400 kg
mountain gorilla	180 kg
human	70 kg
bowling ball	7 kg
half gallon of milk	1.81 kg = 4 lbs
baseball	0.141–0.148 kg
golf ball	0.045 kg
female calliope hummingbird (smallest bird in North America)	3.5×10^{-3} kg = $\frac{1}{8}$ oz
raindrop	3×10^{-5} kg
antibody molecule (IgG)	2.5×10^{-22} kg
hydrogen atom	1.67×10^{-27} kg

Length

orbital radius of Earth (around Sun)	1.5×10^{8} km
orbital radius of Moon (around Earth)	3.8×10^{5} km
altitude of geosynchronous satellite	35,800 km = 22,300 mi
radius of Earth	6370 km
altitude of Earth's ozone layer	50 km
height of Mt. Everest	8848 m
height of Washington Monument	169 m = 555 ft
pitcher's mound to home plate	18.44 m
baseball bat	1.067 m
CD (diameter)	120 mm
aorta (diameter)	18 mm
period in sentence (diameter)	0.5 mm
red blood cell	$7.8\ \mu$m = $\frac{1}{3300}$ in.
typical bacterium (*E. coli*)	$2\ \mu$m
wavelength of green light	550 nm
virus	20–300 nm
large protein molecule	25 nm
diameter of DNA molecule	2.0 nm
radius of hydrogen atom	5.29×10^{-11} m

Time

estimated age of Earth	approx. 4.6 billion y $\approx 10^{17}$ s
estimated age of human species	approx. 150,000 y $\approx 5 \times 10^{12}$ s
half life of carbon-14	5730 y = 1.81×10^{11} s
period of Halley's comet	76 y = 2.40×10^{9} s
half life of technetium-99	6 h = 2.16×10^{4} s
time for driver of car to apply brakes	0.46 s
human reaction time	60–180 ms
air bag deployment time	10 ms

period of middle C sound wave	3.9 ms
collision time for batted ball	2 ms
decay of excited atomic state	10^{-8} s
period of green light wave	1.8×10^{-15} s

Speed

light	3×10^8 m/s
meteor	35–95 km/s
space shuttle (orbital velocity)	8.5 km/s = 19,000 mi/h
rifle bullet	700–750 m/s
sound in air (STP)	340 m/s
fastest human nerve impulses	140 m/s
747 at takeoff	80.5 m/s
kangaroo	18.1 m/s = 40.5 mi/h
200-m dash (Olympic record)	10.1 m/s
butterfly	1 m/s
blood speed in aorta	0.35 m/s
giant tortoise	0.076 m/s = 0.170 mi/h
Mer de Glace glacier (French Alps)	4×10^{-6} m/s

Acceleration

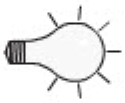
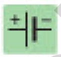
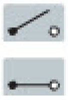
protons in particle accelerator	9×10^{13} m/s^2
ultracentrifuge	3×10^6 m/s^2
meteor impact	10^5 m/s^2
baseball struck by bat	3×10^4 m/s^2
loss of consciousness	$7.14g = 70$ m/s^2
acceleration of gravity on Earth (g)	9.81 m/s^2
braking auto	8 m/s^2
acceleration of gravity on the moon	1.62 m/s^2
rotation of Earth at equator	3.4×10^{-2} m/s^2

Appendix C Planetary data

Name	Equatorial Radius (km)	Mass (Relative to Earth's)*	Mean Density (kg/m^3)	Surface Gravity (Relative to Earth's)	Orbital Semimajor Axis		Escape Speed (km/s)	Orbital Period (Years)	Orbital Eccentricity
					$\times 10^6$ km	A. U.			
Mercury	2440	0.0553	5430	0.38	57.9	0.387	4.2	0.240	0.206
Venus	6052	0.816	5240	0.91	108.2	0.723	10.4	0.615	0.007
Earth	6370	1	5510	1	149.6	1	11.2	1.000	0.017
Mars	3394	0.108	3930	0.38	227.9	1.523	5.0	1.881	0.093
Jupiter	71,492	318	1360	2.53	778.4	5.203	60	11.86	0.048
Saturn	60,268	95.1	690	1.07	1427.0	9.539	36	29.42	0.054
Uranus	25,559	14.5	1270	0.91	2871.0	19.19	21	83.75	0.047
Neptune	24,776	17.1	1640	1.14	4497.1	30.06	24	163.7	0.009
Pluto	1137	0.0021	2060	0.07	5906	39.84	1.2	248.0	0.249

*Mass of Earth = 5.97×10^{24} kg

Appendix D Elements of electrical circuits

Circuit Element	Symbol	Physical Characteristics
resistor		Resists the flow of electric current. Converts electrical energy to thermal energy.
capacitor		Stores electrical energy in the form of an electric field.
inductor		Stores electrical energy in the form of a magnetic field.
incandescent lightbulb		A device containing a resistor that gets hot enough to give off visible light.
battery		A device that produces a constant difference in electrical potential between its terminals.
ac generator		A device that produces a potential difference between its terminals that oscillates with time.
switches (open and closed)		Devices to control whether electric current is allowed to flow through a portion of a circuit.
ground		Sets the electric potential at a point in a circuit equal to a constant value usually taken to be $V = 0$.

Appendix E Periodic table of the elements

Atomic number — 26 **Fe** — Symbol
55.85 — Atomic mass
Outer electron configuration — $3d^64s^2$

PERIODS	*s*		*d*											*p*					
	GROUP I	GROUP II	Transition elements											GROUP III	GROUP IV	GROUP V	GROUP VI	GROUP VII	GROUP VIII
1	1 **H** 1.01 $1s^1$																		2 **He** 4.00 $1s^2$
2	3 **Li** 6.94 $2s^1$	4 **Be** 9.01 $2s^2$												5 **B** 10.81 $2p^1$	6 **C** 12.01 $2p^2$	7 **N** 14.01 $2p^3$	8 **O** 16.00 $2p^4$	9 **F** 19.00 $2p^5$	10 **Ne** 20.18 $2p^6$
3	11 **Na** 22.99 $3s^1$	12 **Mg** 24.31 $3s^2$												13 **Al** 26.98 $3p^1$	14 **Si** 28.09 $3p^2$	15 **P** 30.97 $3p^3$	16 **S** 32.07 $3p^4$	17 **Cl** 35.45 $3p^5$	18 **Ar** 39.95 $3p^6$
4	19 **K** 39.10 $4s^1$	20 **Ca** 40.08 $4s^2$	21 **Sc** 44.96 $3d^14s^2$		22 **Ti** 47.88 $3d^24s^2$	23 **V** 50.94 $3d^34s^2$	24 **Cr** 52.00 $3d^54s^1$	25 **Mn** 54.94 $3d^54s^2$	26 **Fe** 55.85 $3d^64s^2$	27 **Co** 58.93 $3d^74s^2$	28 **Ni** 58.69 $3d^84s^2$	29 **Cu** 63.55 $3d^{10}4s^1$	30 **Zn** 65.39 $3d^{10}4s^2$	31 **Ga** 69.72 $4p^1$	32 **Ge** 72.61 $4p^2$	33 **As** 74.92 $4p^3$	34 **Se** 78.96 $4p^4$	35 **Br** 79.90 $4p^5$	36 **Kr** 83.80 $4p^6$
5	37 **Rb** 85.47 $5s^1$	38 **Sr** 87.62 $5s^2$	39 **Y** 88.96 $4d^15s^2$		40 **Zr** 91.22 $4d^25s^2$	41 **Nb** 92.91 $4d^45s^1$	42 **Mo** 95.94 $4d^55s^1$	43 **Tc** (98) $4d^55s^2$	44 **Ru** 101.07 $4d^75s^1$	45 **Rh** 102.91 $4d^85s^1$	46 **Pd** 106.42 $4d^{10}5s^0$	47 **Ag** 107.87 $4d^{10}5s^1$	48 **Cd** 112.41 $4d^{10}5s^2$	49 **In** 114.82 $5p^1$	50 **Sn** 118.71 $5p^2$	51 **Sb** 121.76 $5p^3$	52 **Te** 127.60 $5p^4$	53 **I** 126.90 $5p^5$	54 **Xe** 131.29 $5p^6$
6	55 **Cs** 132.91 $6s^1$	56 **Ba** 137.33 $6s^2$	57 **La** 138.91 $5d^16s^2$	*	72 **Hf** 178.49 $5d^26s^2$	73 **Ta** 180.95 $5d^36s^2$	74 **W** 183.85 $5d^46s^2$	75 **Re** 186.21 $5d^56s^2$	76 **Os** 190.2 $5d^66s^2$	77 **Ir** 192.22 $5d^76s^2$	78 **Pt** 195.08 $5d^96s^1$	79 **Au** 196.97 $5d^{10}6s^1$	80 **Hg** 200.59 $5d^{10}6s^2$	81 **Tl** 204.36 $6p^1$	82 **Pb** 207.2 $6p^2$	83 **Bi** 208.98 $6p^3$	84 **Po** (209) $6p^4$	85 **At** (210) $6p^5$	86 **Rn** (222) $6p^6$
7	87 **Fr** (223) $7s^1$	88 **Ra** 226.03 $7s^2$	89 **Ac** 227.03 $6d^17s^2$	†	104 **Rf** (261) $6d^27s^2$	105 **Db** (262) $6d^37s^2$	106 **Sg** (266) $6d^47s^2$	107 **Bh** (264) $6d^57s^2$	108 **Hs** (269) $6d^67s^2$	109 **Mt** (268) $6d^77s^2$	110 (271)	111 (272)	112 (277)		114 (289)		116 (289)		118 (293)

	f															
*	58 **Ce** 140.12 $5d^14f^16s^2$	59 **Pr** 140.91 $4f^36s^2$	60 **Nd** 144.24 $4f^46s^2$	61 **Pm** (145) $4f^56s^2$	62 **Sm** 150.36 $4f^66s^2$	63 **Eu** 151.96 $4f^76s^2$	64 **Gd** 157.25 $5d^14f^76s^2$	65 **Tb** 158.93 $4f^96s^2$	66 **Dy** 162.50 $4f^{10}6s^2$	67 **Ho** 164.93 $4f^{11}6s^2$	68 **Er** 167.26 $4f^{12}6s^2$	69 **Tm** 168.93 $4f^{13}6s^2$	70 **Yb** 173.04 $4f^{14}6s^2$	71 **Lu** 174.97 $5d^14f^{14}6s^2$	Lanthanides
†	90 **Th** 232.04 $6d^27s^2$	91 **Pa** 231.04 $5f^26d^17s^2$	92 **U** 238.03 $5f^36d^17s^2$	93 **Np** 237.05 $5f^46d^17s^2$	94 **Pu** (244) $5f^66d^07s^2$	95 **Am** (243) $5f^76d^07s^2$	96 **Cm** (247) $5f^76d^17s^2$	97 **Bk** (247) $5f^86d^17s^2$	98 **Cf** (251) $5f^{10}6d^07s^2$	99 **Es** (252) $5s^{11}6d^07s^2$	100 **Fm** (257) $5f^{12}6d^07s^2$	101 **Md** (258) $5f^{13}6d^07s^2$	102 **No** (259) $5f^{14}6d^07s^2$	103 **Lr** (262) $5f^{14}6d^17s^2$	Actinides

Appendix F Properties of selected isotopes

Atomic Number (Z)	Element	Symbol	Mass Number (A)	Atomic Mass*	Abundance (%) or Decay Mode† (if radioactive)	Half-Life (if radioactive)
0	(Neutron)	n	1	1.008665	β^-	10.6 min
1	Hydrogen	H	1	1.007825	99.985	
	Deuterium	D	2	2.014102	0.015	
	Tritium	T	3	3.016049	β^-	12.33 y
2	Helium	He	3	3.016029	0.00014	
			4	4.002603	≈100	
3	Lithium	Li	6	6.015123	7.5	
			7	7.016003	92.5	
4	Beryllium	Be	7	7.016930	EC, γ	53.3 d
			8	8.005305	2α	6.7×10^{-17} s
			9	9.012183	100	
5	Boron	B	10	10.012938	19.9	
			11	11.009305	80.1	
			12	12.014353	β^-	20.2 ms
6	Carbon	C	11	11.011433	β^+, EC	20.3 min
			12	12.000000	98.89	
			13	13.003355	1.11	
			14	14.003242	β^-	5730 y
7	Nitrogen	N	13	13.005739	β^-	9.96 min
			14	14.003074	99.63	
			15	15.000109	0.37	
8	Oxygen	O	15	15.003065	β^+, EC	122 s
			16	15.994915	99.76	
			18	17.999159	0.204	
9	Fluorine	F	19	18.998403	100	
			18	18.000938	EC	109.77 min
10	Neon	Ne	20	19.992439	90.51	
			22	21.991384	9.22	
11	Sodium	Na	22	21.994435	β^+, EC, γ	2.602 y
			23	22.989770	100	
			24	23.990964	β^-, γ	15.0 h
12	Magnesium	Mg	24	23.985045	78.99	
13	Aluminum	Al	27	26.981541	100	
14	Silicon	Si	28	27.976928	92.23	
			31	30.975364	β^-, γ	2.62 h
15	Phosphorus	P	31	30.973763	100	
			32	31.973908	β^-	14.28 d
16	Sulfur	S	32	31.972072	95.0	
			35	34.969033	β^-	87.4 d
17	Chlorine	Cl	35	34.968853	75.77	
			37	36.965903	24.23	
18	Argon	Ar	40	39.962383	99.60	
19	Potassium	K	39	38.963708	93.26	
			40	39.964000	β^-, EC, γ, β^+	1.28×10^9 y

Atomic Number (Z)	Element	Symbol	Mass Number (A)	Atomic Mass*	Abundance (%) or Decay Mode[†] (if radioactive)	Half-Life (if radioactive)
20	Calcium	Ca	30	39.962591	96.94	
24	Chromium	Cr	52	51.940510	83.79	
25	Manganese	Mn	55	54.938046	100	
26	Iron	Fe	56	55.934939	91.8	
27	Cobalt	Co	59	58.933198	100	
			60	59.933820	β^-, γ	5.271 y
28	Nickel	Ni	58	57.935347	68.3	
			60	59.930789	26.1	
			64	63.927968	0.91	
29	Copper	Cu	63	62.929599	69.2	
			64	63.929766	β^-, β^+	12.7 h
			65	64.927792	30.8	
30	Zinc	Zn	64	63.929145	48.6	
			66	65.926035	27.9	
33	Arsenic	As	75	74.921596	100	
35	Bromine	Br	79	78.918336	50.69	
36	Krypton	Kr	84	83.911506	57.0	
			89	88.917563	β^-	3.2 min
			92	91.926153	β^-	1.84 s
38	Strontium	Sr	86	85.909273	9.8	
			88	87.905625	82.6	
			90	89.907746	β^-	28.8 y
39	Yttrium	Y	89	89.905856	100	
41	Niobium	Nb	98	97.910331	β^-	2.86 s
43	Technetium	Tc	98	97.907210	β^-, γ	4.2×10^6 y
47	Silver	Ag	107	106.905095	51.83	
			109	108.904754	48.17	
48	Cadmium	Cd	114	113.903361	28.7	
49	Indium	In	115	114.90388	95.7; β^-	5.1×10^{14} y
50	Tin	Sn	120	119.902199	32.4	
51	Antimony	Sb	133	132.915237	β^-	2.5 min
53	Iodine	I	127	126.904477	100	
			131	130.906118	β^-, γ	8.04 d
54	Xenon	Xe	132	131.90415	26.9	
			136	135.90722	8.9	
55	Cesium	Cs	133	132.90543	100	
56	Barium	Ba	137	136.90582	11.2	
			138	137.90524	71.7	
			141	140.914406	β^-	18.27 min
			144	143.92273	β^-	11.9 s
61	Promethium	Pm	145	144.91275	EC, α, γ	17.7 y
74	Tungsten (Wolfram)	W	184	183.95095	30.7	
76	Osmium	Os	191	190.96094	β^-, γ	15.4 d
			192	191.96149	41.0	
78	Platinum	Pt	195	194.96479	33.8	
79	Gold	Au	197	196.96656	100	

Atomic Number (Z)	Element	Symbol	Mass Number (A)	Atomic Mass[*]	Abundance (%) or Decay Mode[†] (if radioactive)	Half-Life (if radioactive)
81	Thallium	Tl	205	204.97441	70.5	
			210	209.990069	β^-	1.3 min
82	Lead	Pb	204	203.973044	β^-, 1.48	1.4×10^{17} y
			206	205.97446	24.1	
			207	206.97589	22.1	
			208	207.97664	52.3	
			210	209.98418	α, β^-, γ	22.3 y
			211	210.98874	β^-, γ	36.1 min
			212	211.99188	β^-, γ	10.64 h
			214	213.99980	β^-, γ	26.8 min
83	Bismuth	Bi	209	208.98039	100	
			211	210.98726	α, β^-, γ	2.15 min
			212	211.991272	α	60.55 min
84	Polonium	Po	210	209.98286	α, γ	138.38 d
			212	211.988852	α	0.299 μs
			214	213.99519	α, γ	164 μs
86	Radon	Rn	222	222.017574	α, β	3.8235 d
87	Francium	Fr	223	223.019734	α, β^-, γ	21.8 min
88	Radium	Ra	226	226.025406	α, γ	1.60×10^3 y
			228	228.031069	β^-	5.76 y
89	Actinium	Ac	227	227.027751	α, β^-, γ	21.773 y
90	Thorium	Th	228	228.02873	α, γ	1.9131 y
			231	231.036297	α, β^-	25.52 h
			232	232.038054	100; α, γ	1.41×10^{10} y
			234	234.043596	β^-	24.10 d
91	Protactium	Pa	234	234.043302	β^-	6.70 h
92	Uranium	U	232	232.03714	α, γ	72 y
			233	233.039629	α, γ	1.592×10^5 y
			235	235.043925	0.72; α, γ	7.038×10^8 y
			236	236.045563	α, γ	2.342×10^7 y
			238	238.050786	99.275; α, γ	4.468×10^9 y
			239	239.054291	β^-, γ	23.5 min
93	Neptunium	Np	239	239.052932	β^-, γ	2.35 d
94	Plutonium	Pu	239	239.052158	α, γ	2.41×10^4 y
95	Americium	Am	243	243.061374	α, γ	7.37×10^3 y
96	Curium	Cm	245	245.065487	α, γ	8.5×10^3 y
97	Berkelium	Bk	247	247.07003	α, γ	1.4×10^3 y
98	Californium	Cf	249	249.074849	α, γ	351 y
99	Einsteinium	Es	254	254.08802	α, γ, β^-	276 d
100	Fermium	Fm	253	253.08518	EC, α, γ	3.0 d
101	Mendelevium	Md	255	255.0911	EC, α	27 min
102	Nobelium	No	255	255.0933	EC, α	3.1 min
103	Lawrencium	Lr	257	257.0998	α	≈35 s

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[*] The masses given throughout this table are those for the neutral atom, including the Z electrons.

[†] EC stands for electron capture.

Answers to Your Turn Problems

CHAPTER 1

Active Example 1–1 1.26 km/h

CHAPTER 2

Active Example 2–1 (a) 10.7 mi.
(b) $\Delta\vec{\mathbf{x}} = (2.1\ \text{mi})\hat{\mathbf{x}}$. Note that these results are independent of the location of the origin.

CHAPTER 3

Active Example 3–1 D will decrease by a factor of two, but θ is unchanged. Numerical calculation gives $D = 2.33$ m and $\theta = 20.5°$.
Active Example 3–2 Reducing the time interval by a factor of two increases the magnitude of the acceleration by a factor of two, but does not change the direction. We find $a_{av} = 2.68\ \text{m/s}^2$, and $\theta = 53.6°$ north of east.

CHAPTER 4

Active Example 4–1 4.89 s. As expected, more time is required in this case.
Active Example 4–2 With $v_0 = 22$ m/s we find $R = 49$ m, for an increase of 20 percent (to two significant figures). In general, the fact that R depends on the *second* power of v_0 means that an increase of p percent in v_0 will result in roughly a $2p$ percent increase in R.

CHAPTER 5

Active Example 5–1 Doubling the force doubles the acceleration. This, in turn, reduces the stopping distance by a factor of two. We find $\Delta x = 61.0$ m.
Active Example 5–2 (a) In this case, the horizontal component of force will be greater than before. Therefore, the final speed will be greater as well. **(b)** $v_x = 1.40$ m/s.

CHAPTER 6

Active Example 6–1 Referring to Active Example 6–1, we see that the angle must be less than 20.0°. Numerical calculation yields $\theta = 14.0°$.
Active Example 6–2 For a tension greater than that found in Active Example 6–2, the sag angle must be less than 3.50°. We find $\theta = 2.96°$.
Active Example 6–3 Referring to Active Example 6–3, we see that the speed must be greater than 17.0 m/s. In fact, we find $v = 19.4$ m/s.

CHAPTER 7

Active Example 7–1 Doubling the mass doubles the initial kinetic energy of the block. Because the potential energy of the spring depends on the compression squared, the compression will be increased by a factor of the square root of 2. Therefore, the new compression is 0.17 m.
Active Example 7–2 Recalling that $P = Fv$, it follows that increasing the speed from 29.1 m/s to 32.0 m/s requires an increase in power by the factor (32.0/29.1). Thus, the needed power is 4.10×10^4 W.

CHAPTER 8

Active Example 8–1 If we set the energy at the halfway position equal to $-mg(d/2) + \frac{1}{2}k(d/2)^2 + \frac{1}{2}mv^2$, we find $v = 0.664$ m/s. Notice that this is *greater* than the speed when the block reaches the position $y = 0$. The reason is that when the block is between $y = -mg/k$ and $y = 0$ the net force acting on it is downward, and hence it decelerates before it reaches $y = 0$.
Active Example 8–2 Using $d = 3.50$ m in step 3, we find $W_{nc} = -6060$ J.
Active Example 8–3 In this case, we find $h = 14.8$ m. Note that the height is less for an increased mass.

CHAPTER 9

Active Example 9–1 This time of contact would result in a final speed of 74.4 m/s.
Active Example 9–2 Doubling the mass of the stick means that the bee's velocity will be doubled in magnitude. Therefore, $\vec{\mathbf{v}}_b = \vec{\mathbf{p}}_b/m_b = (7.60\ cm/s)\hat{\mathbf{x}}$.
Active Example 9–3 No. The stick will move in the opposite direction with a greater speed, but the center of mass will remain at rest.

CHAPTER 10

Active Example 10–1 The time required is one-half the time for the pulley to come to rest. During this time, the pulley rotates through three-quarters of its total angular displacement; that is, $\theta - \theta_0 = \frac{3}{4}(6.94\ \text{rad}) = 5.21$ rad.
Active Example 10–2 Notice that both a_{cp} and a_t depend linearly on the radius, r. Therefore, at half the radius to the bottom of the tubes, the total acceleration has half the magnitude given in Active Example 10–2. The direction of the acceleration is unchanged, however. Thus, $a = 5.20\ \text{m/s}^2$ and $\phi = 33.9°$.
Active Example 10–3 The final speed decreases if the moment of inertia is increased. This is because with a larger moment of inertia, there is more kinetic energy of rotation for given speed. In this case, we find $v = 0.74$ m/s.

CHAPTER 11

Active Example 11–1 The child moved to the left (away from the father). The distance from the child to the father is now 0.40 L; therefore, the child moved to the left a distance of 0.15 L.
Active Example 11–2 Zero force condition: $F_2 - Mg - mg = 0$. Zero torque condition: $-Mg(1.56\ \text{m}) + F_2(2.06\ \text{m}) - mg(3.56\ \text{m}) = 0$.
Active Example 11–3 Zero force condition, horizontal: $f_2 - f_3 = 0$. Zero force condition, vertical: $f_1 - mg = 0$. Zero torque condition, with L = distance from base of ladder to wall: $mg(L - b) + f_2(a) - f_1(L) = 0$.
Active Example 11–4 This period corresponds to an angular speed of 420 rad/s; therefore, the radius of the star must be less than 20.0 km. Straightforward substitution yields $R_f = 17$ km.
Active Example 11–5 If it takes 22.5 s to complete one revolution, the angular speed of the merry-go-round is 0.279 rad/s. Noting that the angular speed of the merry-go-round is proportional to the initial speed of the child, we find that $v = 2.46$ m/s. As expected, this result is less than 2.80 m/s.

CHAPTER 12

Active Example 12–1 8.67×10^7 m
Active Example 12–2 7.63 km/s

CHAPTER 13

Active Example 13–1 A direct application of $K_{max} = \frac{1}{2}mv_{max}{}^2$ yields $m = 0.275$ kg.
Active Example 13–2 We know that $v_{max} = A\omega$ and $\omega = 2\pi/T$, with $T = 0.700$ s. Therefore, $A = 0.0877$ m.
Active Example 13–3 The amplitude is directly proportional to the initial speed; therefore, doubling the initial speed doubles the amplitude. The period, however, is independent of the amplitude. As a result, the time required to come to rest does not change.
Active Example 13–4 The moment of inertia of a solid sphere is less than that for a hollow sphere. Therefore, the solid sphere has the smaller period. Substituting $I = \frac{7}{5}MR^2$ in Equation 13–21 yields $T = 2\pi\sqrt{\frac{R}{g}}\left(\sqrt{\frac{7}{5}}\right)$.

CHAPTER 14

Active Example 14–1 Comparing to a whisper at 1 m, we find $r = 8.63$ km. Of course, other intervening sounds over such a large distance would surely drown out the "whisper."
Active Example 14–2 The next higher frequency resulting in constructive interference corresponds to a path length difference of 1.5λ. This means that $\lambda = 1.10$ m, and hence $f = 312$ Hz.

CHAPTER 15

Active Example 15–1 0.0140 N
Active Example 15–2 The volume of the water must be 0.955 times the volume of the wood, or $V_{water} = 3.22 \times 10^{-3}\ \text{m}^3$. The volume of the wood is $(0.150\ \text{m})^3$; that is, $V_{wood} = 3.38 \times 10^{-3}\ \text{m}^3$.
Active Example 15–3 4.06 m

CHAPTER 16

Active Example 16–1 Referring to the figure in Example 16–1, we see that the correct temperature should be somewhere between 70 °F and 90 °F. In fact, if we solve the equation $3t = 9t/5 + 32$, we find $t = T_C = (80/3)$ °C and $3t = T_F = 80$ °F.

Active Example 16–2 The iron has a lower specific heat than aluminum; therefore less heat is required for a given change in temperature. This implies that the final temperature of the system with an iron can will be greater than with an aluminum can. Numerical calculation yields $T = 31$ °C to two significant figures. If three significant figures are used, we find $T = 30.7$ °C for the aluminum can and $T = 31.3$ °C for the iron can.

CHAPTER 17

Active Example 17–1 Recall that $n = PV/RT$. Halving the temperature, by itself, doubles the number of moles. On the other hand, halving the diameter reduces the volume—and the number of moles—by a factor of eight. Combining the two effects, we find that the number of moles is reduced by a factor of 4.

Active Example 17–2 The height is proportional to the temperature. Therefore, changing the final height by a factor of (19/28) changes the final temperature by the same factor. The final temperature, then, is 330 K (19/28) = 220 K. Note that this is less than the initial temperature, as expected.

Active Example 17–3 The shear deformation, Δx, is proportional to the height of the pancakes, L_0. Therefore, the shear deformation doubles to 5.0 cm.

Active Example 17–4 Brass has a smaller bulk modulus than gold, and hence its volume changes more for a given change in pressure. The change in volume of a brass doubloon is $\Delta V = -7.2 \times 10^{-10}\ \mathrm{m}^3$.

CHAPTER 18

Active Example 18–1 There are an infinite number of ways in which this can be done. Perhaps the simplest is to move straight up from point A to a pressure of 200 kPa, then expand at constant pressure from 0.25 m^3 to 0.54 m^3. Finally, drop straight down in pressure back to the value of 120 kPa and point B.

Active Example 18–2 Increasing T_h by 20 K gives $e = 0.277$; decreasing T_c by 20 K gives $e = 0.291$. Clearly, it is more effective to decrease the temperature of the cold reservoir.

Active Example 18–3 In this case, we find that the heat released to the cold reservoir is 595 J. This increases the entropy of the cold reservoir by 1.95 J/K. Therefore, the total entropy increase of the universe is 1.95 J/K − 1.82 J/K = 0.13 J/K. Note that this is a positive value, as expected.

CHAPTER 19

Active Example 19–1 The point of zero force remains in the same place. This can be seen most clearly in step 3, where we see that doubling each charge simply yields an additional factor of two on each side of the equation. Since the factor of two appears on both sides of the equation, it cancels.

Active Example 19–2 The new sphere exerts less force than the original sphere. Specifically, the new sphere has half the radius of the original sphere, and one quarter its surface area. Therefore, it has one quarter the total charge, and exerts one quarter as much force.

Active Example 19–3 The new Gaussian surface has zero electric flux—there is no flux through either end cap, nor through the curved sides of the cylindrical surface. This means that the net charge contained within the Gaussian surface is zero, which is evident when we note that the two plates of the capacitor have opposite charge densities of equal magnitude.

CHAPTER 20

Active Example 20–1 We are given that the electric potential at point A is *higher* than at point B; therefore, the electric potential energy of an electron (with its negative charge) is *less* at point A than at point B. As an electron moves from point A to point B its electric potential energy increases by 7.2×10^{-19} J.

Active Example 20–2 The initial speed must be considerably greater than 5.00 m/s. In fact, it must be 14.6 m/s.

Active Example 20–3 There is no change in the electric potential energy. The reason is that moving the charge as described does not change the *separation* between any pair of charges in the system. Therefore, the total electric potential energy is as given in step 4.

CHAPTER 21

Active Example 21–1 The required time is 230 s.

Active Example 21–2 In this case, we find $I_1 = 0.13$ A, $I_2 = 0.11$ A, and $I_3 = 0.020$ A. Notice that each current flows in the direction indicated in the sketch of the circuit.

Active Example 21–3 The 5.00-μF capacitor stores more energy than the 10.0-μF capacitor because more work is required to force a given amount of charge onto its plates. In fact, we find that the 5.00-μF capacitor stores 1.60×10^{-4} J of energy, twice as much (to three significant figures) as the 7.98×10^{-5} J stored in the 10.0-μF capacitor.

CHAPTER 22

Active Example 22–1 The reason is that the orbital speed is directly proportional to the radius, as we see in Equation 22–3. Therefore, reducing the radius (or circumference) by a given factor reduces the speed by the same factor. It follows that the time required to travel a distance equal to one circumference is independent of the radius.

Active Example 22–2 In this case, the fields produced by the two wires are in the same direction; namely, into the page. The net field is 9.1×10^{-6} T, into the page.

CHAPTER 23

Active Example 23–1 One way to calculate the current is to note that the light bulb consumes a power of 5.0 W and has a resistance of 12 Ω. We can solve $P = I^2R$ to find $I = 0.65$ A. A second way is to note from Example 23–3 that the external force acting on the rod has a magnitude of 1.6 N. The rod moves with constant speed, however, and hence the magnetic force acting on it, $F = ILB$, must have the same magnitude. If we equate these magnitudes, we find $I = 0.64$ A. The slight discrepancy between these answers is due to round-off error, as can be verified by repeating the calculations with more significant figures.

Active Example 23–2 The value of the inductance changes by a greater factor if we double the number of turns. This is because the inductance depends on the square of the number of turns, but depends only linearly on the cross-sectional area. Specifically, we find the following: (a) doubling N quadruples the inductance; (b) tripling A triples the inductance.

Active Example 23–3 From Equation 23–22 we see that the voltage in the secondary circuit is $V_s = V_p(N_s/N_p)$. Therefore, if $V_p \rightarrow 2V_p$ and $N_p \rightarrow 4N_p$, it is clear that we must double N_s to keep V_s the same.

CHAPTER 24

Active Example 24–1 The capacitive reactance is equal to 64 Ω when the frequency is reduced to 9.2 Hz. At this frequency, the current is 1.2 A.

Active Example 24–2 (a) 40 V. **(b)** 58 V.

Active Example 24–3 Setting the impedance of the circuit equal to 2.50 V/1.50 A = 1.67 Ω, we find $f = 68.0$ Hz and $f = 108$ Hz, to three significant figures.

CHAPTER 25

Active Example 25–1 If the beam spreads out to twice its initial diameter, its area quadruples. This means, in turn, that the intensity of the beam decreases by a factor of four. The intensity, however, depends on the fields squared. Therefore, it follows that both E_{max} and B_{max} decrease by a factor of two.

Active Example 25–2 With three equally rotated polarizers, we find a transmitted intensity of $0.689I_0$. This is considerably greater than the intensity found with two polarizers. In general, the more smoothly and continuously the plane of polarization is rotated, the greater the transmitted intensity.

CHAPTER 26

Active Example 26–1 The magnification of the tooth will decrease. After all, as the object moves closer to the mirror, the mirror behaves more and more like a plane mirror, in which case the magnification is 1. With $f = 1.38$ cm and $d_o = 1.00$ cm we find $d_i = -3.63$ cm and $m = 3.63$.

Active Example 26–2 Referring to Figure 26–34, it is clear that to obtain a larger magnification we must move the object closer to the lens. To obtain $m = 0.75$, we find that the object distance must be reduced from 12 cm to $d_o = 2.633$ cm, to four significant figures. The corresponding image distance is −1.975 cm.

CHAPTER 27

Active Example 27–1 The camera is now focussed at a distance of 1.72 m.

Active Example 27–2 The only change from the analysis given in the text for Figure 27–5 is that the concave mirror has a positive focal length (+12.5 cm) rather than a negative focal length. Therefore, the image distance for the mirror is 21.4 cm. This image is then an object for the lens, producing the final image of the system 15.4 cm to the left of the lens. The final magnification is −0.384, indicating an inverted image 38.4% of its original height.

Active Example 27–3 In this case, the far point is 202 cm from the person's eyes. Note that this far point is closer to the eye than the far point in Example 27–2; therefore, the required refractive power has a magnitude that is greater than 0.312.

Active Example 27–4 The second person's vision needs more correction, since the near point is farther from the eyes. Therefore, the refractive power of the second person's contacts must be greater, which, in turn, means that the focal length must be smaller. In fact, we find $f = 28.6$ cm.

CHAPTER 28

Active Example 28–1 The desired minimum thickness is one-quarter the wavelength in the material. Recall, however, that the wavelength in a material with an index of refraction n is $\lambda_n = \lambda/n$ (Equation 28–4). Therefore, if the index of refraction is increased, the minimum thickness will be decreased. In this case, we find a minimum thickness of 97.4 nm.

Active Example 28–2 The second dark fringe corresponds to $m = 2$ in Equation 28–12. With this substitution, we find that the linear distance is $y = 6.96$ cm.

Active Example 28–3 As the aperture of a telescope increases, the minimum angular separation that can be resolved decreases, as can be seen from Equation 28–15. If a telescope can resolve smaller angular separations, it follows that its maximum resolution distance is greater. For the case $D = 3.0$ m, we find $L = 1.1 \times 10^{10}$ m.

Active Example 28–4 First, convert the wavelength 486.2 nm to the frequency $f = 6.170 \times 10^{14}$ Hz and the wavelength 563.0 nm to the frequency $f' = 5.329 \times 10^{14}$ Hz. With these results, we can now apply Equation 25–3 to find $u = 4.089 \times 10^{7}$ m/s. Since this is only 13.6% of the speed of light, the approximations used to derive Equation 25–3 should be valid.

CHAPTER 29

Active Example 29–1 The speed in this case is $v = 0.953c$.

Active Example 29–2 In this case, the velocity of the probe relative to the planet is $v = 0.306c$. The corresponding length is $L = 9.52$ m.

CHAPTER 30

Active Example 30–1 Increasing the wavelength by a factor of 1.25 results in a reduction in the frequency by a factor of 1.25. Similarly, the energy of a photon (which is proportional to frequency) is reduced by a factor of 1.25. Since each photon carries less energy, it follows that more photons will be required per second at this new wavelength. In fact, the minimum number of photons per second will be increased by the factor 1.25.

Active Example 30–2 The de Broglie wavelength is inversely proportional to speed; therefore, doubling the speed results in a wavelength that is reduced by a factor of two.

CHAPTER 31

Active Example 31–1 In this case, the final state is $n_f = 2$.

Active Example 31–2 In singly ionized helium, the charge of the nucleus is $+Ze = +2e$; therefore, $Z = 2$. Referring to Equation 31–9, we see that the energy of any given energy level depends on Z^2. It follows that the energy—and frequency—of the absorbed photon increases by a factor of $2^2 = 4$.

Active Example 31–3 Direct substitution in Equation 31–14 shows that $Z = 51$ is the largest value of Z that requires an acceleration voltage less than 35 kV.

CHAPTER 32

Active Example 32–1 Doubling the wavelength reduces the frequency of the gamma ray (and its energy) by a factor of two. Since the mass difference is proportional to the energy of the gamma ray, it too will be reduced by a factor of two.

Active Example 32–2 Direct substitution in Equation 32–9 shows that the number of radon atoms has decreased by a factor of two when $t = 3.83$ d. Note that this result is in agreement with Equation 32–10.

Active Example 32–3 Using Equation 32–12, we see that the activity of the radon decreases to 10.0 Bq after 12.7 d.

Active Example 32–4 This reaction releases 12.9 MeV.

Answers to Odd-Numbered Conceptual Questions

CHAPTER 1

1. No. The factor of 2 is dimensionless.
3. **(a)** Not possible, since units have dimensions. For example, seconds can only have the dimension of time. **(b)** Possible, since different units can be used to measure the same dimensions. For example, time can be measured in seconds, minutes, or hours.
5. To the nearest power of ten: **(a)** 1 m; **(b)** 10^{-2} m; **(c)** 10 m; **(d)** 100 m; **(e)** 10^{7} m.

CHAPTER 2

1. The displacement is the same for you and your dog; the distance covered by the dog is greater.
3. **(a)** Yes. If you drive in a complete circle your distance is the circumference of the circle, but your displacement is zero. **(b)** Yes. The distance and the magnitude of the displacement are equal if you drive in a straight line. **(c)** No. Any deviation from a straight line results in a distance that is greater than the magnitude of the displacement.
5. Their velocities are different because they travel in different directions.
7. Since the car circles the track its direction of motion must be changing. Therefore, its velocity changes as well. Its speed, however, can be constant.
9. Constant-velocity motion; that is, straight-line motion with constant speed.
11. **(a)** The time required to stop is doubled. **(b)** The distance required to stop increases by a factor of four.
13. Yes, if it moves with constant velocity.
15. **(a)** No. If air resistance can be ignored, the acceleration of the ball is the same at each point on its flight. **(b)** Same answer as part (a).
17. Ignoring air resistance, the two gloves have the same acceleration.

CHAPTER 3

1. **(a)** scalar; **(b)** vector; **(c)** vector; **(d)** scalar.
3. **(a)** $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ have the same magnitude. **(b)** $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ have opposite directions.
5. Yes, if they have the same magnitude and point in opposite directions.
7. Note that the magnitudes A, B, and C satisfy the Pythagorean theorem. It follows that $\vec{\mathbf{A}}$, $\vec{\mathbf{B}}$, and $\vec{\mathbf{C}}$ form a right triangle, with $\vec{\mathbf{C}}$ as the hypotenuse. Thus, $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ are perpendicular to one another.
9. $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ must be collinear and point in opposite directions. In addition, the magnitude of $\vec{\mathbf{A}}$ must be greater than the magnitude of $\vec{\mathbf{B}}$; that is, $|A| > |B|$.
11. The vector $\vec{\mathbf{A}}$ points in one of two directions: (1) 135° counterclockwise from the x axis; (2) 45° clockwise from the x axis. Case (1) corresponds to $A_x < 0$ and case (2) corresponds to $A_x > 0$.
13. Tilt the umbrella forward so that it points in the opposite direction of the rain's velocity relative to you.

CHAPTER 4

1. Ignoring air resistance, the acceleration of a projectile is vertically downward at all times.
3. The projectile was launched at an angle of 30° above the positive x axis; when it landed its direction of motion was 30° below the positive x axis. Hence, its change in direction was 60° clockwise.
5. At its highest point, the projectile is moving horizontally. This means that gravity

has reduced its y component of velocity to zero. The x component of velocity is unchanged by gravity, however. Therefore, the projectile has a velocity equal to $\vec{v} = (4\text{ m/s})\hat{x}$ at the highest point in its trajectory.

7. Less than 45°. See Figure 4–9.
9. **(a)** From the child's point of view the scoop of ice cream falls straight downward. **(b)** From the point of view of the parents the scoop of ice cream follows a parabolic trajectory.
11. **(a)** At its highest point the projectile moves horizontally. Therefore, its launch angle was 50°. **(b)** In this case, the launch angle was 150°, or, equivalently, 30° above the negative x axis.

CHAPTER 5

1. The force exerted on the car by the brakes causes it to slow down, but your body continues to move forward with the same velocity (due to inertia) until the seat belt exerts a force on it to decrease its speed.
3. No. You are at rest relative to your immediate surroundings, but you are in motion relative to other objects in the universe.
5. When the magnitude of the force exerted on the girl by the rope equals the magnitude of her weight, the net force acting on her is zero. As a result, she moves with constant velocity.
7. **(a)** The upper string breaks, because the tension in it is equal to the applied force on the lower string plus the weight of the block. When the tension in the upper string reaches the breaking point, the tension in the lower string is below this value. **(b)** The lower string breaks in this case, because of the inertia of the block. As you move your hand downward rapidly the lower string stretches and breaks before the block can move a significant distance and stretch the upper string.
9. Each time the astronauts throw or catch the ball they exert a force on it, and it exerts an equal and opposite force on them. This causes the astronauts to move farther apart from one another with increasing speed as the game progresses.
11. Mr. Ed's reasoning is incorrect because he is adding two action-reaction forces that act on *different* objects. Wilbur should point out that the net force exerted on the cart is simply the force exerted on it by Mr. Ed. Thus the cart will accelerate. The equal and opposite reaction force acts on Mr. Ed, and does not cancel the force acting on the cart.
13. The whole brick has twice the force acting on it, but it also has twice the mass. Since the acceleration of an object is proportional to the force exerted on it and inversely proportional to its mass, the whole brick has the same acceleration as the half brick.
15. Yes. An object with zero net force acting on it has a constant velocity. This velocity may or may not have zero magnitude.
17. The acceleration of an object is inversely proportional to its mass. The diver and the Earth experience the same force, but the Earth—with its much larger mass—has a much smaller acceleration.
19. An astronaut can tell which of two objects is more massive by pushing on both with the same force. Since acceleration is inversely proportional to mass, the more massive object can be recognized by its smaller acceleration.
21. On solid ground you come to rest in a much smaller distance than when you plunge into water. The smaller the distance over which you come to rest the greater the acceleration, and the greater the acceleration the greater the force exerted on you. Thus, when you land on solid ground the large force it exerts on you may be enough to cause injury.
23. Yes, in fact it happens all the time. Whenever you throw a ball upward it moves in the opposite direction to the net force acting on it, until it reaches the top of its trajectory.
25. This is an example of bad physics. Though the rocket-powered backpack may well produce enough force to give the truck a large acceleration, that force must be transmitted to the truck through the boy's arms. A force large enough to rapidly accelerate a truck would crush a person's arms.

CHAPTER 6

1. The clothesline has a finite mass, and so the tension in the line must have an upward component to oppose the downward force of gravity. Thus, the line sags much the same as if a weight were hanging from it.
3. The braking distance of a skidding car depends on its initial speed and the coefficient of kinetic friction. Thus, if the coefficient of friction is known reasonably well, the initial speed can be determined from the length of the skid marks.
5. The force that ultimately is responsible for stopping a train is the frictional force between its metal wheels and the metal track. These are fairly smooth surfaces. In contrast, the frictional force that stops a car is between the rubber tires and the concrete roadway. These are rougher surfaces with a greater coefficient of friction.
7. As you brake harder your car has a greater acceleration. The greater the acceleration of the car, the greater the force required to give the flat of strawberries the same acceleration. When the required force exceeds the maximum force of static friction the strawberries begin to slide.
9. For a drop of water to stay on a rotating wheel an inward force is required to give the drop the necessary centripetal acceleration. Since the force between a drop of water and the wheel is small, the drop will separate from the wheel rather than follow its circular path.
11. A centripetal force is required to make the motorcycle follow a circular path, and this force increases rapidly with the speed of the cycle. If the necessary centripetal force exceeds the weight of the motorcycle, because its speed is high enough, then the track must exert a downward force on the cycle at the top of the circle. This keeps the cycle in firm contact with the track.
13. Since the passengers are moving in a circular path a centripetal force must be exerted on them. This force, which is radially inward, is supplied by the wall of the cylinder.
15. This helps because the students sitting on the trunk increase the normal force between your tires and the road. Since the force of friction is proportional to the normal force, this increases the frictional force enough (one hopes) to allow your car to move.
17. The normal force exerted on a gecko by a vertical wall is zero. If the gecko is to stay in place, however, the force of static friction must exert an upward force equal to the gecko's weight. For this to happen when the normal force is zero would require an infinite coefficient of static friction. Thus, we conclude that the physics of gecko feet is more complex than our simple models of friction.
19. Yes. The steering wheel can accelerate a car—even if its speed remains the same—by changing its direction of motion.
21. When a bicycle rider leans inward on a turn, the force applied to the wheels of the bicycle by the ground is both upward and inward. It is this inward force that produces the centripetal acceleration of the rider.

CHAPTER 7

1. No. Work requires that a force acts through a distance.
3. True. To do work on an object a force must have a nonzero component along its direction of motion.
5. Yes, you must do work against the force of gravity to raise your body upward out of bed.
7. The frictional force between your shoes and the ground does positive work on you whenever you begin to walk.
9. Gravity exerts an equal and opposite force on the package, and hence the net work done on it is zero. The result is no change in kinetic energy.
11. No, we must also know how much time it takes for engine 1 to do the work. For example, if engine 1 takes twice as much time to do twice the work of engine 2, it has the same power output as engine 2. If it takes more than twice as much time, then engine 1 actually produces less power than engine 2.

CHAPTER 8

1. The kinetic energy cannot be negative, since m and v^2 are always positive or zero. The gravitational potential energy can be negative since any level can be chosen to be zero.

3. Since both distance and average force are doubled, the work done in stretching the spring is quadrupled. Equivalently, the potential energy of the spring is proportional to $(\Delta x)^2$, and hence doubling the stretch distance quadruples the spring's potential energy.
5. If the spring is permanently deformed, it will not return to its original length. As a result, the work that was done to stretch the spring is not fully recovered—some of it goes into the energy of deformation. For this reason, the spring force is not conservative during the deformation. If the spring is now stretched or compressed by a small amount about its new equilibrium position, its force is again conservative—though the force constant will be different.
7. When the term "energy conservation" is used in everyday language, it doesn't refer to the total amount of energy in the universe. Instead, it refers to using energy wisely, especially when a particular source of energy—like oil or natural gas—is finite and nonrenewable.
9. A variety of conservative and nonconservative forces are involved in the situation shown in the photo. First, the engine of the earth mover does positive nonconservative work as it digs out and lifts a load of rocks. At the same time, gravity does negative conservative work on the rocks as the gravitational potential energy of the system increases. Next, the earth mover does positive nonconservative work to transport the rocks to the dump truck. When the rocks are released, gravity does positive conservative work as the gravitational potential energy of the system is converted to kinetic energy. Nonconservative frictional forces do negative work to convert the kinetic energy of the rocks into sound and heat when they land in the truck. Finally, the increased load in the truck does conservative work as it compresses the springs, storing part of the system's energy in the form of spring potential energy.
11. Zero force implies that the rate of change in the potential energy with distance is zero—that is, the potential energy is constant—but the value of the potential energy can be anything at all. Similarly, if the potential energy is zero, it does not mean that the force is zero. Again, what matters is the rate of change of the potential energy with distance.
13. The dive begins with the diver climbing the ladder to the diving board, which converts chemical energy in the muscles into an increased gravitational potential energy. Next, by jumping on the board the diver causes the board to flex and to store potential energy. As the board rebounds, the diver springs into the air, using the kinetic energy derived from the leg muscles and the potential energy released by the board. The diver's kinetic energy is then converted into an increased gravitational potential energy until the highest point of the dive is reached. After that, gravitational potential energy is converted back to kinetic energy as the diver moves downward. Finally, the kinetic energy of the diver is converted into heat, sound, and flowing water as splashdown occurs.

CHAPTER 9

1. The momentum of the keys increases as they fall because a net force acts on them. The momentum of the universe is unchanged because an equal and opposite force acts on the Earth.
3. If the kinetic energy is zero the speeds must be zero as well. This means that the momentum is zero.
5. Yes, in much the same way that a propeller in water can power a speedboat.
7. When a heavy object and a light object collide they exert equal and opposite forces on one another. Since the light object has less mass, its acceleration is greater. This can result in more severe injuries for the light vehicle.
9. No. The fact that the initial momentum of the system is nonzero means that the final momentum must also be nonzero. Thus, it is not possible for both objects to be at rest after the collision.
11. **(a)** Yes. Suppose two objects have momenta of equal magnitude. If these objects collide in a head-on, completely inelastic collision, they will be at rest after the collision. In this case, all of the initial kinetic energy is converted to other forms of energy. **(b)** No. In order for its momentum to change, an external force must act on the system. We are given, however, that the system is isolated. Therefore, the only forces acting on it are internal forces.
13. The kinetic energy of the bullet is much greater than that of the gun. Thus, less energy is dissipated in stopping the gun.
15. The plane weighs the same whether the fly lands on the dashboard or flies about the cockpit. The reason is that the fly must exert a downward force on the air in the cockpit equal in magnitude to its own weight in order to stay aloft. This force ultimately acts downward on the plane, just as if the fly had landed.
17. Your center of mass is somewhere directly above the area of contact between your foot and the ground.

CHAPTER 10

1. All points on the rigid object have the same angular speed. Not all points have the same linear speed, however. The farther a given point is from the axis of rotation the greater its linear speed.
3. No. As long as you are driving in a circular path you will have a nonzero centripetal acceleration.
5. **(a)** No, because your direction of motion is constantly changing. **(b)** Yes, your linear speed is simply the radius of the wheel times your angular speed. **(c)** Yes. It is equal to your linear speed squared divided by the radius of the wheel. **(d)** No. Your centripetal acceleration is always toward the center of the wheel, but this is in a different direction as you rotate to different locations.
7. **(a)** A basketball thrown with no spin. **(b)** A spinning airplane propeller on a plane that is at rest. **(c)** A bicycle wheel on a moving bicycle.
9. When the chunky stew is rolled down the aisle, all of the contents of the can roll together with approximately the same angular speed. This is because the chunky stew is thick and almost solid. The beef broth, however, is little more than water. Therefore, when the broth is rolled down the aisle, almost all that is actually rolling is the metal can itself. It follows that the stew has the greater initial kinetic energy, and hence it rolls a greater distance.

CHAPTER 11

1. No. Torque depends both on the magnitude of the force and on the distance from the axis of rotation, or moment arm, at which it is applied. A small force can produce the same torque as a large force if it is applied farther from the axis of rotation.
3. The long pole has a large moment of inertia, which means that for a given applied torque the walker and pole have a small angular acceleration. This allows more time for the walker to "correct" his balance.
5. A force applied radially to a wheel produces zero torque, though the net force is nonzero.
7. No. In most cars the massive engine is located in the front, thus the car's center of mass is not in the middle of the car, but is closer to the front end. This means that the force exerted on the front tires is greater than the force exerted on the rear tires. (This situation is analogous to Active Example 11–1.)
9. You are in static equilibrium as you sit in your chair; so is the building where you have your physics class.
11. The angular speed of the dust cloud increases, just like a skater pulling in her arms, due to conservation of angular momentum.
13. Yes. Imagine turning on a ceiling fan. This increases the fan's angular momentum, without changing its linear momentum.

CHAPTER 12

1. No. The force of Earth's gravity is practically as strong in orbit as it is on the surface of the Earth. The astronauts experience weightlessness because they are in constant free fall.
3. If the gravitational force depended on the sum of the two masses, it would predict a

nonzero force even when one of the masses is zero. That is, there would be a gravitational force between a mass and a point in empty space, which is certainly not what is observed.

5. No. The amount of area swept out per time varies from planet to planet; what is constant is the amount of area swept out by a *given* planet per time.

7. Once the period of Charon is determined, the mass of the body it orbits (Pluto) can be calculated using Equation 12–7.

9. On the Moon, where there is no atmosphere, a rock can orbit at any altitude where it clears the mountains—as long as it has sufficient speed. Thus, if you could give the rock enough speed, it would orbit the Moon and come up to you from behind.

11. No. In the weightless environment of the Shuttle there would be no convection, which is needed to bring fresh oxygen to the flame. Without convection a flame usually goes out very quickly. In carefully controlled experiments on the Shuttle, however, small flames have been maintained for considerable times. These "weightless" flames are spherical in shape, as opposed to the tear-shaped flames here on Earth.

13. The net force acting on the Moon is always directed toward the Sun, never away from the Sun. Therefore, the Moon's orbit must always curve toward the Sun. The path shown in the upper part of Figure 12–20, though it seems "intuitive," sometimes curves toward the Sun, sometimes away from the Sun. The correct path, shown in the lower part of Figure 12–20, curves sharply toward the Sun when both the Sun and the Earth pull inward on the Moon, and curves only slightly toward the Sun when the Moon is pulled in opposite directions by the Sun and the Earth.

CHAPTER 13

1. The motion is periodic. It is not simple harmonic, however, because the position and velocity of the ball do not vary sinusoidally with time.

3. The motion of the air cart is periodic; it repeats after a fixed length of time. It is not simple harmonic motion, however, because the position and velocity of the cart do not vary sinusoidally with time.

5. The period remains the same because, even though the distance traveled by the object is doubled, its speed at any given time is also doubled.

7. Referring to Equation 13–6, we see that the constant C represents the maximum speed of the object, $C = v_{\max} = A\omega$; similarly, the constant D is the angular frequency, $D = \omega = 2\pi/T$. It follows that the amplitude is $A = C/D$ and the period is $T = 2\pi/D$.

9. If soldiers march in synchrony, the bridge will oscillate with the frequency of their step. If this frequency is near a resonance frequency of the bridge, the amplitude of oscillation could increase to dangerous levels.

CHAPTER 14

1. To generate a longitudinal wave, hit the nail on the head in a direction parallel to its length. To generate a transverse wave, hit the nail in a direction that is perpendicular to its length.

3. Typical waves at stadiums are transverse, since people move vertically up and down while the wave moves horizontally. To produce a longitudinal wave people could move back-and-forth to their left or right.

5. If the speed of sound depended on frequency, the sound in the first row—where the travel time is small—would not be affected significantly. Farther back from the stage, however, sounds with different frequencies would arrive at different times—the bass would be "out of sync" with the treble.

7. The part of the nail that vibrates most freely is the portion not yet in the wood. As you drive the nail farther into the wood, therefore, the part that vibrates becomes shorter and shorter. The vibrating portion of the nail is similar to the vibrating air column in an organ pipe, and hence the frequency goes up as the length decreases.

9. When you tune a violin you change the tension in the string. This causes the speed of waves in the string to change. The wavelength of a given mode of oscillation is unchanged, however, due to the fixed length of string. Thus, changing the speed while keeping the wavelength constant results in a change in frequency, according to the relation $v = f\lambda$.

11. No, the energy of oscillation is the same at all times. When the string is flat, the energy of oscillation is purely kinetic.

13. You hear no beats because the difference in frequency between these notes is too great to produce detectable beats.

CHAPTER 15

1. To draw a liquid up a straw you expand your lungs, which reduces the air pressure inside your mouth to less than atmospheric pressure. The resulting difference in pressure produces a net upward force on the liquid in the straw.

3. The pressure in a tank of water increases with depth, hence the pressure is greatest near the bottom. To provide sufficient support there, the metal bands must be spaced more closely together.

5. This experiment shows that a certain pressure is needed at the bottom of the water column and not just a certain weight of water. To blow the top off the barrel it is necessary to increase the pressure in the barrel enough so that the increase in pressure times the surface area of the top exceeds 400 N. Thus, the required height of water is the height that gives the necessary increase in pressure. But the increase in pressure, $\rho g h$, depends only on the height of the water in the tube, not on its weight.

7. Two quantities are unknown; the object's density and its volume. The two weight measurements provide two independent conditions that can be solved for the two unknowns.

9. The Great Salt Lake has water with a higher salinity, and hence a higher density, than ocean water. In fact, the density of its water is somewhat greater than the density of a typical human body. This means that a person can float in the Great Salt Lake much like a block of wood floats in fresh water.

11. The problem is that as you go deeper into the water, the pressure pushing against your chest and lungs increases rapidly. Even if you had a long tube on your snorkel, you would find it difficult to expand your lungs to take a breath. The air coming through the snorkel is at atmospheric pressure, but the water pushing against your chest might have twice that pressure or more. Thus, scuba gear not only holds air for you to breathe in a tank, it also feeds this air to you under pressure.

13. As the water falls it speeds up. Still, the amount of water that passes a given point in a given time is the same at any height. If the thickness of the water stayed the same, and its speed increased, the amount of water per time would increase. Hence, the thickness of the water must decrease to offset the increase in speed.

15. If you takeoff into the wind the air speed over the wings is greater than if you takeoff with the wind. This means that more lift is produced when taking off into the wind, which is clearly the preferable situation.

17. The ball should spin so that the side facing the batter is moving upward and the side facing the pitcher is moving downward.

CHAPTER 16

1. The coffee is not in equilibrium because its temperature is different from that of its surroundings. Over time the temperature of the coffee will decrease, until finally it is the same as room temperature. At this point it will be in equilibrium—as long as the room stays at the same temperature.

3. The discrepancy is not serious. After all, a temperature of 15,000,000 °C is equivalent to a temperature of 15,000,273.15 K. A difference of 273.15 out of 15 million is generally insignificant.

5. If the glass and the mercury had the same coefficient of volume expansion, the level of mercury in the glass would not change with temperature. This is because the volume of the cavity in the glass would expand by the same amount as the volume of mercury.

7. The mercury level drops at the beginning because the glass is the first to increase its temperature when it comes into contact with the hot liquid. Therefore, the glass expands before the mercury, leading to a drop in level. As the mercury attains the same temperature few moments later, its level will increase.
9. As the temperature of the house decreases, the length of the various pieces of wood from which it is constructed will decrease as well. As the house adjusts to these changing lengths, it will often creak or groan.
11. If the objects have different masses, the less massive object will have a greater temperature change, since it has the smaller heat capacity. On the other hand, the objects may have the same mass but differ in the material from which they are made. In this case, the object with the smaller specific heat will have the greater temperature change.
13. As the ground warms up on a sunny day, the ground of the surrounding suburbs warms up faster, since it has a smaller specific heat. This would lead to a wind blowing from the city to the suburbs.
15. Even though the flame at the far end of the match is very hot, the wood from which it is made is a poor conductor of heat. The air between the flame and your finger is an even poorer conductor of heat.
17. Two important factors work in favor of the water-filled balloon. First, the water has a large heat capacity, hence it can take on a large amount of heat with little change in temperature. Second, water is a better conductor of heat than air, hence the heat from the flame is conducted into a large volume of water—which gives it a larger effective heat capacity.
19. When penguins (or people) huddle together their rate of heat production is the same, but the surface area over which this heat is radiated to the surroundings is decreased. This results in the penguins being warmer.
21. Object 1 must have the higher temperature, to compensate for object 2's greater emissivity. Since radiated power depends on temperature raised to the fourth power, the temperature of object 1 must be greater by a factor of 2 to the one fourth power.

CHAPTER 17

1. The volume of an ideal gas is given by $V = nRT/P$. Thus, we expect the volume of the oxygen bags to vary inversely with pressure—the lower the pressure in the cabin, the larger the bags.
3. Recall that velocity takes into account both the speed of an object and its direction of motion. Therefore, the average *velocity* of air molecules in a room is zero, since they move randomly in all directions.
5. Airplanes can have a difficult time taking off from high-altitude airports because the air is thin and provides less lift than air at sea level. When the air is cool, however, its density is greater than when it is warm. Therefore, taking off in the morning or evening will provide the airplane with more lift—which can be a very important advantage at high altitude.
7. The boiling temperature of water depends on the pressure at which the boiling occurs—the higher the pressure, the higher the boiling temperature. Thus, in the autoclave, where the pressure is greater than atmospheric pressure, the temperature of boiling water is greater than 100 °C.
9. The alcohol, besides having antiseptic qualities, evaporates readily. As it evaporates, it draws heat from the body.
11. As high-speed molecules leave the drop, it draws heat from its surroundings to keep its temperature constant. As long as the temperature of the drop is constant, it will continue to have the same fraction of molecules moving quickly enough to escape.

CHAPTER 18

1. No. If the engine has friction it is not reversible.
3. The answer, in both cases, is yes. **(a)** Compress a gas in a thermally insulated cylinder. This will cause its temperature to rise. **(b)** If you expand a gas in a thermally insulated cylinder, its temperature will decrease.
5. One cannot conclude that heat was added to the system. For example, if a gas in a thermally insulated cylinder is compressed, its temperature will rise with no heat transfer.
7. Yes. You can convert mechanical work completely into heat by rubbing your hands together.
9. **(a)** No; **(b)** yes; **(c)** no; **(d)** no; **(e)** yes; **(f)** no.
11. Yes, this is possible. The problem is that you would need low-temperature reservoirs of ever lower temperature to keep the process going.
13. No. As you do work to put things in order you give off heat to the atmosphere. This increases the entropy of the air by more than the decrease in entropy of the room, for a net increase in entropy.
15. **(a)** Popped popcorn; **(b)** an omelet; **(c)** a pile of bricks; **(d)** a burned piece of paper.

CHAPTER 19

1. No. When an object becomes charged it is because of a transfer of charge between it and another object.
3. The charged comb causes the paper to become polarized, with the side nearest the comb acquiring a charge opposite to the charge of the comb. The result is an attractive interaction between the comb and the paper.
5. Yes. If the suspended object were neutral, it would be attracted to the charged rod by polarization effects. The fact that the suspended object is repelled indicates it has a charge of the same sign as that of the rod.
7. Both force laws depend on the product of specific properties of the objects involved; in the case of gravity it is the mass that is relevant, in the case of electrostatics it is the electric charge. In addition, both forces decrease with increasing distance as $1/r^2$. The extremely important difference between the forces, however, is that gravity is always attractive, whereas electrostatic forces can be attractive or repulsive.
9. No. Only for very special displacements will the electrostatic force act in a direction that points back toward the equilibrium point. For a general displacement the electrostatic force does not point toward the equilibrium point, and the fifth charge would move farther from equilibrium, making the system unstable.
11. One difference is that when an object is charged by induction, there is no physical contact between the object being charged and the object used to do the charging. In contrast, charging by contact—as the name implies—involves direct physical contact to transfer charge from one object to another. The main difference is that when an object is charged by induction, the sign of the charge the object acquires is opposite to that of the object used to do the charging. Charging by contact gives the object being charged the same sign of charge as the original charged object.
13. No. The direction of the forces might be different simply because the sign of the charges are different. The magnitude of the forces might be different simply because the magnitudes of the charges are different.
15. By definition, electric field lines point in the direction of the electric force on a positive charge at any given location in space. This force can point in only one direction at any one location, however. Therefore, electric field lines cannot cross, because if they did, it would imply two different directions for the electric force at the same location.
17. The electric field depends on both charges. The total electric field at any point is simply the superposition of the electric field produced by each charge separately.
19. Gauss's law is useful as a calculational tool only in cases of high symmetry, where one can produce a gaussian surface on which the electric field is either constant or has no perpendicular component. It is not possible to do this in any simple way for the case of a charged disk.

Gauss's law still applies—it's just not particularly useful.

CHAPTER 20

1. The electric field is a measure of how much the electric potential changes from one position to another. Therefore, the electric field in each of these regions is zero.
3. Not necessarily. The electric field is related to the rate of change of electric potential, not to the value of the electric potential. Therefore, if the electric field is zero in some region of space, it follows that the electric potential is constant in that region. The constant value of the electric potential may be zero, but it may also be positive or negative.
5. Zero. The electric field is perpendicular to an equipotential, therefore the work done in moving along an equipotential is zero.
7. If the electric field is not perpendicular to an equipotential, the field would do work on a charge that moves along the equipotential. In this case, the potential energy of the charge would change, and the surface would not in fact be an equipotential.
9. When the capacitor is disconnected from the battery, the charge on the capacitor plates simply remains where it is—there is no way for it to go anywhere else. When the terminals are connected to one another the charges flow from plate to plate until both plates have zero charge.
11. The capacitance of a capacitor depends on **(b)** the separation of the plates and **(e)** the area of the plates. The capacitance does not depend on **(a)** the charge on the plates, **(c)** the voltage difference between the plates, or **(d)** the electric field between the plates.
13. No. As an example, note that the volume of a milk container is not zero just because the container happens to be empty of milk. The same can be said about the capacitance of a capacitor that happens to be uncharged.

CHAPTER 21

1. Electric current is in the opposite direction to the motion of negative charge, therefore the electric current of the falling electron is upward.
3. No. By rubbing the comb through your hair you have transferred charge from your hair to the comb, but the net charge of you and the comb together is still zero. Therefore, no current is produced when you walk.
5. No. An electron may have a fairly large velocity at any given time, but because its direction of motion keeps changing—due to its collisions with atoms in the wire—its average velocity is almost zero.
7. Connect the four resistors in a parallel arrangement with two branches, each branch containing two resistors connected in series. In this way, the equivalent resistance of each branch is $2R$, and the equivalent resistance of two resistors of $2R$ in parallel is simply R, as desired.
9. Resistors connected in series have the same current flowing through them.
11. Each electron in the wire affects its neighbors by exerting a force on them, causing them to move. Thus, when electrons begin to move out of a battery their motion sets up a propagating influence that moves through the wire at nearly the speed of light, causing electrons everywhere in the wire to begin moving.
13. A number of factors come into play here. First, the bottom of a bird's foot is tough, and definitely not a good conductor of electricity. Second, and more important, is the fact that a potential difference is required for there to be a flow of current. Just being in contact with a high-voltage wire isn't enough to cause a problem; somewhere else there must be contact with a lower voltage. But the bird is in contact with essentially the same high voltage in two different places (where its feet touch the wire), which doesn't lead to a potential difference. The only potential difference the bird experiences is due to the very small voltage drop along the segment of wire between the bird's two feet.
15. The junction rule is based on conservation of electric charge; the loop rule is based on the conservation of energy.
17. Capacitors in parallel have the same potential difference between their plates.

CHAPTER 22

1. No. The particles may have charge of the same sign but move in opposite directions along the same line. In this way, they would both move perpendicular to the field, but would deflect in opposite directions.
3. No. If the electron moves in the same direction as the magnetic field, or opposite to the direction of the field, the magnetic force exerted on it will be zero. As a result, its velocity will remain constant.
5. The radius of curvature is proportional to the speed of the particle. It follows that the particle moving in a circle of large radius (and large circumference) has a proportionally larger speed than the particle moving in a circle of small radius (and small circumference). Therefore, the time required for an orbit ($t = d/v$) is the same for both particles.

CHAPTER 23

1. The magnetic field indicates the strength and direction of the magnetic force that a charged particle moving with a certain velocity would experience at a given point in space. The magnetic flux, on the other hand, can be thought of as a measure of the "amount" of magnetic field that passes through a given area.
3. As the magnet falls, it induces eddy currents in the copper tube. These induced currents produce a magnetic field opposite in direction to that of the magnet. This results in a magnetic repulsion that slows the fall of the magnet. In fact, the motion of the magnet is much the same as if it had been dropped into a tube filled with honey.
5. When the switch is closed, a magnetic field is produced in the wire coil and in the iron rod. This results in an increasing magnetic flux through the metal ring, and a corresponding induced emf. The current produced by the induced emf generates a magnetic field opposite in direction to the field in the iron rod. The resulting magnetic repulsion propels the ring into the air.
7. Initially, the rod accelerates to the left, due to the downward current it carries. As it speeds up, however, the motional emf it generates will begin to counteract the emf of the battery. Eventually the two emfs balance one another, and current stops flowing in the rod. From this point on, the rod continues to move with constant speed.
9. As the shuttle orbits, it moves through the Earth's magnetic field at high speed. A long conducting wire moving through the field can generate an induced emf. In fact, the emf is given by the product of the length of the wire, the speed of the shuttle, and the perpendicular component of the magnetic field. With such large values for the speed and length, the induced emf can be great enough to provide substantial electrical power.
11. The final current in an RL circuit is determined only by the resistor R and the emf of the battery. The reason is that when the current stops changing, the back emf in an inductor vanishes. Thus, the inductor behaves like an ideal wire of zero resistance when the current reaches its final value.

CHAPTER 24

1. The average voltage in an ac circuit is zero because it oscillates symmetrically between positive and negative values. To calculate the rms voltage, however, one first squares the voltage. This gives values that are always greater than or equal to zero. Therefore, the rms voltage will be nonzero unless the voltage in the circuit is zero at all times.
3. An LC circuit consumes zero power because ideal inductors and capacitors have no resistance. From a different point of view, the phase angle in an LC circuit is either $\phi = +90°$ or $\phi = -90°$, depending on whether the frequency is less than or greater than the resonance frequency, respectively. In either case, the power factor, $\cos \phi$, is zero; hence the power consumed by the circuit is zero.

5. In the phasor diagram for an *LC* circuit, the impedance is always perpendicular to the current—the only question, therefore, is whether ϕ is +90° or −90°. At a frequency less than the resonance frequency the capacitive reactance ($X_C = 1/\omega C$) is greater than the inductive reactance ($X_L = \omega L$). Therefore, the situation is similar to that of a circuit with only a capacitor, in which case the phase angle is $\phi = -90°$.
7. As frequency is increased there is no change in resistance, *R*. On the other hand, the capacitive reactance ($X_C = 1/\omega C$) decreases and the inductive reactance ($X_L = \omega L$) increases.
9. Mass resists changes in its motion due to its inertia. Similarly, an inductor resists changes in the current flowing through it due to its inductance. Therefore, mass and inductance are analogous. As for the spring constant, a stiff spring (large spring constant) gives little stretch for a given force. Similarly, a capacitor with a small capacitance stores little charge for a given voltage. Since charge is what moves in a circuit, it follows that displacement and charge are analogous. Therefore, the spring constant and the inverse of the capacitance are analogous.
11. Yes. Recall that the impedance of an *RLC* circuit is $Z = \sqrt{R^2 + (X_L - X_C)^2}$. Because the quantity in parentheses is squared, we get the same impedance when X_L is greater than X_C by a certain amount as when X_C is greater than X_L by the same amount.

CHAPTER 25

1. Presumably, an "invisible man" would be invisible because light passes through his body unimpeded, just as if it were passing through thin air. If some light were deflected or absorbed, we would see this effect and the person would no longer be invisible. For a person to see, however, some light must be absorbed by the retina. This absorption would cause the invisible man to be visible.
3. As a grain of dust becomes smaller, its volume—and therefore its mass—decreases more rapidly than does its area. It follows that radiation pressure, which acts on the surface of the grain, becomes increasingly important as the size of the grain is decreased. Gravity, which acts on the mass of the grain, becomes less important in this limit.
5. Your watch must have an LCD display. In such watches, the light coming from the display is linearly polarized. If the polarization direction of the display and the sunglasses align, you can read the time. If these directions are at 90° to one another no light will pass through the sunglasses, and the display will appear black.
7. Radio stations generate their electromagnetic waves with large vertical antennas. As a result, their waves are polarized in the vertical direction, as in Figure 25–1. On the other hand, the light we see from the sun and from light bulbs is unpolarized because the atoms emitting the light can have any orientation relative to one another. Hence, even if individual atoms emit polarized light, the net result from a group of atoms is light with no preferred direction of polarization.
9. Sound waves cannot be polarized. This is because sound is a longitudinal wave, and the molecules can move in only a single direction—back and forth along the direction of propagation. In contrast, the electric field in an electromagnetic wave, which is transverse, can point in any direction within the plane that is transverse to the direction of propagation. This means that the electromagnetic wave can have different polarizations.
11. The two projected images give a view of a scene from slightly different angles, just as your eyes view a three-dimensional object from different angles. Without the headsets, the screen is a confusing superposition of the two images; with the headsets, your right eye sees one view of the scene and your left eye sees the other view. As these views are combined in your brain, you experience a realistic three-dimensional effect.

CHAPTER 26

1. Three images are formed of object A. One extends from (−2 m, 2 m) to (−1 m, 2 m) to (−1 m, 3 m). Another image forms an "L" from (1 m, −3 m) to (1 m, −2 m) to (2 m, −2 m). Finally, the third image extends from (−1 m, −3 m) to (−1 m, −2 m) to (−2 m, −2 m).
3. A plane mirror is flat, which means that its radius of curvature is infinite. This means that the focal length of the mirror is also infinite. Whether you consider the focal length to be positive infinity (the limit of a concave mirror) or negative infinity (the limit of a convex mirror) doesn't matter, because in either case the term $1/f$ in the mirror equation will be zero.
5. We can consider the Sun to be infinitely far from the mirror. As a result, its parallel rays will be focused at the focal point of the mirror. Therefore, the distance from the mirror to the paper should be $f = \frac{1}{2}R$.
7. The key to this system is the fact that the lifeguards can run much faster on the sand than they can swim in the water. Therefore, the path ACB—even though it is longer—has a shorter travel time because more time is spent on the sand and less time is spent in the water.
9. In a real image, light passes through the location of the image before reaching the eye. In a virtual image, light propagates *as if* it were coming from the image—though the reflected or refracted light never actually passes through the image location.
11. When the mug is filled with water, light coming upward from the bottom of the mug is bent toward the horizontal when it passes from water to air. If the light had not been bent, it would have passed over your head—placing the bottom of the mug out of sight. With the bending, however, the light can now propagate to your eyes—making the bottom of the mug visible.
13. No. In order to see, a person's eyes must first bring light to a focus, and then must absorb the light to convert it to nervous impulses that can travel to the brain. Both the bending of the light and its absorption would give away the presence of the invisible man. Therefore, if the man were truly invisible, he would be unable to see.

CHAPTER 27

1. When you focus on an object at infinity your ciliary muscles are relaxed. It takes muscular effort to focus your eyes on nearby objects.
3. If you are a distance *D* in front of a mirror your image is a distance *D* behind the mirror. Therefore, you can see your image clearly if the distance from you to your image, 2*D*, is equal to *N*. In other words, the minimum distance to the mirror is $D = N/2$.
5. The person with the smaller near-point distance can examine an object at closer range than the person with the larger near-point distance. Therefore, the person with the larger near-point distance benefits more from the magnifier.
7. The image you see when looking through a telescope is virtual. First, the objective forms a real image of a distant object, as shown in Figure 27–16. Next, the eyepiece forms an upright and enlarged image of the objective's image. The situation with the eyepiece is essentially the same as that shown in Figure 26–35 (b). Therefore, it is clear that the final image is virtual in this case.

CHAPTER 28

1. At a point where destructive interference is complete, there is no energy. The total energy in the system is unchanged, however, because those regions with constructive interference have increased amounts of energy. One can simply think of the energy as being redistributed.
3. No. The net signal could be near zero if the waves from the two antennas interfere destructively.
5. In this case, the interference pattern would be reversed. That is, bright fringes in the ordinary pattern would now be the location of dark fringes, and dark fringes would be replaced with bright fringes. For example, in the usual case there is a bright fringe halfway between the slits because the paths lengths are equal. Changing the phase of the light from one slit by 180°, however, results in destructive interference (a dark fringe) at the center of the pattern.

7. A ray of light reflected from the lower surface of the curved piece of glass has no phase change. On the other hand, a ray of light reflected from the top surface of the flat piece of glass undergoes a phase change of half a wavelength. Near the center of the pattern the path difference for these two rays goes to zero. As a result, they are half a wavelength out of phase there, and undergo destructive interference.
9. In general, the larger the aperture in an optical instrument, the greater the resolution. This follows directly from Equation 28–14, where we see that a large aperture diameter D implies a small angle θ. The angular separation that can be resolved is decreased—by making θ smaller—and the resolution is increased.
11. The soap film in the photograph is thinnest near the top (as one might expect) because in that region the film appears black. Specifically, the light reflected from the front surface of the film has its phase changed by 180°; light that reflects from the back surface of the film has no change in phase. Therefore, light from the front and back surfaces of the film will undergo destructive interference as the path length between the surfaces goes to zero. This is why the top of the film, where the film is thinnest, appears black in the photo.

CHAPTER 29

1. The light received from these galaxies moves with the speed c, as is true for all light in a vacuum.
3. Velocities add by simple addition in the limit $c \to \infty$. This is evident from Equation 29–4 when one notices that the second term in the denominator vanishes in this limit, making the denominator equal to 1.
5. Yes. All light, regardless of its wavelength, has the same speed in a vacuum. The *frequency* of this "red shifted" light will be affected, however. Recalling that $v = \lambda f$, we see that a longer wavelength also implies a smaller frequency.
7. Since the total energy of an object of finite mass goes to infinity in the limit that $v \to c$, an infinite amount of energy is required to accelerate an object to the speed c.

CHAPTER 30

1. The "ultraviolet catastrophe" refers to the classical prediction that the intensity of light emitted by a blackbody increases without limit as the frequency is increased.
3. No, all objects with finite temperature give off blackbody radiation. Only an object at absolute zero—which is unattainable—gives off no blackbody radiation.
5. If you look at a painting, photo, decal, or similar object, you are viewing light that it reflects to you. Therefore, when an area appears red, it is because the pigments there absorb blue photons and reflect red photons. Similarly, a blue area absorbs red photons. Blue photons carry considerably more energy than red photons, however, and hence blue photons are more likely to cause damage to the pigment molecules, or to alter their structure. It follows that red pigments (which absorb blue photons) are more likely to become faded when exposed to intense light.
7. If two blackbody curves intersected, there would be a range of frequencies where the low-temperature blackbody gives off more energy than the high-temperature blackbody. In this frequency range, then, it would be possible for energy to be spontaneously transferred from the low-temperature body to the high-temperature body, in violation of the second law of thermodynamics.
9. The likely explanation is that the second metal has a greater work function than the first metal. In this case, a shorter-wavelength photon—that is, a photon with higher frequency and higher energy—would be required to supply the additional energy needed to eject an electron.
11. The resolution of a microscope is determined by the wavelength of the imaging radiation—the smaller the wavelength the greater the resolution. Since the typical wavelength of an electron in an electron microscope is much smaller than the wavelength of visible light, the electron microscope has the greater resolution.

CHAPTER 31

1. Rutherford's alpha particle scattering experiments indicate that the positive charge in an atom is concentrated in a small volume, rather than spread throughout the atom, as in Thomson's model.
3. In the Bohr model, the electron orbits at a well-defined radius; in the quantum mechanical model, the electron can be found at virtually any distance from the nucleus.
5. **(a)** The glass tube of a neon sign contains a low-pressure gas. Therefore, we expect the light from the sign to be in the form of a line spectrum. **(b)** The light from an incandescent lightbulb is basically blackbody radiation from a hot object; therefore, its radiation is distributed continuously as a function of frequency.
7. No, there is no upper limit to the radius of a Bohr orbit. In fact, the radius increases as n^2 for $n = 1, 2, 3, \ldots$.
9. No, the energy does not increase without limit. The energy of a given level in hydrogen ranges from a low of −13.6 eV to a maximum of 0.
11. **(a)** The angular momentum in the quantum mechanical model of the hydrogen atom is zero if the quantum number ℓ is zero. In the $n = 1$ state, the only allowed value for ℓ is 0, and hence the angular momentum must be zero for $n = 1$. **(b)** Yes. For $n > 1$, there are n allowed values for ℓ. One of these values is always zero, therefore the angular momentum can be zero for any value of n.
13. These elements all have similar configurations of their outermost electrons. In fact, the outermost electrons in fluorine, chlorine, and bromine are $2p^5$, $3p^5$, and $4p^5$, respectively. Therefore, each of these atoms is one electron shy of completing the p subshell. This accounts for their similar chemical behavior.

CHAPTER 32

1. The radius of a nucleus is given by the following expression: $r = (1.2 \times 10^{-15}\ \text{m})A^{1/3}$. Therefore, the radius depends only on the total number of nucleons in the nucleus, A, and not on the number of protons and neutrons separately. If the number of protons plus the number of neutrons is the same for two nuclei, their radii will be equal as well.
3. No. An alpha particle contains two protons, whereas any form of hydrogen contains only a single proton. Therefore, hydrogen cannot give off an alpha particle.
5. A nucleus that contained more than one proton and no neutrons would be unstable because the electrostatic repulsion between the protons would blow the nucleus apart. Neutrons tend to push the protons farther apart, reducing their mutual repulsion, and at the same time add more to the attractive strong nuclear force that holds nuclei together.
7. Carbon-14 dating is useful for objects that are of biological origin and—at most—are on the order of thousands of years old. **(a)** It is useful for dating such things as human or animal remains, plant tissue, clothing, and charcoal from a fire. **(b)** It is not useful for dating inorganic materials, like rocks and minerals, or biological materials that are millions of years old, like dinosaur fossils.
9. The obsidian arrowhead cannot be dated with carbon-14, because it is not of biological origin.
11. Yes. The two samples may contain different quantities of the radioactive isotope, and hence their activities may be different.
13. No. The RBE is related to the amount of biological effect produced by a given type of radiation, not to the amount of energy it delivers.

Answer to Odd-Numbered Problems and Conceptual Exercises

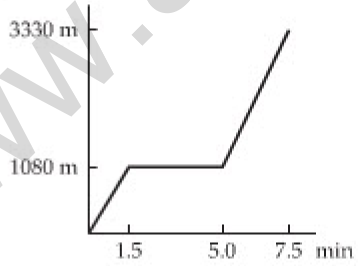
Note: In cases where an ambiguity might arise, numbers in this text are assumed to have the smallest possible number of significant figures. For example, a number like 150 is assumed to have just two significant figures—the zero simply indicates the location of the decimal point. To represent this number with three significant figures, we would use the form 1.50×10^2.

CHAPTER 1

1. (a) 0.114 gigadollar
   (b) 1.14×10^{-4} teradollar
3. 3×10^8 m/s
5. (a) consistent (b) consistent (c) consistent
7. (a) No (b) Yes (c) No (d) Yes
9. $p = -2$
11. $[\mathrm{M}]\frac{[\mathrm{L}]}{[\mathrm{T}]^2}$
13. (a) 3.14 (b) 3.1416 (c) 3.141593
15. 383.9 m
17. (a) two (b) four
19. (a) 75 ft/s (b) 51 mi/h
21. 18 ft^3
23. 0.9788 km
25. 32.9 m
27. (a) greater than (b) 88 km/h
29. 322 $\mathrm{ft/s^2}$
31. (a) 67 mutchkins (b) 0.031 gal
33. (a) 0.060 $\mathrm{m^2}$ (b) $\frac{1}{4}\,A_{\mathrm{old}}$
35. 32.2 ft/s
37. (a) 10^{10} gal/y (b) 10^9 lb/y
39. (a) 10^6 lb (b) 10^4 lb
41. (a) No (b) Yes (c) Yes (d) Yes
43. 7.41×10^{-4} m/s
45. (a) 3.05 m and 5.14 m/s
47. (a) 310 mi/h (b) 0.70 m
49. (a) 51 revolutions (b) 8.7 ft/rev
51. $q = -\frac{1}{2}; p = \frac{1}{2}$
53. plot C
55. C. 64.3 °F

CHAPTER 2

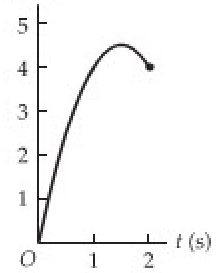
1. (a) 1.95 mi (b) 0.75 mi
3. (a) 15 m (b) 10 m
5. (a) 130 m; 100 m (b) 260 m; 0
7. (a) less than (b) I
9. 10.13 m/s; 22.66 mi/h
11. (a) 3.5 km (b) 14 s
13. 2.57 s
15. 0.010 s
17. 6.0 m/s
19. 11 m
21. (a)



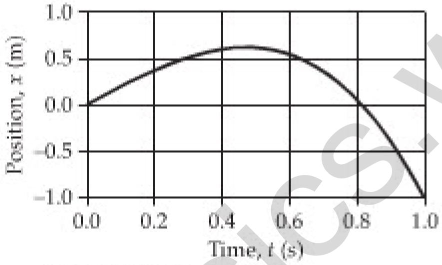
   (b) 7.4 m/s
23.

	A	B	C	D
(a)–(d)	positive	zero	positive	negative
(e)–(h)	2.0 m/s	0 m/s	1.0 m/s	−1.5 m/s

25. (a)



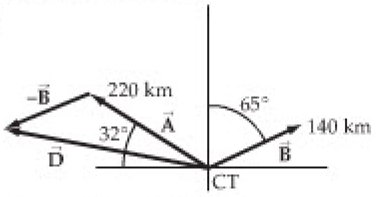
   (b) 4.0 m/s (c) 4.0 m/s
27. 35 mi/h
29. (a)



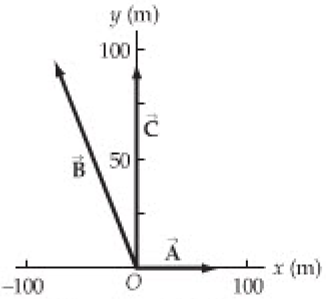
   (b) 0.55 m/s (c) 0.56 m/s
   (d) closer to 0.56 m/s
31. (a) less than (b) III
33. (a) 3.8 m/s (b) 9.9 m/s
35. (a) 27.9 m/s north (b) 9.48 m/s north
37. (a) 10 m (b) 20 m (c) 40 m
39. (a) a factor of two (b) 3.8 s (c) 7.6 s
41. 10.3 m/s
43. 3.53 $\mathrm{m/s^2}$ to the north
45. (a) cases 3 and 4 (b) case 2 (c) cases 2 and 3
47. (a) 2.06 m/s (b) 9.83 m
49. (a) 0.90 m (b) 3.6 m (c) 8.1 m
51. 600g
53. (a) 0.077 s (b) 0.46 μm
55. 3.8×10^4 $\mathrm{m/s^2}$
57. (a) 21 m (b) greater than 6.0 m/s; 8.49 m
59. (a) 32 $\mathrm{m/s^2}$ (b) less than 8.0 cm; 4.0 cm
61. 180g
63. (a) 0.25 s (b) 110 $\mathrm{m/s^2}$ (c) 0.55 m; 11 m/s
65. (a) 6.3 s (b) 22 m (c) 10 m/s
67. 11.3 m
69. B. The speed of ball 1 is equal to the speed of ball 2.
71. The statement is accurate.
73. 4.9 m/s
75. (a) 8.4 m/s upward
   (b) 1.4 m/s downward
77. 0.10 s
79. (a) equal to (b) II
81. $x_{\mathrm{Bill}} = (3.0\ \mathrm{m}) - (4.9\ \mathrm{m/s^2})t^2$
   $x_{\mathrm{Ted}} = (1.0\ \mathrm{m}) + (4.2\ \mathrm{m/s})t - (4.9\ \mathrm{m/s^2})t^2$
83. (a) 11 m (b) 15 m/s (c) 2.1 s
85. 9.6 m
87. (a) the first (dropped) ball
   (b) ball 1: 25.3 m/s; ball 2: 16.5 m/s
89. (a) 0.49 s (b) 4.8 m/s
91. (a) more than 2.0 m (b) 8 m
93. (a) 6.7 m/s (b) −5.9 m/s (c) 9.6 m/s
95. 5.8 m/s
97. −29 $\mathrm{m/s^2}$
99. more for ball A
101. (a) 3.8 $\mathrm{m/s^2}$ (b) 15 m/s
103. (a) 2 (b) 4
   (c) 0.41 s and 0.82 s; 0.20 m and 0.82 m
105. (a) 2.64 s (b) more than
   (c) 1.87 s > 0.77 s
107. (a) 9.81 $\mathrm{m/s^2}$ downward
   (b) 13.9 m (c) 2.21 s (d) 16.5 m/s
109. 3.0 m
111. (a) $\frac{1}{2}gt^2$ (d) gt (c) 13.4 m (d) 16.2 m/s
113. 6.67 cm
115. (a) 3.0 m; 4.4 m/s (b) 130 drops/min
117. 5.5 m; 11 m/s
119. (a) 10.0 ms (b) 4.50 m/s (c) 10.0 cm
123. B. 6.78 ft/s
125. plot C
127. 4.3 $\mathrm{m/s^2}$
129. (a) 2.3 s (b) 20 m/s

CHAPTER 3

1. (a) factor of 2
   (b) factor of 1
3. D < C < B < A
5. 119 ft
7. 3°
9. (a) (90 ft)$\hat{\mathbf{x}}$ + (90 ft)$\hat{\mathbf{y}}$
   (b) (90 ft)$\hat{\mathbf{y}}$ (c) (0 ft)$\hat{\mathbf{x}}$ + (0 ft)$\hat{\mathbf{y}}$
11. 1.5 Å
13. (a) 3.5 cm (b) less than (c) 1.7 cm
15. (a) $\vec{A}$ (b) $\vec{B}$
17. (a) 51 m deep (b) 140 m
19. (a) less than (b) equal to
21. (a)

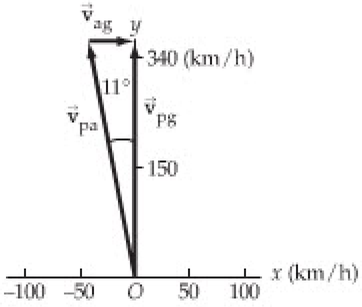


   (b) 320 km, 10° north of west
23. (a)



   (b) about 120 m; about 130°
   (c) 121 m; 128°

25. **(a)** $-27°$; 11 units **(b)** 207°; 11 units
    (c) 27°; 11 units
27. $(40\text{ m})\hat{\mathbf{x}} + (-36\text{ m})\hat{\mathbf{y}}$
29. **(a)** 23 m **(b)** 23 m
31. **(a)** $-22°$; 5.4 m **(b)** 110°; 5.4 m **(c)** 45°; 4.2 m
33. **(a)** $(23\text{ m})\hat{\mathbf{x}} + (-27\text{ m})\hat{\mathbf{y}}$
    (b) $(-23\text{ m})\hat{\mathbf{x}} + (27\text{ m})\hat{\mathbf{y}}$
35. $(2.1\text{ m})\hat{\mathbf{x}} + (0.74\text{ m})\hat{\mathbf{y}}$
37. **(a)** equal to
    (b) 7.8 cm at 153°; 7.8 cm at 63°
39. 0.037 m/s; 31° west of north
41. 59° north of east; 4.9 m/s
43. $(-9.8\text{ m/s}^2)\hat{\mathbf{y}}$
45. 9.59 m/s
47. **(a)** $(-0.00233\text{ m/s}^2)\hat{\mathbf{x}}$
    (b) $(-0.00233\text{ m/s}^2)\hat{\mathbf{x}}$
49. 15.3 m/s
51. 25 s
53. **(a)** 11° west of north
    (b)



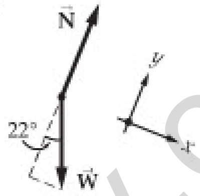
    (c) increased
55. 11 m/s
57. **(a)** Jet Ski A **(b)** $\frac{\Delta t_A}{\Delta t_B} = 0.82$
59. **(a)** equal to **(b)** II
61. $-53.1°$; 40.3 m
63. between 270° and 360°
65. **(a)** toward the rear **(b)** 19.8 m/s
    (c) 17.9 m/s
67. $A_x = 44$ m, $A_y = 31$ m, $A_z = 37$ m
69. **(a)** $(-9.81\text{ m/s}^2)\hat{\mathbf{y}}$ **(b)** $(-9.81\text{ m/s}^2)\hat{\mathbf{y}}$
    (c) $(-9.81\text{ m/s}^2)\hat{\mathbf{y}}$
71. **(a)** ≈ 38 ft
    (b) 39 ft; 15° clockwise from $\overrightarrow{\mathbf{A}}$
73. **(a)** 3.7 **(b)** 67 m/s
75. **(a)** 10° **(b)** $(7.1\text{ m/s})\hat{\mathbf{x}}$ **(c)** decrease
77. 28 m; 19 m
79. **C.** 1.00 m/s
81. **C.** 0.806 m/s
83. **(a)** 12° upstream **(b)** decrease

CHAPTER 4

1. **(a)** straight upward **(b)** III
3. **(a)** 12.0 s **(b)** 55.5 s
5. **(a)** $x = -55$ m; $y = 31$ m
   (b) $v_x = -22$ m/s; $v_y = 6.2$ m/s
   (c) increase with time
7. **(a)** 27° **(b)** 1.1 m/s
9. **(a)** greater than **(b)** II
11. 46.2 m/s
13. 1.77 m/s^2
15. **(a)** 9.9 m **(b)** 0.99 m
17. **(a)** 3.1 m **(b)** 3.4 m beyond the far edge
19. 2.6 m/s
21. **(a)** 0.982 m/s **(b)** 1.52 m
23. **(a)** 29.4 m
    (b) 57.8 m/s; 85.0° below horizontal
25. **(a)** 9.81 m/s^2 downward
    (b) 1.1 m/s **(c)** 3.2 m/s
27. **(a)** A < B < C **(b)** C < B < A
29. **(a)** 14.3 m/s **(b)** 2.24 s
31. 1.27 m/s
33. 1.3 m
35. **(a)** the same as **(b)** 18 m/s; 18 m/s
37. **(a)** 121 m **(b)** 24.3 m/s
39. 24.8 m/s
41. **(a)** 17 m/s; 25° **(b)** No; the y-component of the velocity is still positive.
43. 1.07 m
45. 111 m/s
47. **(a)** 32° **(b)** 0.76 s
49. **(a)** 29.8 m/s **(b)** 4.29 s
51. **(a)** plot B **(b)** III
53. **(a)** 9.43 m/s; 11.4° above horizontal
    (b) 9.26 m/s; 3.68° below horizontal
55. **(a)** 213 m **(b)** 52.5°
57. equal to
59. **(a)** equal to **(b)** II
61. **(a)** 64° west of north **(b)** 350 m
63. 0.786 m
65. **(a)** $(5.00\text{ m/s})\hat{\mathbf{x}} + (-2.00\text{ m/s})\hat{\mathbf{y}}$
    (b) 5.39 m/s; 21.8° below horizontal
    (c) 6.00 m **(d)** 0.92 s
67. **(a)** 1.52 m **(b)** $(4.03\text{ m/s})\hat{\mathbf{y}}$
69. **(a)** 0.199 s **(b)** 0.452 m
71. **(a)** 9.29 m/s **(b)** 56.4° below horizontal
73. **(a)** 12.1 m/s; top **(b)** 12.9 m/s; 19.9°
    (c) 0.978 m **(d)** 0.978 m
75. 14.5 m/s
77. **(a)** To find the initial speed of the puck, eliminate t from the equations $x = (v_0 \cos\theta)t$ and $y = (v_0 \sin\theta)t - (12)gt^2$, then solve for v_0.
    (b) 25.1 m/s
79. **(a)** 64.9° **(b)** 21 m/s **(c)** 1.8 s
81. **(a)** 2.48 cm **(b)** 0.0187 s
83. 76.0°
85. $v = \sqrt{v_0^2 + 2gh}$ independent of angle θ
89. **(a)** 9.9 m/s; top **(b)** 11 m/s; 24°
    (c) 0.98 m **(d)** 0.98 m
91. **C.** 12.3 m
93. **A.** 13.2 m
95. **(a)** 60.5° **(b)** 15.9 m **(c)** 41.6° **(d)** 18.4 m
97. **(a)** 42.3° **(b)** 3.12 m **(c)** 7.36 m/s

CHAPTER 5

1. $\frac{1}{2}T$
3. 2.57 m
5. 1.6 kN
7. **(a)** less than **(b)** III
9. **(a)** $(85\text{ N})\hat{\mathbf{x}}$ **(b)** increased
11. **(a)** 5.1 kN opposite to the direction of motion **(b)** 15.3 m
13. **(a)** 18.7 kN opposite to the direction of motion **(b)** Determine the acceleration from the speeds and displacement and the force from the acceleration and mass.
15. **(a)** greater than **(b)** II
17. **(a)** two forces **(b)** gravity and your hand
    (c) No **(d)** No
19. **(a)** the same as **(b)** more than **(c)** 0.70 m/s^2
21. **(a)** 1.04 N **(b)** 3.59 N
23. **(a)** sometimes true **(b)** never true
    (c) always true **(d)** sometimes true
25. 11 kN
27. 28 N
29. A < D < B < C
31. **(a)** 0.42 kN **(b)** less than
33. 146°; 7.8 N
35. **(a)** 24.5° **(b)** 4.77×10^{20} N
    (c) 0.00649 m/s^2
37. **(a)** 0.023 N **(b)** 6.6 days
39. **(a)** 2.3 m/s^2 **(b)** -2.4 m/s^2
41. 1.5 m/s^2 downward
43. **(a)** 72 N **(b)** 1.4 m/s^2
45. **(a)**



    (b) 0.59 kN
47. **(a)** $\frac{1}{2}mg$ **(b)** mg **(c)** $2mg$
49. **(a)** 23 N **(b)** increase
51. 60°
53. **(a)** higher than **(b)** I
55. **(a)** greater than **(b)** III
57. $(-18.3\text{ N})\hat{\mathbf{x}}$
59. **(a)** $5.5 \times 10^{-3}\text{ m/s}^2$ **(b)** 8.3×10^9 m **(c)** 1/3
61. 9.1 kg
63. **(a)** 99 m/s^2 **(b)** 0.22 N
    (c) stay the same **(d)** increase
65. **(a)** 0.42 kN opposite the direction of motion **(b)** 2
67. **(a)** 2.2 N **(b)** 1.4 s
69. 290 kg
71. **(a)** 4.2×10^5 N **(b)** Determine the acceleration during takeoff using the given data (x, t). Then calculate the force using $F = ma$.
73. **(a)** 2.06 kg **(b)** 5.00 kg
75. 74 kg
77. $F_1 = \frac{1}{2}m(a_1 + a_2)$; $F_2 = \frac{1}{2}m(a_1 - a_2)$
79. **C.** 1.05×10^4 N
81. **D.** 4.21×10^4 N
83. **(a)** decreased **(b)** 3.33 kg **(c)** 1.50 m/s^2
85. **(a)** greater than **(b)** 36° **(c)** 0.079 m/s^2

CHAPTER 6

1. **(a)** equal to **(b)** II
3. 1.8 m
5. 1.2
7. 0.75 N opposite the direction of the push
9. **(a)** As the hanging fraction of the tie is increased, the gravitational force is increased and the mass of the tie still lying on the table is reduced, so that the maximum static friction force is decreased. When the gravitational force exceeds the force of static friction, the tie begins sliding off the table.
   (b) $\mu_s = 1/3$
11. 3.5 m/s^2
13. **(a)** 0.39
    (b) First, determine the runner's acceleration from $v^2 = v_0^2 + 2a\Delta x$. Next, equate the force associated with this acceleration to the force of static friction between the runner's shoes and the track. Solve for μ_s.
15. **(a)** 13 m **(b)** increase **(c)** stay the same
17. **(a)** 2.55 m/s^2 opposite the direction of motion **(b)** 4.26 m/s
19. **(a)** greater than **(b)** less than
21. 2.13 kN/m

23. 948 N
25. 0.072
27. **(a)** 2.64 s **(b)** A shorter time would require a larger acceleration, which in turn would require greater tension in the rope because $T = ma + mg = m(a + g)$. Thus the tension would become greater than 755 N and the rope would break.
29. **(a)** When the car accelerates from the stoplight, the string must exert a forward force on the tassel in order to accelerate it in the horizontal direction at the same rate as the car's acceleration. The string must also continue to exert an upward force on the tassel to balance the force of gravity. As a result the tassel hangs at an angle, deflected toward the back of the car. **(b)** 1.11 m/s^2
31. **(a)** less than **(b)** 0.85 N **(c)** 2.0 N
33. **(a)** 0.31 kN downward **(b)** 0.63 kN **(c)** 0.63 kN
35. **(a)** 5.1 N **(b)** 15 N
37. 4.5 kg
39. 0.85 N
41. **(a)** 60.0° **(b)** 106 N
43. **(a)** decrease **(b)** I
45. **(a)** upward **(b)** 0.076 m/s^2
47. **(a)** 4.9 N **(b)** 15 N
49. **(a)** 3.2 m/s^2 **(b)** 2.6 N **(c)** decrease
51. more
53. **(a)** No **(b)** Yes **(c)** Yes **(d)** No
55. 5.6 kN
57. 36 m/s
59. 0.67 kN
61. **(a)** Your apparent weight is greater at the bottom of the Ferris wheel, where the normal force must both support your weight and provide the upward centripetal acceleration. **(b)** 0.52 kN at top; 0.56 kN at bottom
63. 19 m/s
65. less than
67. A < C < B
69. 2.2 kg
71. 0.140
73. 5.62 kg
75. **(a)** 0.76 m/s^2 **(b)** 6.0 N
77. **(a)** 0.030 N down the incline **(b)** 0.042 N up the incline
79.

Applied Force	Friction Force Magnitude	Motion
0 N	0 N	at rest
5.0 N	5.0 N	at rest
11 N	11 N	at rest
15 N	8.8 N	accelerating
11 N	8.8 N	accelerating
8.0 N	8.8 N → 8.0 N	decelerating → at rest
5.0 N	5.0 N	at rest

81. **(a)** 23 N **(b)** stay the same
83. **(a)** greater than **(b)** 3.4 N **(c)** 0.41 kg
85. **(a)** 19° **(b)** 0.78 N
87. **(a)** 32 N **(b)** increase
89. **(a)** greater than **(b)** 1.88 kN
91. **(a)** static **(b)** 0.50
93. 26 m/s^2
95. 8.6°; The mass of the dice drops out of the equations.
97. 28°
99. $T = mg \sin\theta$
101. 5.4 cm
103. left string: $T_1 = \left(\dfrac{m_1 m_3}{m_1 + m_2 + m_3}\right)g$; right string: $T_2 = \left[\dfrac{m_3(m_1 + m_2)}{m_1 + m_2 + m_3}\right]g$
105. $v = \sqrt{\dfrac{Mrg}{m}}$
107. **(a)** 10 m/s^2 **(b)** 47° **(c)** Because the weight and centripetal acceleration both depend linearly on the mass, the mass cancels out of the expression for the angle θ.
109. **(a)** 24 kg **(b)** 0.27
111. **D.** 25 N/m
113. **C.** 2.5 N/m
115. **(a)** less than **(b)** 22.5° **(c)** 4.34 s
117. **(a)** 1.00 kg **(b)** 6.98 N **(c)** 0.712

CHAPTER 7

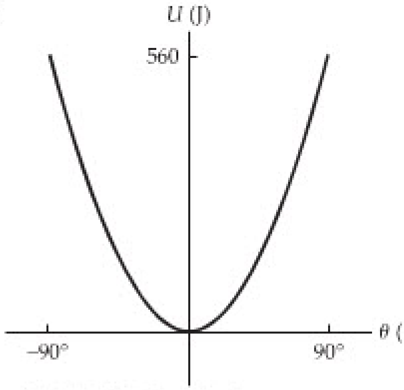
1. zero
3. **(a)** negative **(b)** zero
5. 4.36 kg
7. 3.37 m
9. **(a)** positive **(b)** 7.8 kJ
11. 0.15 kJ
13. **(a)** 14 J **(b)** decrease
15. **(a)** 1700 J **(b)** −1700 J
17. 21°
19. 2.2 kJ
21. **(a)** 8.03 kJ **(b)** 2.01 kJ **(c)** 32.1 kJ
23. D < A = D < B
25. **(a)** −10 J **(b)** 0.63 N upward
27. **(a)** −587 J **(b)** 0.284
29. **(a)** less than 3.5 m/s **(b)** −3.1 m/s
31. $\frac{1}{2}\Delta x$
33. 14 m/s
35. **(a)** 0.45 J **(b)** 0.24 J
37. $\sqrt{2}(\Delta x)$
39. **(a)** 16 kN/m **(b)** more than 180 J; 540 J
41. **(a)** 0.82 kJ **(b)** 1.1 kJ
43. 380 W = 0.51 hp
45. 0.32 mW
47. 2.20 m/s
49. **(a)** 33.3 N **(b)** double the speed
51. **(a)** 1.15×10^{-4} W **(b)** decreased
53. **(a)** 3T **(b)** $v\sqrt{2}$
55. positive
57. 2v
59. **(a)** 630 N **(b)** 76 W
61. 386 W
63. **(a)** 1.15×10^5 J **(b)** 170 m
65. **(a)** $W_0/4$ **(b)** $3W_0/4$
67. 74 m/s
69. **(a)** 10 kJ **(b)** −10 kJ
71. **(a)** increase **(b)** 8.2 W **(c)** 12 W
73. **(a)** 0.96 J **(b)** 1.3 J **(c)** −1.2 J
75. 86 N
77. **(a)** 130 J **(b)** 2200 W **(c)** more than
79. **(a)** 15 h **(b)** 0.62 m/s **(c)** 1.6 s
81. -8.4×10^6 N
83. $\dfrac{\frac{1}{2}x^2}{1/k_1 + 1/k_2}$
85. **(a)** 42.2° **(b)** 14.8 kg
87. **C.** 2.5−25 m/s
89. **A.** 0.65 N
91. **(a)** 1.6 kg **(b)** greater than **(c)** 0.63 m/s

CHAPTER 8

1. **(a)** −3 J **(b)** −4 J
3. path 1: −100 J; path 2: −47 J; path 3: −66 J
5. **(a)** 51 J; 51 J **(b)** increase
7. **(a)** equal to **(b)** II
9. 0.54 kN
11. 6.5 mJ
13. **(a)** a factor of 4 **(b)** 3.85 J
15. **(a)** 1.2 cm **(b)** 2.3 cm
17. −0.70 J
19. **(a)** greater than **(b)** equal to 3 m/s
21. **(a)** $v/2$ **(b)** II
23. B = D = F < E < C
25. 6.78 m/s
27. Only statement **(C)** is correct.
29.

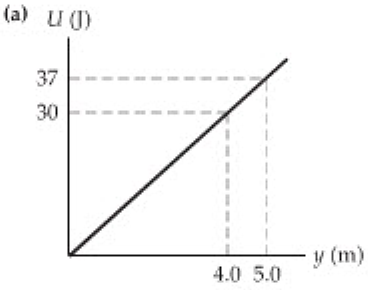
y (m)	4.0	3.0	2.0	1.0	0
U (J)	8.2	6.2	4.1	2.1	0
K (J)	0	2.1	4.1	6.2	8.2
E (J)	8.2	8.2	8.2	8.2	8.2

31. **(a)** 15 m/s **(b)** 43 m
33. **(a)** 0; 113 J; 113 J **(b)** 113 J; 226 J; 113 J
35. **(a)** 0.95 J **(b)** 0.95 J **(c)** 41°
37. 4 cm
39. **(a)** less than **(b)** III
41. 2.7 m/s
43. −57 MJ
45. **(a)** decrease **(b)** stay the same **(c)** decrease
47. **(a)** −314 J **(b)** 0.305
49. 134 kJ
51. **(a)** 0.937 m **(b)** 16.5 J **(c)** −7.72 J
53. 415 N/m
55. **(a)** 3.8 m/s **(b)** 2.7 m/s **(c)** 3.0 m/s **(d)** points A and E
57.



59. **(a)** 8.6 J **(b)** 0.2 m **(c)** 4.8 m

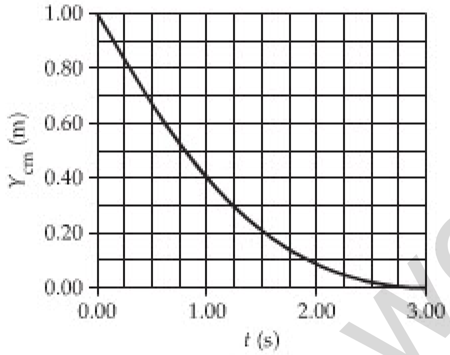
61. **(a)**

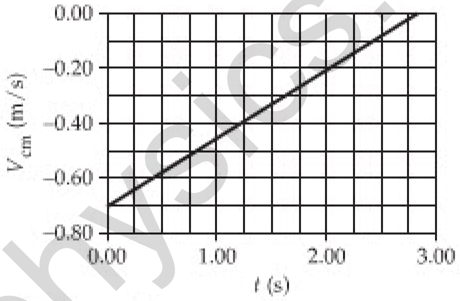


(b) 4.0 m
63. **(a)** disagree **(b)** agree **(c)** agree
65. greater than
67. **(a)** less than **(b)** equal to
69. 2.87 m
71. **(a)** 1.5 mm **(b)** 0.46 J
73. **(a)** −0.86 J **(b)** greater than **(c)** −1.2 J
75. **(a)** 53.0 MJ **(b)** 218 m/s
77. 1.04 m
79. **(a)** 634 N **(b)** decrease
81. 7.20 m/s
83. 0.121 m
85. 1.1 kN
87. 0.85 m
89. 5.3 cm
91. **(b)** Tension depends on a_{cp}, which is directly proportional to v^2 and inversely proportional to the radius r. Therefore, l cancels out because both v_B^2 and r are proportional to l.
93. 48.2°
95. **(a)** 0.79 m/s **(b)** positive **(c)** 0.36 J
97. 0.688 m
99. **(a)** negative **(b)** −46 J **(c)** 38 N
101. **C.** 290 N/m
103. **A.** 0.766 mJ
105. **(a)** 0.948 m/s **(b)** 1.29 kg

CHAPTER 9

1. 2.49×10^5 mi/h
3. 77.1° north of east; 0.980 m/s
5. 1.38 m
7. 2.51 kg; 5.21 kg
9. **(a)** equal to **(b)** III
11. **(a)** equal to **(b)** II
13. 7.44 kg · m/s
15. 7.0 ms
17. **(a)** 0.133 kg · m/s **(b)** greater than
19. **(a)** 5.6 kg · m/s; 27° above horizontal
(b) The magnitude would double but the direction would stay the same.
(c) Neither the magnitude nor the direction would change.
21. 440 kg
23. −0.519 mm/s
25. 14 m
27. $\sqrt{2}v$ at 225° from the direction of the first piece
29. minivan: $v_i = 12$ m/s; wreckage: $v_f = 11$ m/s
31. **(a)** less than **(b)** initial: 54 kJ; final: 48 kJ
33. **(a)** No **(b)** 3.86 cm
35. **(a)** 1/16 **(b)** 5/3
37. $v_{truck} = 6.25$ m/s; $v_{car} = 21.7$ m/s
39. **(a)** 16.9 m/s **(b)** Kinetic energy has been transferred from the elephant to the ball.
41. 1.32 m/s; 107° counterclockwise from the $+x$ axis
43. **(a)** $\frac{v_0}{2}$ **(b)** $\frac{v_0}{\sqrt{2}}$
45. $\frac{11}{12}L$
47. 4.67×10^6 m; 1.70×10^6 m below the surface of the Earth
49. **(a)** positive **(b)** less than
51. $x_{cm} = -4.2$ in.; $y_{cm} = 4.2$ in.
53. **(a)** $X_{cm} = 0.67$ m; $Y_{cm} = 0.17$ m
(b) The location of the center of mass would not be affected.
55. $Y_{cm} = [1.00 - (0.355\ s^{-1})t]^2$ m, $0 < t < 2.82$ s;
$V_{cm} = (0.252\ m/s^2)t - 0.710$ m/s





57. **(a)** zero **(b)** zero
59. 29 rocks/min
61. 0.489 m/s
63. **(a)** 0.25 N **(b)** more than 2.5 N **(c)** 2.8 N
65. C < A < B
67. equal to
69. **(a)** green path **(b)** II
71. 2.20 m
73. 0.24 N
75. 0.354 mm
77. **(a)** greater than **(b)** 3.6 m
79. **(a)** 13.2 N **(b)** 12.9 N
81. $2m$
83. $X_{cm} = 6.5 \times 10^{-12}$ m; $Y_{cm} = 0$
85. **(a)** 27.8 m/s **(b)** $(19.7\ m/s)\hat{y}$ both before and after **(c)** $(-9.81\ m/s^2)\hat{y}$ both before and after
87. $\frac{25}{24}L$
89. **(a)** 0.23 m/s **(b)** 0.065 J **(c)** 0.45 m/s; −0.23 m/s
93. 0.828 m/s^2
95. **(b)** The net force on the two masses must point downward, so that the scale force upward must be less than the weight of the masses; $(m_1 + m_2)g$.
97. **A.** $v_i + u$
99. **C.** $v_f = v_i + 2u$
101. **(a)** 0.160 km/s **(b)** 1.58 m/s
103. **(a)** 0.19 m/s **(b)** −0.022 J

CHAPTER 10

1. $\frac{\pi}{6}; \frac{\pi}{4}; \frac{\pi}{2}; \pi$
3. **(a)** 1 rev/h **(b)** 2 rev/day
5. tire, propeller, drill
7. 1.90×10^{-6} rev/min
9. 190 rad/s
11. **(a)** 1.3×10^2 rad/s **(b)** 2.1×10^2 rad/s **(c)** 3.0×10^2 rad/s **(d)** positive **(e)** 85 rad/s^2; 85 rad/s^2
13. $\omega/2$
15. 3.78 rad
17. 47 rad
19. **(a)** 69 rev **(b)** 52 rev
21. 3:08:11
23. -6.14×10^{-22} rad/s^2
25. **(a)** −29.6 rev/s^2 **(b)** 242 ft **(c)** 10.0 in.
27. **(a)** equal to **(b)** III
29. **(a)** equal to **(b)** I
31. **(a)** 1.4 rad/s for each child
(b) child 1: 2.8 m/s; child 2: 2.1 m/s
33. **(a)** 0.38 m/s **(b)** 0.24 m/s
35. $a_{cp} = 5.20$ m/s^2; $a_t = 4.46$ m/s^2; $a = 6.85$ m/s^2; 49.4°
37. **(a)** 0.303 m/s **(b)** 1.53 m/s^2
(c) 0.152 m/s; 0.765 m/s^2
39. **(a)** 0.29 m/s^2 downward
(b) 0.29 m/s^2 upward
41. **(a)** 2.2 rad/s **(b)** increase
43. $a_t = 0.742$ m/s^2; $a_{cp} = 1.3$ km/s^2
45. $\sqrt{1/\alpha}$
47. 48 rad/s
49. 34.3 rad/s
51. **(a)** 2.03 rad/s^2 **(b)** greater than
53. **(a)** increase **(b)** I
55. 0.36 m
57. 0.054 kg · m^2
59. $I_1 < I_2 < I_3$
61. $K_i = 170$ J; $K_f = 0.072$ J
63. -3.5×10^{12} W
65. less than
67. 0.29 m
69. **(a)** 3.3 m/s **(b)** 2.8 m/s
71. **(a)** 1.1×10^2 rad/s **(b)** 0.56 m
73. **(a)** 3.0 m/s **(b)** decrease
75. **(a)** 15 J **(b)** 4.9 J **(c)** 9.8 J
77. greater than
79. increase
81. 6.8 rad/s
83. 874 m
85. $I_3 < I_2 < I_1$
87. **(a)** 22.1 m/s **(b)** 190 m/s
(c) 60 cm **(d)** 7.0 N
89. **(a)** 0.27 rev
(b) It does not depend on her initial speed.
91. **(a)** decrease **(b)** 50.0 rad/s **(c)** 20.8 rad/s
(d) -7.31×10^{-3} rad/s^2
93. **(a)** 4.1×10^2 rad/s^2 **(b)** 6.2×10^2 rad/s
95. **(a)** 92 s **(b)** 240° cw from north **(c)** 10 m
97. **(a)** 6.9 rad/s^2 **(b)** It doubles.
99. **(a)** 0.334 m **(b)** 1.01 kN
101. **(a)** 15 rad/s^2 **(b)** 4.0×10^3 rad
103. **(a)** 8.3×10^{-16} rad/s **(b)** 1.7×10^{17} mi
105. **(a)** $0.95g$ **(b)** 8.9 m/s
107. **(a)** $\sqrt{3g/L}$ **(b)** $\sqrt{3gL}$
109. **(a)** 0.50 m **(b)** 2.4 rotations
111. **(a)** 1.5 m **(b)** 2.7 rev **(c)** increase
113. **D.** 48.5 rpm
115. **C.** 3 ft

117. **(a)** Solid sphere wins, then disk, then hollow sphere. **(b)** All kinetic energies are equal.
119. **(a)** greater than **(b)** 5.3×10^{-5} kg · m^2

CHAPTER 11

1. 60 N
3. **(a)** 9.56 N · m **(b)** 8.83 N · m
5. **(a)** −2.14 N · m **(b)** clockwise **(c)** increase
7. **(a)** less than **(b)** III
9. C < B < A
11. 0.982 kg · m^2
13. 2.10 N · m
15. **(a)** 11 N · m **(b)** 12 N · m **(c)** 23 N · m
17. **(a)** forward **(b)** backward **(c)** decrease
19. **(a)** 81 rad/s^2 **(b)** 0.14 m
21. **(a)** more likely **(b)** II
23. 57 N
25. **(a)** more than **(b)** 90.3 N
27. 1.1 m
29. 9.14 cm
31. 3.32 kN; −2.21 kN
33. **(a)** 39 N **(b)** 39 N **(c)** 36 N
35. $f_1 = 0.90$ kN; $f_2 = f_3 = 0.17$ kN
37. $F_H = 330$ N; $F_J = 534$ N
39. **(a)** 79.5 N **(b)** 159 N
41. 18.7 cm
43. **(a)** less than **(b)** 0.080 kg
45. 1.05 kg
47. **(a)** less than **(b)** 3.22 N
49. **(a)** No; your side of the pulley **(b)** your side: 28 N; other side: 18 N
51. **(a)** 0.104 kg **(b)** 0.156 kg
53. 7.05×10^{33} kg · m^2/s
55. 8.6×10^{-5} kg · m^2/s
57. **(a)** 156 kg · m/s **(b)** 936 kg · m^2/s
59. **(a)** 0.078 kg · m^2/s **(b)** 31 rad/s
61. 2.6×10^{-4} kg · m^2/s
63. **(a)** increase **(b)** increase **(c)** stay the same
65. 0.581
67. a factor of 2
69. 2.84 rad/s
71. 0.37 rad/s
73. **(a)** faster **(b)** 38 rev/min
75. **(a)** $\frac{Iv}{I + mR^2}$ **(b)** As $I \to 0$, $v_{c,g} \to 0$. **(c)** As $I \to \infty$, $v_{c,g} \to v$.
77. 0.28 J
79. 0.423 rad/s
81. 116 W
83. **(a)** 0.88 W **(b)** 1.2 W **(c)** 2.1 W
85. **(a)** counterclockwise **(b)** move to the right
87. **(a)** move toward the left **(b)** II
89. increase
91. 5.5 mJ
93. **(a)** increase **(b)** $2v$
95. 4.4 kN/m
97. 2.0×10^3 kg
99. **(a)** $f_1 = 0.89$ kN; $f_2 = f_3 = 0.15$ kN **(b)** $f_1 = 0.89$ kN; $f_2 = f_3 = 0.22$ kN
101. **(a)** 2.49 m **(b)** 1.49 kN
103. **(a)** $F_A = 196$ N; $F_B = 83.1$ N **(b)** $F_A = 183$ N; $F_B = 95.6$ N
105. **(a)** greater than **(b)** 0.38 kN **(c)** 0.36 kN **(d)** −0.08 kN
107. **(a)** $\frac{25}{24}L$ **(b)** stay the same
109. $\sqrt{15}Mg$
111. $\frac{2\mu_s Mg}{1 - \mu_s}$
115. **(a)** $\frac{F - Mg}{M + \frac{1}{2}m}$ **(b)** F **(c)** $\frac{2MF + mMg}{2M + m}$ **(d)** As $m \to 0$, $a \to F/M - g$ and $T_2 \to F$. As $m \to \infty$, $a \to 0$ and $T_2 \to Mg$.
117. **B.** I = F_{2y}, II = F_{1y}
119. **D.** $F_{1y} = 0.52$ N, $F_{2y} = 1.3$ N
121. **(a)** decrease **(b)** 0.87 N
123. 3.75 m/s

CHAPTER 12

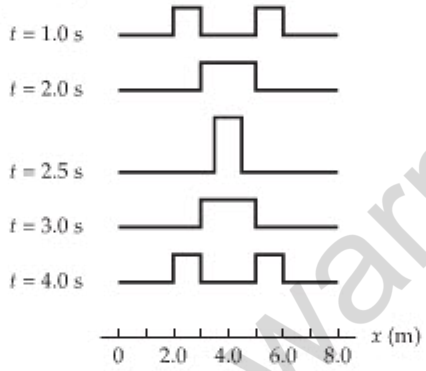
1. B < A < C < D
3. **(a)** 5.2×10^{-9} N **(b)** 1.2 m
5. 0.021 N
7. **(a)** 3.32×10^8 m **(b)** The answer to part (a) is independent of the mass of the spaceship.
9. 4.79×10^{22} N at 24.4° toward Earth off the line from the Moon to the Sun
11. **(a)** 3.37×10^{-9} N **(b)** reduced by a factor of four
13. $\frac{2}{3}D$
15. 2.46×10^6 m
17. 0.00270 m/s^2
19. 2.9×10^7 m **(b)** 0.48 m/s^2 **(c)** 1/4 **(d)** 1/4
21. **(a)** Use $\frac{1}{2}mv_i^2 = mgh_f$ to find g, and use $g = GM/R^2$ to find M. **(b)** 8.94×10^{22} kg
23. **(a)** 6.2×10^{-4} m/s^2 **(b)** 9.7 h
25. **(a)** increase **(b)** stay the same
27. **(a)** increase **(b)** I
29. 3.07 km/s
31. 7.64 h
33. **(a)** Solve Kepler's third law (Equation 12–7) for the mass of 243 Ida, using the orbit distance and period given in the problem. **(b)** 8.9×10^{16} kg
35. **(a)** satellite 2 **(b)** 4.56 km/s
37. **(a)** farther **(b)** 2.36×10^7 m
39. 4.30 km/s
41. **(a)** greater than **(b)** I
43. **(a)** -5.5×10^8 J **(b)** -5.2×10^8 J **(c)** 2.9×10^7 J; $mgh = 3.0 \times 10^7$ J
45. **(a)** 1.1×10^{11} J **(b)** 2.4×10^{12} J
47. less than
49. 5.03 km/s
51. 7.91 km/s
53. **(a)** 4.25 km/s **(b)** 10.4 km/s
55. 1.73 km/s
57. It is 10 times that of the Earth.
59. 2.96 km
61. $\sqrt{(1.00 \times 10^7\ \text{m})h}$
65. increase
67. B < C < A
69. **(a)** zero **(b)** No
71. -6.34×10^{-10} J
73. **(a)** 1.98×10^{20} N **(b)** 4.36×10^{20} N **(c)** orbiting the Sun, with a small effect due to the Earth
75. 7.39×10^{-5} m/s
77. **(a)** less than **(b)** 4.91 m/s^2
81. $\sqrt{\frac{72\pi^2 r_1^3}{Gm_1}}$
83. 1.71×10^7 m
85. 0.886 m/s
87. C = 1.00
89. **(a)** No **(b)** 7.76 km/s **(c)** 1.49 h
91. $\sqrt{\frac{4\pi^2 d^3}{3Gm}}$
93. $\frac{GMm}{2r}$
95. 6.09×10^{24} kg
97. **C.** 1.1×10^{14} kg
99. **D.** 8.2 h
101. **(a)** decrease **(b)** 258 d **(c)** stay the same
103. **(a)** increase **(b)** 15.8 km/s

CHAPTER 13

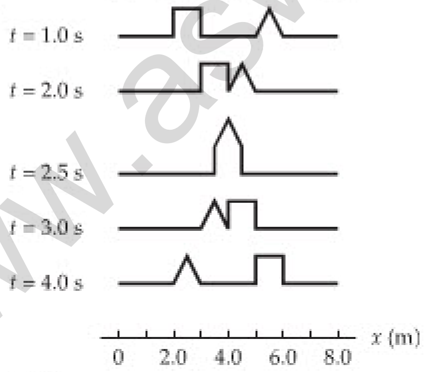
1. 12 s; 0.085 Hz
3. 0.38 s
5. 0.81 s; 1.2 Hz
7. **(a)** 0.022 s; 45 Hz **(b)** 1400 rpm
9. **(a)** $\frac{1}{2}T$ **(b)** $\frac{3}{4}T$
11. **(a)** 1.5 Hz **(b)** 0.34 s
13. **(a)** v_{max} **(b)** zero **(c)** zero **(d)** $-a_{\text{max}}$
15. **(a)** $x = (3.50\ \text{nm})\cos(\omega t)$ where $\omega = 4.00\pi \times 10^{14}$ rad/s **(b)** sine
17. **(a)** 0.88 s **(b)** −1.4 cm
19. $T/3$
21. **(a)** $v_{\text{max}}^2/a_{\text{max}}$ **(b)** $2\pi v_{\text{max}}/a_{\text{max}}$
23. **(a)** 28 m **(b)** 42 s
25. **(a)** $0.0495g$ **(b)** 0.128 m/s **(c)** minimum
27. $12g$
29. **(a)** 1.1 km/s^2 **(b)** 6.2 m/s
31. **(a)** The rider must begin hanging on when a_{max} (at the top of the cycle) equals g. **(b)** 0.14 m
33. **(a)** less than **(b)** I
37. D < C < A < B
39. 0.47 kg
41. **(a)** 1.06×10^3 kg **(b)** 932 kg
43. 7.68 cm
45. **(a)** greater than **(b)** $\sqrt{2}T$
47. 1.43 m/s
49. 1.2 J
51. **(a)** 0.26 m/s **(b)** 2.8 cm
53. 0.30 m/s
55. **(a)** 897 m/s **(b)** 0.0687 s
57. **(a)** run slow **(b)** I
59. 8.95 m
61. 2.4 s
63. **(a)** increase **(b)** 2.45 s
65. 0.011 kg · m^2
67. 1.49 m
69. **(a)** $2\pi\sqrt{\frac{L}{g + a}}$ **(b)** $2\pi\sqrt{\frac{L}{g - a}}$
71. **(a)** 1/2 **(b)** 1/2 **(c)** 1/2 **(d)** 1/4 **(e)** 1.00
73. **(a)** remain the same **(b)** remain the same
75. 0.49 m/s
77. 4×10^{14} m/s^2; $(4 \times 10^{13})g$
79. 5.52 N/m
81. **(a)** 0.13 m **(b)** 84 N/m **(c)** 0.83 Hz
83. **(a)** 0.018 rad/s **(b)** 250 m
85. 9.20 s
87. 0.95 s
89. **(a)** 0.112 m **(b)** 0.142 s
91. **(a)** greater than 0.50 m/s **(b)** 0.79 m/s **(c)** 1.2 J
93. **(a)** 7.9 N/m **(b)** 4.6 kg
95. **(a)** less than **(b)** $\pi\sqrt{\ell/g} + \pi\sqrt{L/g}$ **(c)** 1.5 s
99. **(a)** The pencil begins to rattle when the maximum acceleration of the speaker exceeds the acceleration due to gravity. **(b)** $\frac{1}{2}\sqrt{g/A}$
101. **C.** 74 °F
103. **B.** 1700
105. **(a)** $1/\sqrt{2}$ **(b)** 5.90 cm **(c)** 0.0702 s

CHAPTER 14

1. **(a)** 56 cm **(b)** 6.5 cm
3. 1.2 m
5. **(a)** 0.61 m **(b)** 1.1 m **(c)** The answer in part (a) is unchanged; the answer in part (b) is halved.
7. 0.51 m/s; 67 Hz
9. 4.00
11. **(a)** greater than **(b)** I
13. 4.00
15. **(a)** less time **(b)** 0.18 s **(c)** 0.17 s
17. 1.4
19. $y = (0.16\ \text{m})\cos\left(\frac{2\pi}{2.1\ \text{m}}x - \frac{\pi}{0.90\ \text{s}}t\right)$
21. **(a)** positive **(b)** $\lambda = 2\pi/B$ **(c)** $f = C/2\pi$ **(d)** $x = \pi/B$
23. **(a)** 15 cm **(b)** 10 cm **(c)** 24 s **(d)** 0.42 cm/s **(e)** to the right
25. **(a)** A and C **(b)** B and D **(c)** C **(d)** A **(e)** C
27. **(a)** 0.098 s **(b)** 28 mm
29. **(a)** 0.807 m **(b)** decrease **(c)** 0.722 m
31. 1.78 m/s
33. 1.6 mW/m^2
35. 67.6 W/m^2
37. **(a)** 104 dB **(b)** 99.6 dB **(c)** 2.0 × 10^6 m
39. **(a)** 69.5 dB **(b)** less than
41. 21.7 m
43. $\lambda_3 < \lambda_2 < \lambda_1$
45. 1.50 × 10^2 Hz
47. **(a)** 35.3 kHz **(b)** higher **(c)** 35.4 kHz
49. 524 Hz
51. 51 m/s
53. **(a)** 0.33 kHz **(b)** (i) bicyclist A speeds up
55. 11.2 m/s
57.



59.



61. 1.2 kHz
63. 0.322 m
65. 0.31 kHz
67. **(a)** a lower frequency **(b)** III
69. 77 Hz
71. **(a)** 3.6 kHz; 9.6 cm **(b)** 11 kHz; 3.2 cm **(c)** greater than
73. **(a)** 7.60 Hz **(b)** 15.2 Hz **(c)** increase
75. **(a)** 93.5 Hz **(b)** 31.2 Hz
77. **(a)** 55 Hz **(b)** 3.1 m
79. **(a)** equal to **(b)** I
81. 264 Hz and 258 Hz
83. **(a)** 13.8 Hz **(b)** increase **(c)** 18.3 Hz
85. 1.21 m
87. **(a)** minimum **(b)** maximum
89. A, **III**; B, **I**; C, **I**; D, **III**; E, **II**; F, **II**
91. 2.9 km
93. 6.72 × 10^6 m
95. four
97. 9.0 km
99. **(a)** increase **(b)** 618 Hz
101. 36 m/s
103. 6.73 m/s if approaching, 7.00 m/s if receding
105. **(a)** 2.00 **(b)** 1/3 **(c)** 2.00
107. **(a)** 0.0032 J **(b)** 0.0081 J **(c)** No
109. 0.83 m
111. 3.9 × 10^7 years
113. **(a)** increase
115. $\sqrt{\frac{2\pi\lambda}{g}}$
117. **C.** 64 Hz
119. **B.** 2.3 m
121. **(a)** greater than **(b)** 30.1 m/s
123. **(a)** increase **(b)** 464 Hz

CHAPTER 15

1. 10^3 N
3. No
5. 1.05 × 10^4 kg/m; silver
7. **(a)** 10^{-1} Pa **(b)** 10^{-6} atm
9. 4.3
11. 615 N
13. **(a)** greater than **(b)** equal to
15. 2.17 × 10^6 Pa
17. **(a)** 98.2 kPa **(b)** 10.0 m
19. 0.11 N
21. **(a)** 995 m **(b)** greater than
23. **(a)** greater than **(b)** 52 Pa
25. 0.16 cm
27. **(a)** 0.770 m **(b)** increased
29. **(a)** equal to **(b)** I
31. fall
33. 41 cm
35. 1.12 kg/m^3
37. **(a)** decrease **(b)** III
39. less than
41. at the same level as
43. **(a)** 2.34 × 10^{-4} m^3 **(b)** 8.70 × 10^3 kg/m^3
45. **(a)** 1.04 × 10^3 kg/m^3 **(b)** 0.0745 m^3 **(c)** 26 N
47. **(a)** 0.008 m^3 **(b)** 18 N
49. 2.1 cm
51. 39 m/s
53. 16 min
55. **(a)** 0.78 cm/s **(b)** 0.13 cm/s
57. 7.9 m/s
59. **(a)** 32 cm/s **(b)** 43 Pa
61. **(a)** 53 m/s **(b)** 19 cm
63. 1.08 × 10^5 Pa
65. **(a)** 1.42 kPa **(b)** 45 kN
67. **(a)** 980 kN **(b)** upward
69. **(a)** less than **(b)** $\Delta P = -\frac{15}{2}\rho v^2$
71. **(a)** 25 cm^3 **(b)** 2.2
73. **(a)** 1.0 m/s **(b)** 0.79 kPa **(c)** 1/2 **(d)** 1/4
75. lean forward
77. **(a)** higher **(b)** stay the same
79. tilted inward toward the axis of rotation
81. greater than
83. 904 m/s; $v/v_s = 2.64$
85. 95.3 kPa
87. 2.4 × 10^5 N
89. **(a)** compressed 0.15 m **(b)** stretched 0.063 m
91. 16 m/s
93. **(a)** 11 N
95. **(a)** 1.050 × 10^5 Pa **(b)** increase **(c)** 1.052 × 10^5 Pa
97. 41 km
99. **(a)** $v = \sqrt{2gd}$ **(b)** the same as
101. **(a)** 9.58 × 10^{-3} m^3 **(b)** 10.1 kg
103. 4.4 × 10^5 Pa
105. **(a)** 17 μm **(b)** Yes **(c)** 21 kg
107. $2\pi\sqrt{\frac{\rho_1 H}{\rho_2 g}}$
109. 0.28
113. 16 kg
115. **C.** 0.28H
117. **B.** 0.40H
119. 0.60 cm
121. 2.00

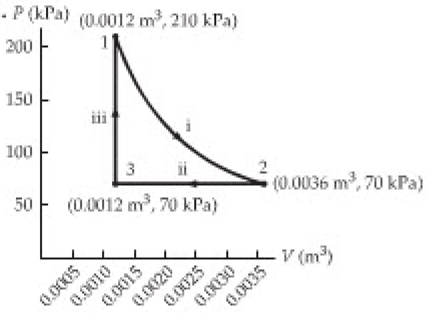
CHAPTER 16

1. −128.6 °F
3. **(a)** 37.0 °C **(b)** 310.2 K
5. **(a)** 5.7 × 10^3 °C **(b)** 1.0 × 10^4 °F
7. **(a)** 79.9 kPa **(b)** 192 °C
9. 0.23 K/s
11. −6.85 °C
13. steel
15. **(a)** B = C < D = E < A **(b)** A = C = E < B < D
17. 1.6 m
19. **(a)** heated **(b)** 430 °C
21. 0.93 L
23. **(a)** aluminum **(b)** 2.5 × 10^{-5} m^3
25. **(a)** Water will overflow. **(b)** 24 cm^3
27. 0.12 kW or 0.16 hp
29. **(a)** 1.4 × 10^{-3} C° **(b)** greater than **(c)** 2.6 × 10^{-3} F°
31. **(a)** greater than **(b)** III
33. 23.3 °C
35. 15 kJ
37. **(a)** 7.2 × 10^2 pellets **(b)** decrease **(c)** 4.4 × 10^2 pellets
39. **(a)** 0.18 kJ/K **(b)** 0.96 kJ/(kg · K)
41. 385 J/(kg · K); copper
43. 70.5 °C
45. $\Delta T_B < \Delta T_A < \Delta T_C$
47. twin 1
49. 65 kJ/min
51. 3.29 h
53. **(a)** 19.4 J/s **(b)** 0.16 C°
55. 2.64 cm
57. **(a)** The heat flow rate through both rods must be the same. **(b)** 89 cm
59. 56
61. too long
63. **(a)** No **(b)** Yes **(c)** No
65. **(a)** greater than **(b)** II
67. 25.1 cm × 2.01 m × 9.9 m
69. **(a)** 2700 °F **(b)** 1800 K
71. 250 °F
73. **(a)** 1.30 × 10^3 J, 1.29 times more than the specific heat
    (b) 4.19 × 10^6 J, 1000 times more than the specific heat
75. 77.9 °F

77. **(a)** increase **(b)** 1.710 mm
(c) 1.955 s before; 1.957 s after
79. 3.5×10^2 C°
81. 0.17 C°
83. **(a)** 1.54×10^6 m **(b)** 5.51 km/s
85. **(a)** 0.21 kW **(b)** 0.42 kW
89. **(a)** decreased **(b)** −83 C°
93. greater than
95. A. 107 ft 7.8 in.
97. 82 °C
99. **(a)** greater than **(b)** 139 °C

CHAPTER 17

1. **(a)** equal to **(b)** less than
3. **(a)** decrease **(b)** I
5. 0.0224 m^3
7. 316 K
9. 1.33×10^3kg
11. 10^{-15} Pa
13. 13 L
15. **(a)** 0.032 m^3 **(b)** 1.9×10^{-4}
(c) The molecules occupy less than 0.02% of the total volume of the gas, so the assumption is valid.
17. **(a)** 3.0×10^{23} molecules/m^3
(b) greater than
(c) 2.68×10^{25} molecules/m^3
19. 348 K
21.



23. increase by a factor of 4.00
25. **(a)** unknowable **(b)** false
(c) unknowable **(d)** false **(e)** true
27. 632 m/s
29. **(a)** greater than **(b)** 2.07 km/s
31. 191 K
33. $v_{238}/v_{235} = 0.996$
35. face 2
37. 67 kg
39. $1.1 \times 10^6 \text{ N/m}^2$
41. $Y_3 < Y_1 = Y_2 < Y_4$
43. **(a)** 1.8×10^{-3} **(b)** 0.60 cm
45. 233 N
47. about 4.2 kPa
49. **(a)** about 3.5 MPa **(b)** increase
51. **(a)** 0 °C **(b)** 100 °C **(c)** increase **(d)** increase
53. **(a)** First the water ice changes from solid to liquid, then the liquid changes to a gas.
(b) The solid water sublimates to a gas.
55. **(a)** First the solid carbon dioxide changes to liquid, then the liquid changes to a gas.
(b) First the solid carbon dioxide changes to liquid, then the liquid changes to a gas.
57. 3.2×10^5 J
59. 362 kJ
61. **(a)** No **(b)** 0 °C; 0.4 kg
63. **(a)** 27.3 s **(b)** 61.5 s **(c)** 246 s
(d) The water is boiling.
65. **(a)** 2.62 kJ **(b)** 30.9 kJ **(c)** 0.058 kg; 0.68 kg
67. 19.1 °C
69. 123 °C (All of the water has vaporized.)
71. **(a)** 3.6 °C **(b)** No ice is present.
73. 50.3 h
75. room 2
77. **(a)** less than **(b)** III
79. 2.0×10^{22} molecules
81. **(a)** 0.39 ft^3 **(b)** 2.0×10^2 atm **(c)** 3.0 kg
83. 1.1×10^{24} molecules
85. **(a)** 7.3 kN **(b)** reduced by a factor of 2
87. **(a)** 4.2×10^{-7} m **(b)** 2.7×10^{-6} m
89. **(a)** 4.6 MJ **(b)** 2.5 km/s
91. **(a)** 0.469 kg **(b)** 0.320 kg **(c)** 0.171 kg
93. 1.4×10^{-4} kg
95. **C.** 91.9 atm
97. **B.** $9.2 \times 10^{-5} \text{ m}^3$
99. **(a)** 18 °C **(b)** five ice cubes

CHAPTER 18

1. **(a)** zero **(b)** zero **(c)** −100 J
3. $\Delta U = -10.8 \times 10^5$ J; $W = 6.7 \times 10^5$ J; $Q = -4.1 \times 10^5$ J
5. **(a)** 119 J **(b)** 35 J **(c)** 0
7. **(a)** −492 kJ **(b)** 117 Cal
9. **(a)** 4.24 MJ/mi **(b)** decrease
11. **(a)** zero **(b)** −53 J **(c)** −150 J
(d) 200 J **(e)** 350 J
13. **(a)** zero **(b)** $5.1 \times 10^{-3} \text{ m}^3$
15. 60 Pa
17. **(a)** on the system **(b)** −670 J
19. **(a)** 1200 kJ **(b)** No
21. **(a)** 332 K **(b)** 555 kJ
23. **(a)** added to the system **(b)** 55 kJ
25. **(a)** 150 kJ **(b)** zero **(c)** 150 kJ
27. **(a)** $T_A = 267$ K; $T_B = 357$ K; $T_C = 89.1$ K
(b) A → B: heat enters; B → C: heat leaves; C → A: heat enters
(c) A → B: 376 kJ; B → C: −375 kJ; C → A: 150 kJ
29. **(a)** 94 kJ into the gas **(b)** 92 kJ into the gas
31. **(a)** $3P_iV_i$ **(b)** $\frac{15}{2}P_iV_i$ **(c)** $\frac{21}{2}P_iV_i$
33. **(a)** greater than **(b)** II
35. **(a)** 0.95 K **(b)** 0.57 K
37. **(a)** 2.9 K **(b)** 4.9 K
39. **(a)** 0.315 **(b)** 0.630 **(c)** 100 kPa; 222 K
41. **(a)** process 1: 159 kJ; process 2: 1060 kJ
(b) 424 kJ **(c)** 795 kJ
43. **(a)** stay the same **(b)** decrease
45. 0.28
47. **(a)** 8.5 kJ **(b)** 6.0 kJ
49. **(a)** 1.16 GW **(b)** 1.71 GW
51. **(a)** 382 K **(b)** decreased **(c)** 327 K
53. 4.5×10^2 K, 5.0×10^2 K
55. **(a)** less than **(b)** I
57. **(a)** 19.7 kJ **(b)** 54.2 kJ
59. 0.41 kW
61. 1.5×10^5 J
63. **(a)** increase **(b)** III
65. **(a)** stay the same **(b)** I
67. −3.8 kJ/K
69. 9.6 W/K
71. **(a)** increase **(b)** 1.3 W/K
73. equal to
75. less than
77. 0.071 kg
79. **(a)** 365 K **(b)** increase **(c)** 1.52 kJ/K
(d) 555 kJ; 555 kJ
81. **(a)** 318 kJ **(b)** 795 kJ **(c)** 1113 kJ
83. **(a)** 751 kJ **(b)** 194 kJ **(c)** 945 kJ
85. **(a)** 1.1×10^{31} J/K **(b)** 3.28×10^{31} J
87. **(a)** 0.0557 m^3 **(b)** −1.22 kJ **(c)** −1.22 kJ
89. **(a)** 0.47 J/K **(b)** 0.40 kJ
91. **(a)** −38 J **(b)** zero **(c)** −171 J **(d)** 212 J
(e) 120 J
93. **(a)**

	Q	W	ΔU
A → B	806 J	806 J	0
B → C	−938 J	−375 J	−563 J
C → A	563 J	0	563 J

(b) 0.31
97. **(a)** 6.10%
99. **(a)** 6.78%
101. **(a)** less than **(b)** 0.46 **(c)** −1.8 J/K
(d) 1.8 J/K

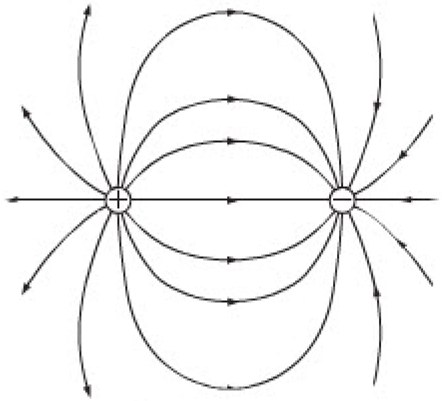
CHAPTER 19

1. **(a)** decrease
(b) I
3. **(a)** negative
(b) toward
5. -7.8×10^{-12} C
7. -1×10^6 C
9. 0.178 C
11. D < A < C < B
13. the center
15. C < A < B
17. 1.37 m
19. 4.7×10^{-10} m
21. 3.0 electrons
23. (63 N)$\hat{\mathbf{x}}$
25. **(a)** $F_1 = F_3 < F_2$
(b) 0°
(c) 150°
(d) 300°
27. 0.12 m
29. 5.5 km
31. 174.6°; 4.2 N
33. **(a)** 35 cm **(b)** No. The forces would reverse direction but would still balance.
35. **(a)** 248°; 58 N **(b)** The direction would not change but the magnitude would be cut to a fourth.
37. **(a)** greater than **(b)** 3.09×10^6 m/s
39. **(a)** 3.7×10^{-7} C **(b)** no
(c) The tension will be zero.
41. $q_1 = 9q_2$
43. **(a)** 6.74×10^4 N/C **(b)** 1.69×10^4 N/C
45. **(a)** $(-3.0 \times 10^7 \text{ N/C})\hat{\mathbf{x}}$
(b) $(5.9 \times 10^7 \text{ N/C})\hat{\mathbf{x}}$
47. **(a)** $(-3.3 \times 10^4 \text{ N/C})\hat{\mathbf{y}}$
(b) $(9.81 \text{ m/s}^2)\hat{\mathbf{y}}$
49. 3.5 pC
51. **(a)** configuration (2)

(b) case 1: $\vec{\mathbf{E}}_{1,\text{ net}} = 0$;
case 2:

$$\vec{\mathbf{E}}_{2,\text{net}} = \left(-\frac{4\sqrt{2}\,k\,q}{a^2}\right)\hat{\mathbf{y}}$$

53. **(a)** positive **(b)** 5.00 μC **(c)** 5.00 μC
55.



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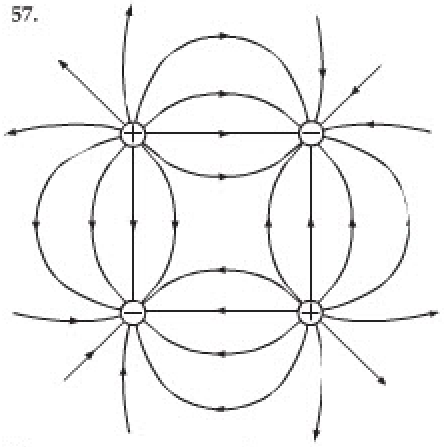

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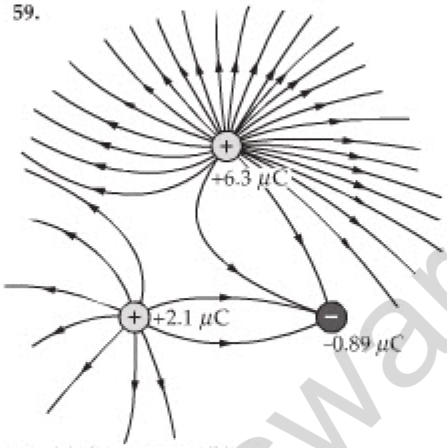
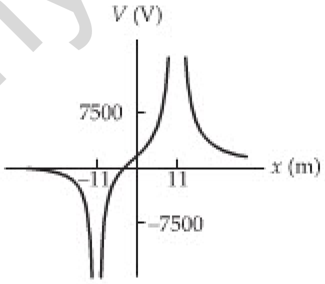


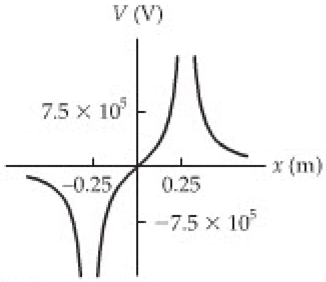
61. **(a)** the same as **(b)** II
63. D < C < B < A
65. 6.8×10^5 N · m^2/C
67. 6.2×10^{-6} C/m^2
69. **(a)** -1.14×10^5 N · m^2/C
(b) 1.46×10^5 N · m^2/C
(c) 3.28×10^5 N · m^2/C
(d) −2.90 μC
71. **(a)** greater than **(b)** II
73. the same as
75. negative
77. $+2q$ and $+q$
79. 8.4×10^8 electrons
81. **(a)** $-Q$ **(b)** $+Q$ **(c)** zero
83. 1.2×10^{25} N; 10^{22} times stronger
85. **(a)** (ii) to the left of $x = 0.30$ m
(b) 0.297 m
87. **(a)** 9.39×10^{-7} C/m **(b)** 0.954 m
89. **(a)** 0.55 N; $-\hat{\mathbf{y}}$ direction
(b) greater than
(c) $(-4.4\text{ N})\hat{\mathbf{y}}$
91. **(a)** 6.7×10^5 N/C **(b)** stay the same
93. **(a)** 5.71×10^{13} C **(b)** no change
95. 0.254 m
97. 8.85×10^{-6} C/m^2
99. **(a)** 1.3×10^3 N/C **(b)** 5.3×10^{-2} N
101. **(a)** 4.13×10^3 N/C **(b)** 6.22×10^6 m/s
103. **B.** 5.81×10^8 electrons
105. **C.** 4.4 cm
107. **(a)** greater than **(b)** less than
(c) 1.83×10^5 N/C **(d)** 11.8°
109. **(a)** greater than **(b)** −4.50 μC

CHAPTER 20

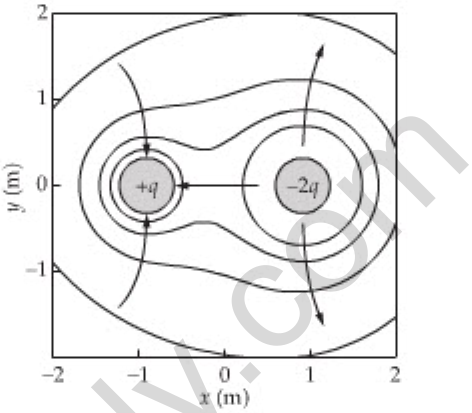
1. increasing
3. **(a)** 0 **(b)** -4.1×10^6 V
(c) -4.1×10^6 V
5. 2.43×10^6 V/m
7. **(a)** 90 V **(b)** 18 V
9. 2×10^4 V
11. **(a)** 1.9 kV **(b)** increase **(c)** 3.8 kV
13. 110 m/s
15. **(a)** region 4, region 4
(b) 1, 13 V/m; 2, 0; 3, −5.1 V/m; 4, 68 V/m
17. **(a)** decrease **(b)** II
19. 9.4×10^7 m/s
21. **(a)** negative x direction **(b)** 3.8 cm/s
(c) less than
23. **(a)** $-\sqrt{2}\ Q$ **(b)** negative
25. **(a)** $-Q$ **(b)** positive **(c)** negative
27. **(a)** -2.2×10^4 V **(b)** -2.2×10^4 V
(c) -1.5×10^4 V
29. 1.34 cm
31. **(a)**



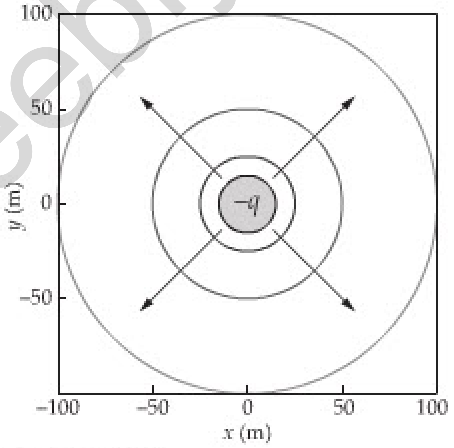
(b) closer to the negative charge
(c) −3.3 m
33. **(a)**



(b) 0.21 m and 0.29 m
35. **(a)** 20.0 m/s **(b)** greater than **(c)** 28.3 m/s
37. **(a)** 0.86 J **(b)** less than **(c)** −0.54 J
39. **(a)** 76.7 kV **(b)** 14.1 m/s
41. $-(4 - \sqrt{2})\,(kQ^2/a)$
43. **(a)** greater than **(b)** III
45. **(a)**

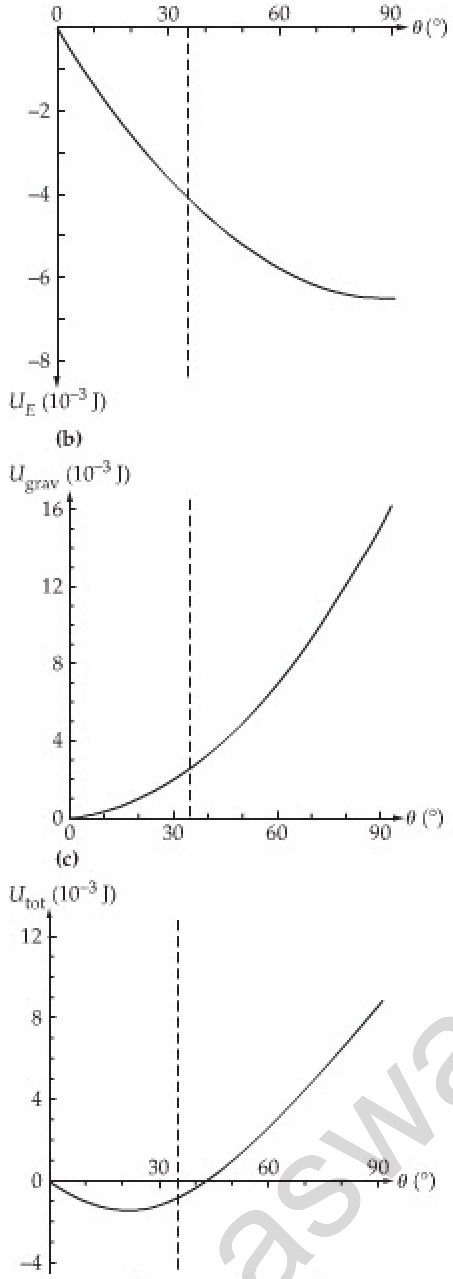


(b)



47. **(a)** to the left
(b) A, positive; B, positive; C, positive; D, negative; E, negative
(c) E < D < A < C < B
(d) less than
49. **(a)** 559 V/m; 243° **(b)** 8.95 mm
51. 1.8 V
53. 0.18 μF
55. **(a)** 19 kV **(b)** decrease **(c)** 9.7 kV
57. **(a)** 1.87 μm **(b)** 6.9 μm
59. 15 kV
61. **(a)** 4.0 nF **(b)** 6.6 C
63. 35 μJ
65. **(a)** 5.8×10^{-14} J **(b)** decrease
67. 10.6 J/m^3
69. **(a)** 0.29 C **(b)** 48 J
71. decreasing
73. **(a)** increase **(b)** increase
75. **(a)** decrease **(b)** decrease
(c) decrease **(d)** decrease
77. **(a)** remain the same **(b)** increase
(c) increase **(d)** increase
79. The capacitance is cut to a fourth.
81. **(a)** $x = -0.5$ m **(b)** region 3 **(c)** $x = -4.5$ m
83. 13.6 eV
85. **(a)** smallest at C, greatest at A
(b) A, 43 kV; B, 31 kV; C, 29 kV; D, 31 kV
87. **(a)** −6.96 J **(b)** 20.1 m/s
89. -5.9×10^{-14} J
91. **(a)** positive **(b)** -1.7×10^{-16} C
93. (a) from one end of its body to the other
(b) 5.3×10^{-9} C

95. **(a)** increase **(b)** 0.071 mm
97. **(a)** directed into the cell; 1.2×10^7 N/C **(b)** 97 mV; outer wall
99. 3.58×10^{-14} m
101. **(a)**



103. $(22\text{ kV})\left(1 - \dfrac{1}{\sqrt{5 + 4\cos\theta}}\right)$
105. 6.92 cm; 1.19 nC
107. **B.** 7.6×10^{-12} F
109. **C.** 1.6×10^{-6} J
111. **(a)** 1.50 m **(b)** −1.50 m

CHAPTER 21

1. 3600 C
3. 9.4×10^{19} electrons/s
5. 6.25×10^4 electrons/s
7. **(a)** 1.5 kC **(b)** 8.5 y
9. material A
11. 1/3
13. 51 Ω
15. 0.68 kΩ
17. **(a)** 2.5 mV **(b)** increase
19. **(a)** 7.2×10^{-13} A **(b)** decrease by a factor of 2
21. **(a)** 0.11 Ω/m **(b)** decrease **(c)** 0.074 Ω/m
23. $\left(\dfrac{C}{A}\right)^2 I_{AB}$
25. **(a)** bulb A **(b)** 4
27. 51 A
29. 0.58 kW
31. $0.072/kWh
33. 155-minute reserve capacity
35. **(a)** in series **(b)** III
37. **(a)** decrease **(b)** III
39. 6 resistors
41. **(a)** 3.1 W **(b)** 1.5 kW
43. **(a)** 71 mA **(b)** $V_{42\,\Omega} = 3.0$ V; $V_{17\,\Omega} = 1.2$ V; $V_{110\,\Omega} = 7.8$ V
45. **(a)** 29 V **(b)** $I_{65\,\Omega} = 0.45$ A; $I_{25\,\Omega} = 1.2$ A; $I_{170\,\Omega} = 0.17$ A
47. 0.16 kV
49. 0.84 Ω
51. **(a)** $I_{7.1\,\Omega} = 0.29$ A, $I_{3.2\,\Omega} = 1.1$ A **(b)** 1.4 A **(c)** 11.3 V
53. **(a)**

R (Ω)	1.5	2.5	4.8	3.3	8.1	6.3
I (A)	6.0	3.6	0.38	0.55	0.22	1.1

(b) less than
55. **(a)** 129 V **(b)** decrease
57. **(a)** stay the same **(b)** I_0
59. **(a)** decrease **(b)** 0.12 A; clockwise
61. **(a)** $I_{11\,\Omega} = 0.92$ A, $I_{6.2\,\Omega} = I_{12\,\Omega} = 0.27$ A, $I_{7.5\,\Omega} = 0.65$ A **(b)** same as (a)
63. **(a)** $I_{9.8\,\Omega} = I_{3.9\,\Omega} = 0.72\,A$, $I_{1.2\,\Omega} = 1.8\,A$, $I_{6.7\,\Omega} = 1.0\,A$ **(b)** greater than **(c)** 2.2 V
65. **(a)** C_1 **(b)** C_2
67. **(a)** increase **(b)** II
69. 1.1 V
71. **(a)** B < A < C **(b)** B < A = C
73. **(a)** 23 μF **(b)** the 15-μF capacitor **(c)** $Q_{7.5\,\mu F} = 110$ μC, $Q_{15\,\mu F} = 230$ μC
75. 2.56 μF
77. 6.47 V
79. **(a)** 2.6×10^{-4} C **(b)** 28 mA
81. **(a)** 9.75 ms **(b)** 668 μC **(c)** 68.6 mA
83. 6.1 kΩ
85. **(a)** 6.7×10^{-4} s **(b)** 1.4 A **(c)** increased
87. charge
89. **(a)** increased **(b)** $\sqrt{2}$
91. **(a)** R_2 **(b)** R_1
93. **(a)** increase **(b)** III
95. **(a)** increase **(b)** stay the same
97. **(a)** increase **(b)** II
99. Connect the 146-Ω and 521-Ω resistors in series. Then connect this pair in parallel with the 413-Ω resistor.
101. 3.1×10^{-8} A
103. **(a)** A = B = C **(b)** A < C < B
105. 0.53 V
107. **(a)** 0.91 J **(b)** 4.0 min
109. **(a)** greater than **(b)** 0.82 A **(c)** 0.54 A
111. **(a)** $R_1 = 18\ \Omega$, $R_2 = 62\ \Omega$
113. $R/9$
115. **(a)** greater **(b)** $I_{45\,\Omega} = 0.27$ A, $I_{35\,\Omega} = I_{82\,\Omega} = 0.103$ A
117. **(a)** 2.4 W/m **(b)** 2.0 W/m
119. **(a)** $P_{13\,\Omega} = 7.7$ W, $P_{6.5\,\Omega} = 3.8$ W, $P_{24\,\Omega} = 9.4$ W; all zero as $t \to \infty$ **(b)** 0.38 mC **(c)** 7.0 mJ **(d)** It quadruples.
121. 44 V, 43 Ω
123. 7.50 Ω
125. **A.** 1.25×10^7 Ω
127. increase
129. **(a)** 329 Ω **(b)** 794 Ω
131. **(a)** 273 μC **(b)** decrease **(c)** 58.7 ms

CHAPTER 22

1. **(a)** less than **(b)** II
3. positive z direction
5. A, negative; B, negative; C, positive
7. 9.9×10^8 m/s^2
9. 0
11. **(a)** 81° **(b)** 38° **(c)** 1.2°
13. 4.4×10^{-16} N
15. **(a)** particle 2 **(b)** 1/4
17. **(a)** $(5.0 \times 10^6\text{ N/C})\hat{\mathbf{x}}$ **(b)** $(-0.2\text{ T})\hat{\mathbf{z}}$
19. 5.4 μm
21. 2.5 km/s
23. **(a)** 1.1 m/s **(b)** bottom electrode; no
25. **(a)** 9.83 m/s **(b)** 13.9 s
27. 3.1 cm
29. **(a)** 1.00 **(b)** 0.0233
31. 3.3 N
33. $(-0.34\text{ T})\hat{\mathbf{z}}$
35. 2.4 A
37. $\tan^{-1}\dfrac{ILB}{mg}$
39. 3.5 A
41. 60°
43. **(a)** less than **(b)** $\pi/4$
45. 2.50×10^{-5} T
49. 1.3 kA
51. **(a)** point B **(b)** point A, 2.1 μT; point B, 13 μT
53. **(a)** 2.57×10^{-5} N/m **(b)** the same as
55. terminal A
57. 35 mA
59. 17.2 T
61. east
63. out of the page
65. greater than $\theta = 45°$ and less than $\theta = 90°$
67. toward wire 3
69. 0
71. 0.946
73. 7.0 μm
75. **(a)** $F_3 < F_2 = F_4 < F_1$ **(b)** $\vec{\mathbf{v}}_3$
77. **(a)** $B_3 < B_1 < B_2$ **(b)** B_1, out of the page; B_2, into the page; B_3, out of the page
79. **(a)** stay the same **(b)** III
81. **(a)** toward the wire **(b)** 3×10^{-5} N
83. $(-2.0 \times 10^3\text{ N/C})\hat{\mathbf{x}} + (3.2 \times 10^3\text{ N/C})\hat{\mathbf{y}}$
85. 2.3 mN; 65° measured from the positive z axis toward the negative y axis in the yz plane
87. **(a)** 4.52×10^7 C/kg **(b)** less than
89. $(-4\ \mu\text{T})\hat{\mathbf{z}}$, $(12\ \mu\text{T})\hat{\mathbf{z}}$, $(-4\ \mu\text{T})\hat{\mathbf{z}}$
91. **(a)** less than **(b)** 1.2 A; to the left
93. **(a)** 1.6×10^{11} N **(b)** The force from the magnetar is 280,000 times greater than the electron-proton force within a hydrogen atom.