

Speed

	ft/s	km/h	METER/SECOND	mi/h	cm/s
1 foot per second = 1		1.097	0.3048	0.6818	30.48
1 kilometer per hour = 0.9113		1	0.2778	0.6214	27.78
1 METER per SECOND = 3.281		3.6	1	2.237	100
1 mile per hour = 1.467		1.609	0.4470	1	44.70
1 centimeter per second = 3.281×10^{-2}		3.6×10^{-2}	0.01	2.237×10^{-2}	1

1 knot = 1 nautical mi/h = 1.688 ft/s 1 mi/min = 88.00 ft/s = 60.00 mi/h

Force

Force units in the colored areas are now little used. To clarify: 1 gram-force (= 1 gf) is the force of gravity that would act on an object whose mass is 1 gram at a location where g has the standard value of 9.80665 m/s^2 .

	dyne	NEWTON	lb	pdl	gf	kgf
1 dyne = 1	10^{-5}	2.248×10^{-6}	7.233×10^{-5}	1.020×10^{-3}	1.020×10^{-6}	
1 NEWTON = 10^5	1	0.2248	7.233	102.0	0.1020	
1 pound = 4.448×10^5	4.448	1	32.17	453.6	0.4536	
1 poundal = 1.383×10^4	0.1383	3.108×10^{-2}	1	14.10	1.410×10^2	
1 gram-force = 980.7	9.807×10^{-3}	2.205×10^{-3}	7.093×10^{-2}	1	0.001	
1 kilogram-force = 9.807×10^5	9.807	2.205	70.93	1000	1	

1 ton = 2000 lb

Pressure

	atm	dyne/cm ²	inch of water	cm Hg	PASCAL	lb/in. ²	lb/ft ²
1 atmosphere = 1		1.013×10^6	406.8	76	1.013×10^5	14.70	2116
1 dyne per centimeter ² = 9.869×10^{-7}	1		4.015×10^{-4}	7.501×10^{-5}	0.1	1.405×10^{-5}	2.089×10^{-3}
1 inch of water ^a at 4°C = 2.458×10^{-3}	2491		1	0.1868	249.1	3.613×10^{-2}	5.202
1 centimeter of mercury ^a							
at 0°C = 1.316×10^{-2}		1.333×10^4	5.353	1	1333	0.1934	27.85
1 PASCAL = 9.869×10^{-6}	10		4.015×10^{-3}	7.501×10^{-4}	1	1.450×10^{-4}	2.089×10^{-2}
1 pound per inch ² = 6.805×10^{-2}		6.895×10^4	27.68	5.171	6.895×10^3	1	144
1 pound per foot ² = 4.725×10^{-4}	478.8		0.1922	3.591×10^{-2}	47.88	6.944×10^{-3}	1

^aWhere the acceleration of gravity has the standard value of 9.80665 m/s^2 .1 bar = $10^6 \text{ dyne/cm}^2 = 0.1 \text{ MPa}$ 1 millibar = $10^3 \text{ dyne/cm}^2 = 10^2 \text{ Pa}$

1 torr = 1 mm Hg

Energy, Work, Heat

Quantities in the colored areas are not energy units but are included for convenience. They arise from the relativistic mass–energy equivalence formula $E = mc^2$ and represent the energy released if a kilogram or unified atomic mass unit (u) is completely converted to energy (bottom two rows) or the mass that would be completely converted to one unit of energy (rightmost two columns).

	Btu	erg	ft · lb	hp · h	JOULE	cal	kW · h	eV	MeV	kg	u
1 British thermal unit = 1	1.055 $\times 10^{10}$	777.9	3.929 $\times 10^{-4}$	1055	252.0	2.930 $\times 10^{-4}$	6.585 $\times 10^{21}$	6.585 $\times 10^{15}$	1.174 $\times 10^{-14}$	7.070 $\times 10^{12}$	
1 erg = $\times 10^{-11}$	9.481	7.376	3.725 $\times 10^{-14}$	10 ⁻⁷	2.389 $\times 10^{-8}$	2.778 $\times 10^{-14}$	6.242 $\times 10^{11}$	6.242 $\times 10^5$	1.113 $\times 10^{-24}$	670.2	
1 foot-pound = $\times 10^{-3}$	1.285 $\times 10^7$	1.356	5.051 $\times 10^{-7}$	1.356	0.3238	3.766 $\times 10^{-7}$	8.464 $\times 10^{18}$	8.464 $\times 10^{12}$	1.509 $\times 10^{-17}$	9.037 $\times 10^9$	
1 horsepower-hour = 2545	2.685 $\times 10^{13}$	1.980 $\times 10^6$	1 $\times 10^6$	2.685 $\times 10^6$	6.413 $\times 10^5$	1.676 $\times 10^{25}$	1.676 $\times 10^{19}$	2.988 $\times 10^{-11}$	1.799 $\times 10^{16}$		
1 JOULE = $\times 10^{-4}$	9.481 $\times 10^{-4}$	10 ⁷	0.7376 $\times 10^{-7}$	1	0.2389	2.778 $\times 10^{-7}$	6.242 $\times 10^{18}$	6.242 $\times 10^{12}$	1.113 $\times 10^{-17}$	6.702 $\times 10^9$	
1 calorie = $\times 10^{-3}$	3.968 $\times 10^7$	4.1868	1.560 $\times 10^{-6}$	4.1868	1	1.163 $\times 10^{-6}$	2.613 $\times 10^{19}$	2.613 $\times 10^{13}$	4.660 $\times 10^{-17}$	2.806 $\times 10^{10}$	
1 kilowatt-hour = 3413	3.600 $\times 10^{13}$	2.655 $\times 10^6$	3.600 $\times 10^6$	8.600 $\times 10^5$	1	2.247 $\times 10^{25}$	2.247 $\times 10^{19}$	4.007 $\times 10^{-11}$	2.413 $\times 10^{16}$		
1 electron-volt = $\times 10^{-22}$	1.519 $\times 10^{-22}$	1.602 $\times 10^{-12}$	1.182 $\times 10^{-19}$	5.967 $\times 10^{-26}$	1.602 $\times 10^{-19}$	3.827 $\times 10^{-20}$	4.450 $\times 10^{-26}$	1	10 ⁻⁶	1.783 $\times 10^{-36}$	1.074 $\times 10^{-9}$
1 million electron-volts = $\times 10^{-16}$	1.519 $\times 10^{-16}$	1.602 $\times 10^{-6}$	1.182 $\times 10^{-13}$	5.967 $\times 10^{-20}$	1.602 $\times 10^{-13}$	3.827 $\times 10^{-14}$	4.450 $\times 10^{-20}$	10 ⁻⁶	1	1.783 $\times 10^{-30}$	1.074 $\times 10^{-3}$
1 kilogram = $\times 10^{13}$	8.521 $\times 10^{13}$	8.987	6.629 $\times 10^{16}$	3.348 $\times 10^{10}$	8.987 $\times 10^{16}$	2.146 $\times 10^{16}$	2.497 $\times 10^{10}$	5.610 $\times 10^{35}$	5.610 $\times 10^{29}$	1	6.022 $\times 10^{26}$
1 unified atomic mass unit = $\times 10^{-13}$	1.415 $\times 10^{-13}$	1.492 $\times 10^{-3}$	1.101 $\times 10^{-10}$	5.559 $\times 10^{-17}$	1.492 $\times 10^{-10}$	3.564 $\times 10^{-11}$	4.146 $\times 10^{-17}$	9.320 $\times 10^8$	932.0	1.661 $\times 10^{-27}$	1

Power

	Btu/h	ft · lb/s	hp	cal/s	kW	WATT
1 British thermal unit per hour = 1	0.2161		3.929×10^{-4}	6.998×10^{-2}	2.930×10^{-4}	0.2930
1 foot-pound per second = 4.628		1	1.818×10^{-3}	0.3239	1.356×10^{-3}	1.356
1 horsepower = 2545		550	1	178.1	0.7457	745.7
1 calorie per second = 14.29	3.088		5.615×10^{-3}	1	4.186×10^{-3}	4.186
1 kilowatt = 3413	737.6		1.341	238.9	1	1000
1 WATT = 3.413	0.7376		1.341×10^{-3}	0.2389	0.001	1

Magnetic Field

gauss	TESLA	milligauss
1 gauss = 1	10^{-4}	1000
1 TESLA = 10^4	1	10^7
1 milligauss = 0.001	10^{-7}	1

 1 tesla = 1 weber/meter²
Magnetic Flux

maxwell	WEBER
1 maxwell = 1	10^{-8}
1 WEBER = 10^8	1

MATHEMATICAL FORMULAS

Geometry

Circle of radius r : circumference = $2\pi r$; area = πr^2 .

Sphere of radius r : area = $4\pi r^2$; volume = $\frac{4}{3}\pi r^3$.

Right circular cylinder of radius r and height h :
area = $2\pi r^2 + 2\pi rh$; volume = $\pi r^2 h$.

Triangle of base a and altitude h : area = $\frac{1}{2}ah$.

\neq is not equal to

\equiv is identical to, is defined as

$>$ is greater than (\gg is much greater than)

$<$ is less than (\ll is much less than)

\geq is greater than or equal to (or, is no less than)

\leq is less than or equal to (or, is no more than)

\pm plus or minus

\propto is proportional to

Σ the sum of

x_{avg} the average value of x

Quadratic Formula

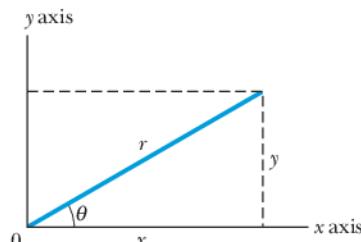
If $ax^2 + bx + c = 0$, then $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$.

Trigonometric Functions of Angle θ

$$\sin \theta = \frac{y}{r} \quad \cos \theta = \frac{x}{r}$$

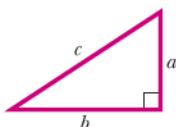
$$\tan \theta = \frac{y}{x} \quad \cot \theta = \frac{x}{y}$$

$$\sec \theta = \frac{r}{x} \quad \csc \theta = \frac{r}{y}$$



Pythagorean Theorem

In this right triangle,
 $a^2 + b^2 = c^2$



Triangles

Angles are A, B, C

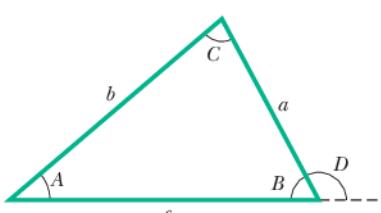
Opposite sides are a, b, c

Angles $A + B + C = 180^\circ$

$$\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}$$

$$c^2 = a^2 + b^2 - 2ab \cos C$$

Exterior angle $D = A + C$



Mathematical Signs and Symbols

$=$ equals

\approx equals approximately

\sim is the order of magnitude of

Trigonometric Identities

$$\sin(90^\circ - \theta) = \cos \theta$$

$$\cos(90^\circ - \theta) = \sin \theta$$

$$\sin \theta / \cos \theta = \tan \theta$$

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

$$\sec^2 \theta - \tan^2 \theta = 1$$

$$\csc^2 \theta - \cot^2 \theta = 1$$

$$\sin 2\theta = 2 \sin \theta \cos \theta$$

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

$$\sin(\alpha \pm \beta) = \sin \alpha \cos \beta \pm \cos \alpha \sin \beta$$

$$\cos(\alpha \pm \beta) = \cos \alpha \cos \beta \mp \sin \alpha \sin \beta$$

$$\tan(\alpha \pm \beta) = \frac{\tan \alpha \pm \tan \beta}{1 \mp \tan \alpha \tan \beta}$$

$$\sin \alpha \pm \sin \beta = 2 \sin \frac{1}{2}(\alpha \pm \beta) \cos \frac{1}{2}(\alpha \mp \beta)$$

$$\cos \alpha + \cos \beta = 2 \cos \frac{1}{2}(\alpha + \beta) \cos \frac{1}{2}(\alpha - \beta)$$

$$\cos \alpha - \cos \beta = -2 \sin \frac{1}{2}(\alpha + \beta) \sin \frac{1}{2}(\alpha - \beta)$$

Binomial Theorem

$$(1 + x)^n = 1 + \frac{nx}{1!} + \frac{n(n-1)x^2}{2!} + \dots \quad (x^2 < 1)$$

Exponential Expansion

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \dots$$

Logarithmic Expansion

$$\ln(1 + x) = x - \frac{1}{2}x^2 + \frac{1}{3}x^3 - \dots \quad (|x| < 1)$$

Trigonometric Expansions (θ in radians)

$$\sin \theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \dots$$

$$\cos \theta = 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - \dots$$

$$\tan \theta = \theta + \frac{\theta^3}{3} + \frac{2\theta^5}{15} + \dots$$

Cramer's Rule

Two simultaneous equations in unknowns x and y ,

$$a_1x + b_1y = c_1 \quad \text{and} \quad a_2x + b_2y = c_2,$$

have the solutions

$$x = \frac{\begin{vmatrix} c_1 & b_1 \\ c_2 & b_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}} = \frac{c_1b_2 - c_2b_1}{a_1b_2 - a_2b_1}$$

and

$$y = \frac{\begin{vmatrix} a_1 & c_1 \\ a_2 & c_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}} = \frac{a_1c_2 - a_2c_1}{a_1b_2 - a_2b_1}.$$

Products of Vectors

Let \hat{i} , \hat{j} , and \hat{k} be unit vectors in the x , y , and z directions. Then

$$\hat{i} \cdot \hat{i} = \hat{j} \cdot \hat{j} = \hat{k} \cdot \hat{k} = 1, \quad \hat{i} \cdot \hat{j} = \hat{j} \cdot \hat{k} = \hat{k} \cdot \hat{i} = 0,$$

$$\hat{i} \times \hat{i} = \hat{j} \times \hat{j} = \hat{k} \times \hat{k} = 0,$$

$$\hat{i} \times \hat{j} = \hat{k}, \quad \hat{j} \times \hat{k} = \hat{i}, \quad \hat{k} \times \hat{i} = \hat{j}$$

Any vector \vec{a} with components a_x , a_y , and a_z along the x , y , and z axes can be written as

$$\vec{a} = a_x \hat{i} + a_y \hat{j} + a_z \hat{k}.$$

Let \vec{a} , \vec{b} , and \vec{c} be arbitrary vectors with magnitudes a , b , and c . Then

$$\vec{a} \times (\vec{b} + \vec{c}) = (\vec{a} \times \vec{b}) + (\vec{a} \times \vec{c})$$

$$(s\vec{a}) \times \vec{b} = \vec{a} \times (s\vec{b}) = s(\vec{a} \times \vec{b}) \quad (s = \text{a scalar}).$$

Let θ be the smaller of the two angles between \vec{a} and \vec{b} . Then

$$\vec{a} \cdot \vec{b} = \vec{b} \cdot \vec{a} = a_x b_x + a_y b_y + a_z b_z = ab \cos \theta$$

$$\begin{aligned} \vec{a} \times \vec{b} &= -\vec{b} \times \vec{a} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix} \\ &= \hat{i} \begin{vmatrix} a_y & a_z \\ b_y & b_z \end{vmatrix} - \hat{j} \begin{vmatrix} a_x & a_z \\ b_x & b_z \end{vmatrix} + \hat{k} \begin{vmatrix} a_x & a_y \\ b_x & b_y \end{vmatrix} \\ &= (a_y b_z - b_y a_z) \hat{i} + (a_z b_x - b_z a_x) \hat{j} \\ &\quad + (a_x b_y - b_x a_y) \hat{k} \\ |\vec{a} \times \vec{b}| &= ab \sin \theta \end{aligned}$$

$$\vec{a} \cdot (\vec{b} \times \vec{c}) = \vec{b} \cdot (\vec{c} \times \vec{a}) = \vec{c} \cdot (\vec{a} \times \vec{b})$$

$$\vec{a} \times (\vec{b} \times \vec{c}) = (\vec{a} \cdot \vec{c})\vec{b} - (\vec{a} \cdot \vec{b})\vec{c}$$

Derivatives and Integrals

In what follows, the letters u and v stand for any functions of x , and a and m are constants. To each of the indefinite integrals should be added an arbitrary constant of integration. The *Handbook of Chemistry and Physics* (CRC Press Inc.) gives a more extensive tabulation.

1. $\frac{dx}{dx} = 1$
2. $\frac{d}{dx}(au) = a \frac{du}{dx}$
3. $\frac{d}{dx}(u + v) = \frac{du}{dx} + \frac{dv}{dx}$
4. $\frac{d}{dx}x^m = mx^{m-1}$
5. $\frac{d}{dx}\ln x = \frac{1}{x}$
6. $\frac{d}{dx}(uv) = u \frac{dv}{dx} + v \frac{du}{dx}$
7. $\frac{d}{dx}e^x = e^x$
8. $\frac{d}{dx}\sin x = \cos x$
9. $\frac{d}{dx}\cos x = -\sin x$
10. $\frac{d}{dx}\tan x = \sec^2 x$
11. $\frac{d}{dx}\cot x = -\csc^2 x$
12. $\frac{d}{dx}\sec x = \tan x \sec x$
13. $\frac{d}{dx}\csc x = -\cot x \csc x$
14. $\frac{d}{dx}e^u = e^u \frac{du}{dx}$
15. $\frac{d}{dx}\sin u = \cos u \frac{du}{dx}$
16. $\frac{d}{dx}\cos u = -\sin u \frac{du}{dx}$
1. $\int dx = x$
2. $\int au \, dx = a \int u \, dx$
3. $\int (u + v) \, dx = \int u \, dx + \int v \, dx$
4. $\int x^m \, dx = \frac{x^{m+1}}{m+1} \quad (m \neq -1)$
5. $\int \frac{dx}{x} = \ln|x|$
6. $\int u \frac{dv}{dx} \, dx = uv - \int v \frac{du}{dx} \, dx$
7. $\int e^x \, dx = e^x$
8. $\int \sin x \, dx = -\cos x$
9. $\int \cos x \, dx = \sin x$
10. $\int \tan x \, dx = \ln|\sec x|$
11. $\int \sin^2 x \, dx = \frac{1}{2}x - \frac{1}{4}\sin 2x$
12. $\int e^{-ax} \, dx = -\frac{1}{a}e^{-ax}$
13. $\int xe^{-ax} \, dx = -\frac{1}{a^2}(ax + 1)e^{-ax}$
14. $\int x^2 e^{-ax} \, dx = -\frac{1}{a^3}(a^2x^2 + 2ax + 2)e^{-ax}$
15. $\int_0^\infty x^n e^{-ax} \, dx = \frac{n!}{a^{n+1}}$
16. $\int_0^\infty x^{2n} e^{-ax^2} \, dx = \frac{1 \cdot 3 \cdot 5 \cdots (2n-1)}{2^{n+1}a^n} \sqrt{\frac{\pi}{a}}$
17. $\int \frac{dx}{\sqrt{x^2 + a^2}} = \ln(x + \sqrt{x^2 + a^2})$
18. $\int \frac{x \, dx}{(x^2 + a^2)^{3/2}} = -\frac{1}{(x^2 + a^2)^{1/2}}$
19. $\int \frac{dx}{(x^2 + a^2)^{3/2}} = \frac{x}{a^2(x^2 + a^2)^{1/2}}$
20. $\int_0^\infty x^{2n+1} e^{-ax^2} \, dx = \frac{n!}{2a^{n+1}} \quad (a > 0)$
21. $\int \frac{x \, dx}{x+d} = x - d \ln(x+d)$

A P P E N D I X F

PROPERTIES OF THE ELEMENTS

All physical properties are for a pressure of 1 atm unless otherwise specified.

Element	Symbol	Atomic Number Z	Molar Mass, g/mol	Density, g/cm ³ at 20°C	Melting Point, °C	Boiling Point, °C	Specific Heat, J/(g · °C) at 25°C
Actinium	Ac	89	(227)	10.06	1323	(3473)	0.092
Aluminum	Al	13	26.9815	2.699	660	2450	0.900
Americium	Am	95	(243)	13.67	1541	—	—
Antimony	Sb	51	121.75	6.691	630.5	1380	0.205
Argon	Ar	18	39.948	1.6626×10^{-3}	-189.4	-185.8	0.523
Arsenic	As	33	74.9216	5.78	817 (28 atm)	613	0.331
Astatine	At	85	(210)	—	(302)	—	—
Barium	Ba	56	137.34	3.594	729	1640	0.205
Berkelium	Bk	97	(247)	14.79	—	—	—
Beryllium	Be	4	9.0122	1.848	1287	2770	1.83
Bismuth	Bi	83	208.980	9.747	271.37	1560	0.122
Bohrium	Bh	107	262.12	—	—	—	—
Boron	B	5	10.811	2.34	2030	—	1.11
Bromine	Br	35	79.909	3.12 (liquid)	-7.2	58	0.293
Cadmium	Cd	48	112.40	8.65	321.03	765	0.226
Calcium	Ca	20	40.08	1.55	838	1440	0.624
Californium	Cf	98	(251)	—	—	—	—
Carbon	C	6	12.01115	2.26	3727	4830	0.691
Cerium	Ce	58	140.12	6.768	804	3470	0.188
Cesium	Cs	55	132.905	1.873	28.40	690	0.243
Chlorine	Cl	17	35.453	3.214×10^{-3} (0°C)	-101	-34.7	0.486
Chromium	Cr	24	51.996	7.19	1857	2665	0.448
Cobalt	Co	27	58.9332	8.85	1495	2900	0.423
Copernicium	Cn	112	(285)	—	—	—	—
Copper	Cu	29	63.54	8.96	1083.40	2595	0.385
Curium	Cm	96	(247)	13.3	—	—	—
Darmstadtium	Ds	110	(271)	—	—	—	—
Dubnium	Db	105	262.114	—	—	—	—
Dysprosium	Dy	66	162.50	8.55	1409	2330	0.172
Einsteinium	Es	99	(254)	—	—	—	—
Erbium	Er	68	167.26	9.15	1522	2630	0.167
Europium	Eu	63	151.96	5.243	817	1490	0.163
Fermium	Fm	100	(237)	—	—	—	—
Flerovium*	Fl	114	(289)	—	—	—	—
Fluorine	F	9	18.9984	1.696×10^{-3} (0°C)	-219.6	-188.2	0.753
Francium	Fr	87	(223)	—	(27)	—	—
Gadolinium	Gd	64	157.25	7.90	1312	2730	0.234
Gallium	Ga	31	69.72	5.907	29.75	2237	0.377
Germanium	Ge	32	72.59	5.323	937.25	2830	0.322
Gold	Au	79	196.967	19.32	1064.43	2970	0.131

Element	Symbol	Atomic Number Z	Molar Mass, g/mol	Density, g/cm ³ at 20°C	Melting Point, °C	Boiling Point, °C	Specific Heat, J/(g·°C) at 25°C
Hafnium	Hf	72	178.49	13.31	2227	5400	0.144
Hassium	Hs	108	(265)	—	—	—	—
Helium	He	2	4.0026	0.1664×10^{-3}	-269.7	-268.9	5.23
Holmium	Ho	67	164.930	8.79	1470	2330	0.165
Hydrogen	H	1	1.00797	0.08375×10^{-3}	-259.19	-252.7	14.4
Indium	In	49	114.82	7.31	156.634	2000	0.233
Iodine	I	53	126.9044	4.93	113.7	183	0.218
Iridium	Ir	77	192.2	22.5	2447	(5300)	0.130
Iron	Fe	26	55.847	7.874	1536.5	3000	0.447
Krypton	Kr	36	83.80	3.488×10^{-3}	-157.37	-152	0.247
Lanthanum	La	57	138.91	6.189	920	3470	0.195
Lawrencium	Lr	103	(257)	—	—	—	—
Lead	Pb	82	207.19	11.35	327.45	1725	0.129
Lithium	Li	3	6.939	0.534	180.55	1300	3.58
Livermorium*	Lv	116	(293)	—	—	—	—
Lutetium	Lu	71	174.97	9.849	1663	1930	0.155
Magnesium	Mg	12	24.312	1.738	650	1107	1.03
Manganese	Mn	25	54.9380	7.44	1244	2150	0.481
Meitnerium	Mt	109	(266)	—	—	—	—
Mendelevium	Md	101	(256)	—	—	—	—
Mercury	Hg	80	200.59	13.55	-38.87	357	0.138
Molybdenum	Mo	42	95.94	10.22	2617	5560	0.251
Neodymium	Nd	60	144.24	7.007	1016	3180	0.188
Neon	Ne	10	20.183	0.8387×10^{-3}	-248.597	-246.0	1.03
Neptunium	Np	93	(237)	20.25	637	—	1.26
Nickel	Ni	28	58.71	8.902	1453	2730	0.444
Niobium	Nb	41	92.906	8.57	2468	4927	0.264
Nitrogen	N	7	14.0067	1.1649×10^{-3}	-210	-195.8	1.03
Nobelium	No	102	(255)	—	—	—	—
Osmium	Os	76	190.2	22.59	3027	5500	0.130
Oxygen	O	8	15.9994	1.3318×10^{-3}	-218.80	-183.0	0.913
Palladium	Pd	46	106.4	12.02	1552	3980	0.243
Phosphorus	P	15	30.9738	1.83	44.25	280	0.741
Platinum	Pt	78	195.09	21.45	1769	4530	0.134
Plutonium	Pu	94	(244)	19.8	640	3235	0.130
Polonium	Po	84	(210)	9.32	254	—	—
Potassium	K	19	39.102	0.862	63.20	760	0.758
Praseodymium	Pr	59	140.907	6.773	931	3020	0.197
Promethium	Pm	61	(145)	7.22	(1027)	—	—
Protactinium	Pa	91	(231)	15.37 (estimated)	(1230)	—	—
Radium	Ra	88	(226)	5.0	700	—	—
Radon	Rn	86	(222)	9.96×10^{-3} (0°C)	(-71)	-61.8	0.092
Rhenium	Re	75	186.2	21.02	3180	5900	0.134
Rhodium	Rh	45	102.905	12.41	1963	4500	0.243
Roentgenium	Rg	111	(280)	—	—	—	—
Rubidium	Rb	37	85.47	1.532	39.49	688	0.364
Ruthenium	Ru	44	101.107	12.37	2250	4900	0.239
Rutherfordium	Rf	104	261.11	—	—	—	—

Element	Symbol	Atomic Number <i>Z</i>	Molar Mass, g/mol	Density, g/cm ³ at 20°C	Melting Point, °C	Boiling Point, °C	Specific Heat, J/(g·°C) at 25°C
Samarium	Sm	62	150.35	7.52	1072	1630	0.197
Scandium	Sc	21	44.956	2.99	1539	2730	0.569
Seaborgium	Sg	106	263.118	—	—	—	—
Selenium	Se	34	78.96	4.79	221	685	0.318
Silicon	Si	14	28.086	2.33	1412	2680	0.712
Silver	Ag	47	107.870	10.49	960.8	2210	0.234
Sodium	Na	11	22.9898	0.9712	97.85	892	1.23
Strontium	Sr	38	87.62	2.54	768	1380	0.737
Sulfur	S	16	32.064	2.07	119.0	444.6	0.707
Tantalum	Ta	73	180.948	16.6	3014	5425	0.138
Technetium	Tc	43	(99)	11.46	2200	—	0.209
Tellurium	Te	52	127.60	6.24	449.5	990	0.201
Terbium	Tb	65	158.924	8.229	1357	2530	0.180
Thallium	Tl	81	204.37	11.85	304	1457	0.130
Thorium	Th	90	(232)	11.72	1755	(3850)	0.117
Thulium	Tm	69	168.934	9.32	1545	1720	0.159
Tin	Sn	50	118.69	7.2984	231.868	2270	0.226
Titanium	Ti	22	47.90	4.54	1670	3260	0.523
Tungsten	W	74	183.85	19.3	3380	5930	0.134
Unnamed	Uut	113	(284)	—	—	—	—
Unnamed	Uup	115	(288)	—	—	—	—
Unnamed	Uus	117	—	—	—	—	—
Unnamed	Uuo	118	(294)	—	—	—	—
Uranium	U	92	(238)	18.95	1132	3818	0.117
Vanadium	V	23	50.942	6.11	1902	3400	0.490
Xenon	Xe	54	131.30	5.495 × 10 ⁻³	-111.79	-108	0.159
Ytterbium	Yb	70	173.04	6.965	824	1530	0.155
Yttrium	Y	39	88.905	4.469	1526	3030	0.297
Zinc	Zn	30	65.37	7.133	419.58	906	0.389
Zirconium	Zr	40	91.22	6.506	1852	3580	0.276

The values in parentheses in the column of molar masses are the mass numbers of the longest-lived isotopes of those elements that are radioactive. Melting points and boiling points in parentheses are uncertain.

The data for gases are valid only when these are in their usual molecular state, such as H₂, He, O₂, Ne, etc. The specific heats of the gases are the values at constant pressure.

Source: Adapted from J. Emsley, *The Elements*, 3rd ed., 1998, Clarendon Press, Oxford. See also www.webelements.com for the latest values and newest elements.

*The names and symbols for elements 114 (Flerovium, Fl) and 116 (Livermorium, Lv) have been suggested but are not official.

A P P E N D I X G

PERIODIC TABLE OF THE ELEMENTS

THE HORIZONTAL PERIODS																																				
		Transition metals																																		
		VIIIB							IB		IIB																									
1	Alkali metals IA		1	H	2	Li	3	Be	4	Na	5	B	6	C	7	N	8	O	2	He																
2	IIA																		10	Ne																
3	11	Mg	Metals																	Noble gases 0																
4	19	K	20	Ca	21	Sc	22	Ti	23	V	24	Cr	25	Mn	26	Fe	27	Co	28	Ni	31	Al	13	Si	14	P	15	S	16	Cl	17	Ar				
5	37	Rb	38	Sr	39	Y	40	Zr	41	Nb	42	Mo	43	Tc	44	Ru	45	Rh	46	Pd	47	Ag	48	Cd	49	In	50	Sn	51	Sb	52	Te	53	I	54	Xe
6	55	Cs	56	Ba	57-71*	Hf	72	Ta	73	W	74	Re	75	Os	76	Ir	77	Pt	78	Au	79	Hg	80	Tl	81	Pb	82	Bi	83	Po	84	At	85	Rn	86	
7	87	Fr	88	Ra	89-103†	Rf	104	Db	105	Sg	106	Bh	107	Hs	108	Mt	109	Ds	110	Rg	111	Cn	112	113	114	Fl	115	116	Lv	117	118					
Inner transition metals																																				
Lanthanide series *																																				
Actinide series †																																				
57	La	58	Ce	59	Pr	60	Nd	61	Pm	62	Sm	63	Eu	64	Gd	65	Tb	66	Dy	67	Ho	68	Er	69	Tm	70	Yb	71	Lu							
89	Ac	90	Th	91	Pa	92	U	93	Np	94	Pu	95	Am	96	Cm	97	Bk	98	Cf	99	Es	100	Fm	101	Md	102	No	103	Lr							

Evidence for the discovery of elements 113 through 118 has been reported. See www.webelements.com for the latest information and newest elements. The names and symbols for elements 114 and 116 have been suggested but are not official.

This page intentionally left blank

A N S W E R S

To Checkpoints and Odd-Numbered Questions and Problems

Chapter 1

- P** **1.** (a) 4.00×10^4 km; (b) 5.10×10^8 km²; (c) 1.08×10^{12} km³
3. (a) 10^9 μm ; (b) 10^{-4} ; (c) 9.1×10^5 μm **5.** (a) 160 rods; (b) 40 chains **7.** 1.1×10^3 acre-feet **9.** 1.9×10^{22} cm³ **11.** (a) 1.43; (b) 0.864 **13.** (a) 495 s; (b) 141 s; (c) 198 s; (d) -245 s **15.** 1.21×10^{12} μs **17.** C, D, A, B, E; the important criterion is the consistency of the daily variation, not its magnitude **19.** 5.2×10^6 m **21.** 9.0×10^{49} atoms **23.** (a) 1×10^3 kg; (b) 158 kg/s **25.** 1.9×10^5 kg **27.** (a) 1.18×10^{-29} m³; (b) 0.282 nm **29.** 1.75×10^3 kg **31.** 1.43 kg/min **33.** (a) 293 U.S. bushels; (b) 3.81×10^3 U.S. bushels **35.** (a) 22 pecks; (b) 5.5 Imperial bushels; (c) 200 L **37.** 8×10^2 km **39.** (a) 18.8 gallons; (b) 22.5 gallons **41.** 0.3 cord **43.** 3.8 mg/s **45.** (a) yes; (b) 8.6 universe seconds **47.** 0.12 AU/min **49.** (a) 3.88; (b) 7.65; (c) 156 ken³; (d) 1.19×10^3 m³ **51.** (a) 3.9 m, 4.8 m; (b) 3.9×10^3 mm, 4.8×10^3 mm; (c) 2.2 m^3 , 4.2 m^3 **53.** (a) 4.9×10^{-6} pc; (b) 1.6×10^{-5} ly **55.** (a) 3 nebuchadnezzars, 1 methuselah; (b) 0.37 standard bottle; (c) 0.26 L **57.** 10.7 habaneros **59.** 700 to 1500 oysters

Chapter 2

- CP** **1.** b and c **2.** (check the derivative dx/dt) (a) 1 and 4; (b) 2 and 3 **3.** (a) plus; (b) minus; (c) minus; (d) plus **4.** 1 and 4 ($a = d^2x/dt^2$ must be constant) **5.** (a) plus (upward displacement on y axis); (b) minus (downward displacement on y axis); (c) $a = -g = -9.8 \text{ m/s}^2$ **Q** **1.** (a) negative; (b) positive; (c) yes; (d) positive; (e) constant **3.** (a) all tie; (b) 4, tie of 1 and 2, then 3 **5.** (a) positive direction; (b) negative direction; (c) 3 and 5; (d) 2 and 6 tie, then 3 and 5 tie, then 1 and 4 tie (zero) **7.** (a) D; (b) E **9.** (a) 3, 2, 1; (b) 1, 2, 3; (c) all tie; (d) 1, 2, 3 **11.** 1 and 2 tie, then 3 **P** **1.** 13 m **3.** (a) +40 km/h; (b) 40 km/h **5.** (a) 0; (b) -2 m; (c) 0; (d) 12 m; (e) +12 m; (f) +7 m/s **7.** 60 km **9.** 1.4 m **11.** 128 km/h **13.** (a) 73 km/h; (b) 68 km/h; (c) 70 km/h; (d) 0 **15.** (a) -6 m/s; (b) -x direction; (c) 6 m/s; (d) decreasing; (e) 2 s; (f) no **17.** (a) 28.5 cm/s; (b) 18.0 cm/s; (c) 40.5 cm/s; (d) 28.1 cm/s; (e) 30.3 cm/s **19.** -20 m/s^2 **21.** (a) 1.10 m/s; (b) 6.11 mm/s²; (c) 1.47 m/s; (d) 6.11 mm/s² **23.** 1.62×10^{15} m/s² **25.** (a) 30 s; (b) 300 m **27.** (a) +1.6 m/s; (b) +18 m/s **29.** (a) 10.6 m; (b) 41.5 s **31.** (a) 3.1×10^6 s; (b) 4.6×10^{13} m **33.** (a) 3.56 m/s²; (b) 8.43 m/s **35.** 0.90 m/s² **37.** (a) 4.0 m/s²; (b) +x **39.** (a) -2.5 m/s^2 ; (b) 1; (d) 0; (e) 2 **41.** 40 m **43.** (a) 0.994 m/s^2 **45.** (a) 31 m/s; (b) 6.4 s **47.** (a) 29.4 m; (b) 2.45 s **49.** (a) 5.4 s; (b) 41 m/s **51.** (a) 20 m; (b) 59 m **53.** 4.0 m/s **55.** (a) 857 m/s^2 ; (b) up **57.** (a) 1.26×10^3 m/s²; (b) up **59.** (a) 89 cm; (b) 22 cm **61.** 20.4 m **63.** 2.34 m **65.** (a) 2.25 m/s; (b) 3.90 m/s **67.** 0.56 m/s **69.** 100 m **71.** (a) 2.00 s; (b) 12 cm; (c) -9.00 cm/s^2 ; (d) right; (e) left; (f) 3.46 s **73.** (a) 82 m; (b) 19 m/s **75.** (a) 0.74 s; (b) 6.2 m/s^2 **77.** (a) 3.1 m/s^2 ; (b) 45 m; (c) 13 s **79.** 17 m/s **81.** +47 m/s **83.** (a) 1.23 cm; (b) 4 times; (c) 9 times; (d) 16 times; (e) 25 times **85.** 25 km/h **87.** 1.2 h **89.** 4H **91.** (a) 3.2 s; (b) 1.3 s **93.** (a) 8.85 m/s; (b) 1.00 m **95.** (a) 2.0 m/s^2 ; (b) 12 m/s; (c) 45 m **97.** (a) 48.5 m/s; (b) 4.95 s; (c) 34.3 m/s; (d) 3.50 s **99.** 22.0 m/s **101.** (a) $v = (v_0^2 + 2gh)^{0.5}$; (b) $t = [(v_0^2 + 2gh)^{0.5} - v_0]/g$; (c) same as (a); (d) $t = [(v_0^2 + 2gh)^{0.5} + v_0]/g$, greater **103.** 414 ms **105.** 90 m **107.** 0.556 s **109.** (a) 0.28 m/s^2 ; (b) 0.28 m/s^2 **111.** (a) 10.2 s;

- (b) 10.0 m **113.** (a) 5.44 s; (b) 53.3 m/s; (c) 5.80 m **115.** 2.3 cm/min **117.** 0.15 m/s **119.** (a) 1.0 cm/s; (b) 1.6 cm/s, 1.1 cm/s, 0; (c) -0.79 cm/s^2 ; (d) 0, -0.87 cm/s^2 , -1.2 cm/s^2

Chapter 3

- CP** **1.** (a) 7 m (\vec{a} and \vec{b} are in same direction); (b) 1 m (\vec{a} and \vec{b} are in opposite directions) **2.** c, d, f (components must be head to tail; \vec{a} must extend from tail of one component to head of the other) **3.** (a) +, +; (b) +, -; (c) +, + (draw vector from tail of \vec{d}_1 to head of \vec{d}_2) **4.** (a) 90° ; (b) 0° (vectors are parallel—same direction); (c) 180° (vectors are antiparallel—opposite directions) **5.** (a) 0° or 180° ; (b) 90°

- Q** **1.** yes, when the vectors are in same direction **3.** Either the sequence \vec{d}_2, \vec{d}_1 or the sequence $\vec{d}_2, \vec{d}_2, \vec{d}_3$ **5.** all but (e) **7.** (a) yes; (b) yes; (c) no **9.** (a) +x for (1), +z for (2), +z for (3); (b) -x for (1), -z for (2), -z for (3) **11.** $\vec{s}, \vec{p}, \vec{r}$ or $\vec{p}, \vec{s}, \vec{r}$ **13.** Correct: c, d, f, h. Incorrect: a (cannot dot a vector with a scalar), b (cannot cross a vector with a scalar), e, g, i, j (cannot add a scalar and a vector).

- P** **1.** (a) -2.5 m; (b) -6.9 m **3.** (a) 47.2 m; (b) 122° **5.** (a) 156 km; (b) 39.8° west of due north **7.** (a) parallel; (b) antiparallel; (c) perpendicular **9.** (a) $(3.0 \text{ m})\hat{i} - (2.0 \text{ m})\hat{j} + (5.0 \text{ m})\hat{k}$; (b) $(5.0 \text{ m})\hat{i} - (4.0 \text{ m})\hat{j} - (3.0 \text{ m})\hat{k}$; (c) $(-5.0 \text{ m})\hat{i} + (4.0 \text{ m})\hat{j} + (3.0 \text{ m})\hat{k}$ **11.** (a) $(-9.0 \text{ m})\hat{i} + (10 \text{ m})\hat{j}$; (b) 13 m; (c) 132° **13.** 4.74 km **15.** (a) 1.59 m; (b) 12.1 m; (c) 12.2 m; (d) 82.5° **17.** (a) 38 m; (b) -37.5° ; (c) 130 m; (d) 1.2° ; (e) 62 m; (f) 130° **19.** 5.39 m at 21.8° left of forward **21.** (a) -70.0 cm; (b) 80.0 cm; (c) 141 cm; (d) -172° **23.** 3.2 **25.** 2.6 km **27.** (a) $8\hat{i} + 16\hat{j}$; (b) $2\hat{i} + 4\hat{j}$ **29.** (a) 7.5 cm; (b) 90° ; (c) 8.6 cm; (d) 48° **31.** (a) 9.51 m; (b) 14.1 m; (c) 13.4 m; (d) 10.5 m **33.** (a) 12; (b) +z; (c) 12; (d) -z; (e) 12; (f) +z **35.** (a) -18.8 units; (b) 26.9 units, +z direction **37.** (a) -21; (b) -9; (c) $5\hat{i} - 11\hat{j} - 9\hat{k}$ **39.** 70.5° **41.** 22° **43.** (a) 3.00 m; (b) 0; (c) 3.46 m; (d) 2.00 m; (e) -5.00 m; (f) 8.66 m; (g) -6.67; (h) 4.33 **45.** (a) -83.4; (b) $(1.14 \times 10^3)\hat{k}$; (c) 1.14×10^3 , θ not defined, $\phi = 0^\circ$; (d) 90.0° ; (e) $-5.14\hat{i} + 6.13\hat{j} + 3.00\hat{k}$; (f) 8.54, $\theta = 130^\circ$, $\phi = 69.4^\circ$ **47.** (a) 140° ; (b) 90.0° ; (c) 99.1° **49.** (a) 103 km; (b) 60.9° north of due west **51.** (a) 27.8 m; (b) 13.4 m **53.** (a) 30; (b) 52 **55.** (a) -2.83 m; (b) -2.83 m; (c) 5.00 m; (d) 0; (e) 3.00 m; (f) 5.20 m; (g) 5.17 m; (h) 2.37 m; (i) 5.69 m; (j) 25° north of due east; (k) 5.69 m; (l) 25° south of due west **57.** 4.1 **59.** (a) $(9.19 \text{ m})\hat{i} + (7.71 \text{ m})\hat{j}'$; (b) $(14.0 \text{ m})\hat{i}' + (3.41 \text{ m})\hat{j}'$ **61.** (a) $11\hat{i} + 5.0\hat{j} - 7.0\hat{k}$; (b) 120° ; (c) -4.9; (d) 7.3 **63.** (a) 3.0 m^2 ; (b) 52 m^3 ; (c) $(11 \text{ m}^2)\hat{i} + (9.0 \text{ m}^2)\hat{j} + (3.0 \text{ m}^2)\hat{k}$ **65.** (a) $(-40\hat{i} - 20\hat{j} + 25\hat{k})$ m; (b) 45 m **67.** (a) 0; (b) 0; (c) -1; (d) west; (e) up; (f) west **69.** (a) 168 cm; (b) 32.5° **71.** (a) 15 m; (b) south; (c) 6.0 m; (d) north **73.** (a) 2k; (b) 26; (c) 46; (d) 5.81 **75.** (a) up; (b) 0; (c) south; (d) 1; (e) 0 **77.** (a) $(1300 \text{ m})\hat{i} + (2200 \text{ m})\hat{j} - (410 \text{ m})\hat{k}$; (b) 2.56×10^3 m **79.** 8.4

Chapter 4

- CP** **1.** (draw \vec{v} tangent to path, tail on path) (a) first; (b) third **2.** (take second derivative with respect to time) (1) and (3) a_x and a_y are both constant and thus \vec{a} is constant; (2) and (4) a_y is constant but a_x is not, thus \vec{a} is not **3.** yes **4.** (a) v_x constant; (b) v_y initially positive, decreases to zero, and then becomes progressively more negative; (c) $a_x = 0$ throughout; (d) $a_y = -g$ throughout **5.** (a) $-(4 \text{ m/s})\hat{i}$; (b) $-(8 \text{ m/s}^2)\hat{j}$

Q **1.** *a* and *c* tie, then *b* **3.** decreases **5.** *a,b,c* **7.** (a) 0; (b) 350 km/h; (c) 350 km/h; (d) same (nothing changed about the vertical motion) **9.** (a) all tie; (b) all tie; (c) 3, 2, 1; (d) 3, 2, 1 **11.** 2, then 1 and 4 tie, then 3 **13.** (a) yes; (b) no; (c) yes **15.** (a) decreases; (b) increases **17.** maximum height

P **1.** (a) 6.2 m **3.** $(-2.0 \text{ m})\hat{i} + (6.0 \text{ m})\hat{j} - (10 \text{ m})\hat{k}$ **5.** (a) 7.59 km/h; (b) 22.5° east of due north **7.** $(-0.70 \text{ m/s})\hat{i} + (1.4 \text{ m/s})\hat{j} - (0.40 \text{ m/s})\hat{k}$ **9.** (a) 0.83 cm/s; (b) 0°; (c) 0.11 m/s; (d) -63° **11.** (a) $(6.00 \text{ m})\hat{i} - (106 \text{ m})\hat{j}$; (b) $(19.0 \text{ m/s})\hat{i} - (224 \text{ m/s})\hat{j}$; (c) $(24.0 \text{ m/s}^2)\hat{i} - (336 \text{ m/s}^2)\hat{j}$; (d) -85.2° **13.** (a) $(8 \text{ m/s}^2)\hat{i} + (1 \text{ m/s})\hat{k}$; (b) $(8 \text{ m/s}^2)\hat{j}$ **15.** (a) $(-1.50 \text{ m/s})\hat{j}$; (b) $(4.50 \text{ m})\hat{i} - (2.25 \text{ m})\hat{j}$ **17.** $(32 \text{ m/s})\hat{i}$ **19.** (a) $(72.0 \text{ m})\hat{i} + (90.7 \text{ m})\hat{j}$; (b) 49.5° **21.** (a) 18 cm; (b) 1.9 m **23.** (a) 3.03 s; (b) 758 m; (c) 29.7 m/s **25.** 43.1 m/s (155 km/h) **27.** (a) 10.0 s; (b) 897 m **29.** 78.5° **31.** 3.35 m **33.** (a) 202 m/s; (b) 806 m; (c) 161 m/s; (d) -171 m/s **35.** 4.84 cm **37.** (a) 1.60 m; (b) 6.86 m; (c) 2.86 m **39.** (a) 32.3 m; (b) 21.9 m/s; (c) 40.4°; (d) below **41.** 55.5° **43.** (a) 11 m; (b) 23 m; (c) 17 m/s; (d) 63° **45.** (a) ramp; (b) 5.82 m; (c) 31.0° **47.** (a) yes; (b) 2.56 m **49.** (a) 31°; (b) 63° **51.** (a) 2.3°; (b) 1.1 m; (c) 18° **53.** (a) 75.0 m; (b) 31.9 m/s; (c) 66.9°; (d) 25.5 m **55.** the third **57.** (a) 7.32 m; (b) west; (c) north **59.** (a) 12 s; (b) 4.1 m/s²; (c) down; (d) 4.1 m/s²; (e) up **61.** (a) $1.3 \times 10^5 \text{ m/s}$; (b) $7.9 \times 10^5 \text{ m/s}^2$; (c) increase **63.** 2.92 m **65.** $(3.00 \text{ m/s}^2)\hat{i} + (6.00 \text{ m/s}^2)\hat{j}$ **67.** 160 m/s² **69.** (a) 13 m/s²; (b) eastward; (c) 13 m/s²; (d) eastward **71.** 1.67 **73.** (a) $(80 \text{ km/h})\hat{i} - (60 \text{ km/h})\hat{j}$; (b) 0°; (c) answers do not change **75.** 32 m/s **77.** 60° **79.** (a) 38 knots; (b) 1.5° east of due north; (c) 4.2 h; (d) 1.5° west of due south **81.** (a) $(-32 \text{ km/h})\hat{i} - (46 \text{ km/h})\hat{j}$; (b) $[(2.5 \text{ km}) - (32 \text{ km/h})t]\hat{i} + [(4.0 \text{ km}) - (46 \text{ km/h})t]\hat{j}$; (c) 0.084 h; (d) $2 \times 10^2 \text{ m}$ **83.** (a) -30°; (b) 69 min; (c) 80 min; (d) 80 min; (e) 0°; (f) 60 min **85.** (a) 2.7 km; (b) 76° clockwise **87.** (a) 44 m; (b) 13 m; (c) 8.9 m **89.** (a) 45 m; (b) 22 m/s **91.** (a) $2.6 \times 10^2 \text{ m/s}$; (b) 45 s; (c) increase **93.** (a) 63 km; (b) 18° south of due east; (c) 0.70 km/h; (d) 18° south of due east; (e) 1.6 km/h; (f) 1.2 km/h; (g) 33° north of due east **95.** (a) 1.5; (b) (36 m, 54 m) **97.** (a) 62 ms; (b) $4.8 \times 10^2 \text{ m/s}$ **99.** 2.64 m **101.** (a) 2.5 m; (b) 0.82 m; (c) 9.8 m/s^2 ; (d) 9.8 m/s^2 **103.** (a) 6.79 km/h; (b) 6.96° **105.** (a) 16 m/s; (b) 23°; (c) above; (d) 27 m/s; (e) 57°; (f) below **107.** (a) 4.2 m, 45°; (b) 5.5 m, 68°; (c) 6.0 m, 90°; (d) 4.2 m, 135°; (e) 0.85 m/s, 135°; (f) 0.94 m/s, 90°; (g) 0.94 m/s, 180°; (h) 0.30 m/s², 180°; (i) 0.30 m/s², 270° **109.** (a) $5.4 \times 10^{-13} \text{ m}$; (b) decrease **111.** (a) 0.034 m/s^2 ; (b) 84 min **113.** (a) 8.43 m; (b) -129° **115.** (a) 2.00 ns; (b) 2.00 mm; (c) $1.00 \times 10^7 \text{ m/s}$; (d) $2.00 \times 10^6 \text{ m/s}$ **117.** (a) 24 m/s; (b) 65° **119.** 93° from the car's direction of motion **121.** (a) $4.6 \times 10^{12} \text{ m}$; (b) $2.4 \times 10^5 \text{ s}$ **123.** (a) 6.29°; (b) 83.7° **125.** (a) $3 \times 10^1 \text{ m}$ **127.** (a) $(6.0\hat{i} + 4.2\hat{j}) \text{ m/s}$; (b) $(18\hat{i} + 6.3\hat{j}) \text{ m}$ **129.** (a) 38 ft/s; (b) 32 ft/s; (c) 9.3 ft **131.** (a) 11 m; (b) 45 m/s **133.** (a) 5.8 m/s; (b) 17 m; (c) 67° **135.** (a) 32.4 m; (b) -37.7 m **137.** 88.6 km/h

Chapter 5

CP **1.** *c,d*, and *e* (\vec{F}_1 and \vec{F}_2 must be head to tail, \vec{F}_{net} must be from tail of one of them to head of the other) **2.** (a) and (b) 2 N, leftward (acceleration is zero in each situation) **3.** (a) equal; (b) greater (acceleration is upward, thus net force on body must be upward) **4.** (a) equal; (b) greater; (c) less **5.** (a) increase; (b) yes; (c) same; (d) yes

Q **1.** (a) 2, 3, 4; (b) 1, 3, 4; (c) 1, +*y*; 2, +*x*; 3, fourth quadrant; 4, third quadrant **3.** increase **5.** (a) 2 and 4; (b) 2 and 4 **7.** (a) *M*; (b) *M*; (c) *M*; (d) *2M*; (e) *3M* **9.** (a) 20 kg; (b) 18 kg; (c) 10 kg; (d) all tie; (e) 3, 2, 1 **11.** (a) increases from initial value *mg*; (b) decreases from *mg* to zero (after which the block moves up away from the floor)

P **1.** 2.9 m/s^2 **3.** (a) 1.88 N; (b) 0.684 N; (c) $(1.88 \text{ N})\hat{i} + (0.684 \text{ N})\hat{j}$ **5.** (a) $(0.86 \text{ m/s}^2)\hat{i} - (0.16 \text{ m/s}^2)\hat{j}$; (b) 0.88 m/s²; (c) -11° **7.** (a)

$(-32.0 \text{ N})\hat{i} - (20.8 \text{ N})\hat{j}$; (b) 38.2 N; (c) -147° **9.** (a) 8.37 N; (b) -133°; (c) -125° **11.** 9.0 m/s^2 **13.** (a) 4.0 kg; (b) 1.0 kg; (c) 4.0 kg; (d) 1.0 kg **15.** (a) 108 N; (b) 108 N; (c) 108 N **17.** (a) 42 N; (b) 72 N; (c) 4.9 m/s^2 **19.** $1.2 \times 10^5 \text{ N}$ **21.** (a) 11.7 N; (b) -59.0° **23.** (a) $(285 \text{ N})\hat{i} + (705 \text{ N})\hat{j}$; (b) $(285 \text{ N})\hat{i} - (115 \text{ N})\hat{j}$; (c) 307 N; (d) -22.0°; (e) 3.67 m/s^2 ; (f) -22.0° **25.** (a) 0.022 m/s^2 ; (b) $8.3 \times 10^4 \text{ km}$; (c) $1.9 \times 10^3 \text{ m/s}$ **27.** 1.5 mm **29.** (a) 494 N; (b) up; (c) 494 N; (d) down **31.** (a) 1.18 m; (b) 0.674 s; (c) 3.50 m/s **33.** $1.8 \times 10^4 \text{ N}$ **35.** (a) 46.7°; (b) 28.0° **37.** (a) 0.62 m/s^2 ; (b) 0.13 m/s^2 ; (c) 2.6 m **39.** (a) $2.2 \times 10^{-3} \text{ N}$; (b) $3.7 \times 10^{-3} \text{ N}$ **41.** (a) 1.4 m/s^2 ; (b) 4.1 m/s **43.** (a) 1.23 N; (b) 2.46 N; (c) 3.69 N; (d) 4.92 N; (e) 6.15 N; (f) 0.250 N **45.** (a) 31.3 kN; (b) 24.3 kN **47.** $6.4 \times 10^3 \text{ N}$ **49.** (a) 2.18 m/s^2 ; (b) 116 N; (c) 21.0 m/s^2 **51.** (a) 3.6 m/s^2 ; (b) 17 N **53.** (a) 0.970 m/s^2 ; (b) 11.6 N; (c) 34.9 N **55.** (a) 1.1 N **57.** (a) 0.735 m/s²; (b) down; (c) 20.8 N **59.** (a) 4.9 m/s^2 ; (b) 2.0 m/s^2 ; (c) up; (d) 120 N **61.** $2Ma/(a + g)$ **63.** (a) 8.0 m/s; (b) $+x$ **65.** (a) 0.653 m/s^3 ; (b) 0.896 m/s³; (c) 6.50 s **67.** 81.7 N **69.** 2.4 N **71.** 16 N **73.** (a) 2.6 N; (b) 17° **75.** (a) 0; (b) 0.83 m/s^2 ; (c) 0 **77.** (a) 0.74 m/s²; (b) 7.3 m/s^2 **79.** (a) 11 N; (b) 2.2 kg; (c) 0; (d) 2.2 kg **81.** 195 N **83.** (a) 4.6 m/s^2 ; (b) 2.6 m/s^2 **85.** (a) rope breaks; (b) 1.6 m/s^2 **87.** (a) 65 N; (b) 49 N **89.** (a) $4.6 \times 10^3 \text{ N}$; (b) $5.8 \times 10^3 \text{ N}$ **91.** (a) $1.8 \times 10^2 \text{ N}$; (b) $6.4 \times 10^2 \text{ N}$ **93.** (a) 44 N; (b) 78 N; (c) 54 N; (d) 152 N **95.** (a) 4 kg; (b) 6.5 m/s^2 ; (c) 13 N **97.** (a) $(1.0\hat{i} - 2.0\hat{j}) \text{ N}$; (b) 2.2 N; (c) -63°; (d) 2.2 m/s^2 ; (e) -63°

Chapter 6

CP **1.** (a) zero (because there is no attempt at sliding); (b) 5 N; (c) no; (d) yes; (e) 8 N **2.** (\vec{a} is directed toward center of circular path) (a) \vec{a} downward, \vec{F}_N upward; (b) \vec{a} and \vec{F}_N upward; (c) same; (d) greater at lowest point

Q **1.** (a) decrease; (b) decrease; (c) increase; (d) increase; (e) increase **3.** (a) same; (b) increases; (c) increases; (d) no **5.** (a) upward; (b) horizontal, toward you; (c) no change; (d) increases; (e) increases **7.** At first, \vec{f}_s is directed up the ramp and its magnitude increases from $mg \sin \theta$ until it reaches $f_{s,\max}$. Thereafter the force is kinetic friction directed up the ramp, with magnitude f_k (a constant value smaller than $f_{s,\max}$). **9.** 4, 3, then 1, 2, and 5 tie **11.** (a) all tie; (b) all tie; (c) 2, 3, 1 **13.** (a) increases; (b) increases; (c) decreases; (d) decreases; (e) decreases

P **1.** 36 m **3.** (a) $2.0 \times 10^2 \text{ N}$; (b) $1.2 \times 10^2 \text{ N}$ **5.** (a) 6.0 N; (b) 3.6 N; (c) 3.1 N **7.** (a) $1.9 \times 10^2 \text{ N}$; (b) 0.56 m/s^2 **9.** (a) 11 N; (b) 0.14 m/s^2 **11.** (a) $3.0 \times 10^2 \text{ N}$; (b) 1.3 m/s^2 **13.** (a) $1.3 \times 10^2 \text{ N}$; (b) no; (c) $1.1 \times 10^2 \text{ N}$; (d) 46 N; (e) 17 N **15.** 2° **17.** (a) $(17 \text{ N})\hat{i}$; (b) $(20 \text{ N})\hat{i}$; (c) $(15 \text{ N})\hat{i}$ **19.** (a) no; (b) $(-12 \text{ N})\hat{i} + (5.0 \text{ N})\hat{j}$ **21.** (a) 19°; (b) 3.3 kN **23.** 0.37 **25.** $1.0 \times 10^2 \text{ N}$ **27.** (a) 0; (b) $(-3.9 \text{ m/s}^2)\hat{i}$; (c) $(-1.0 \text{ m/s}^2)\hat{i}$ **29.** (a) 66 N; (b) 2.3 m/s^2 **31.** (a) 3.5 m/s^2 ; (b) 0.21 N **33.** 9.9 s **35.** $4.9 \times 10^2 \text{ N}$ **37.** (a) $3.2 \times 10^2 \text{ km/h}$; (b) $6.5 \times 10^2 \text{ km/h}$; (c) no **39.** 2.3 **41.** 0.60 **43.** 21 m **45.** (a) light; (b) 778 N; (c) 223 N; (d) 1.11 kN **47.** (a) 10 s; (b) $4.9 \times 10^2 \text{ N}$; (c) $1.1 \times 10^3 \text{ N}$ **49.** $1.37 \times 10^3 \text{ N}$ **51.** 2.2 km **53.** 12° **55.** $2.6 \times 10^3 \text{ N}$ **57.** 1.81 m/s **59.** (a) 8.74 N; (b) 37.9 N; (c) 6.45 m/s; (d) radially inward **61.** (a) 27 N; (b) 3.0 m/s^2 **63.** (b) 240 N; (c) 0.60 **65.** (a) 69 km/h; (b) 139 km/h; (c) yes **67.** $g(\sin \theta - 2^{0.5} \mu_k \cos \theta)$ **69.** 3.4 m/s^2 **71.** (a) 35.3 N; (b) 39.7 N; (c) 320 N **73.** (a) 7.5 m/s^2 ; (b) down; (c) 9.5 m/s^2 ; (d) down **75.** (a) $3.0 \times 10^5 \text{ N}$; (b) 1.2° **77.** 147 m/s **79.** (a) 13 N; (b) 1.6 m/s^2 **81.** (a) 275 N; (b) 877 N **83.** (a) 84.2 N; (b) 52.8 N; (c) 1.87 m/s² **85.** 3.4% **87.** (a) $3.21 \times 10^3 \text{ N}$; (b) yes **89.** (a) 222 N; (b) 334 N; (c) 311 N; (d) 311 N; (e) c, d **91.** (a) $v_0^2/(4g \sin \theta)$; (b) no **93.** (a) 0.34; (b) 0.24 **95.** (a) $\mu_k mg / (\sin \theta - \mu_k \cos \theta)$; (b) $\theta_0 = \tan^{-1} \mu_s$ **97.** 0.18 **99.** (a) 56 N; (b) 59 N; (c) $1.1 \times 10^3 \text{ N}$ **101.** 0.76 **103.** (a) bottom of circle; (b) 9.5 m/s **105.** 0.56

Chapter 7

- CP** 1. (a) decrease; (b) same; (c) negative, zero 2. (a) positive; (b) negative; (c) zero 3. zero
Q 1. all tie 3. (a) positive; (b) negative; (c) negative 5. *b* (positive work), *a* (zero work), *c* (negative work), *d* (more negative work) 7. all tie 9. (a) *A*; (b) *B* 11. 2, 3, 1
P 1. (a) $2.9 \times 10^7 \text{ m/s}$; (b) $2.1 \times 10^{-13} \text{ J}$ 3. (a) $5 \times 10^{14} \text{ J}$; (b) 0.1 megaton TNT; (c) 8 bombs 5. (a) 2.4 m/s ; (b) 4.8 m/s 7. 0.96 J 9. 20 J 11. (a) 62.3° ; (b) 118° 13. (a) $1.7 \times 10^2 \text{ N}$; (b) $3.4 \times 10^2 \text{ m}$; (c) $-5.8 \times 10^4 \text{ J}$; (d) $3.4 \times 10^2 \text{ N}$; (e) $1.7 \times 10^2 \text{ m}$; (f) $-5.8 \times 10^4 \text{ J}$ 15. (a) 1.50 J ; (b) increases 17. (a) 12 kJ ; (b) -11 kJ ; (c) 1.1 kJ ; (d) 5.4 m/s 19. 25 J 21. (a) $-3Mgd/4$; (b) Mgd ; (c) $Mgd/4$; (d) $(gd/2)^{0.5}$ 23. 4.41 J 25. (a) 25.9 kJ ; (b) 2.45 N 27. (a) 7.2 J ; (b) 7.2 J ; (c) 0; (d) -25 J 29. (a) 0.90 J ; (b) 2.1 J ; (c) 0 31. (a) 6.6 m/s ; (b) 4.7 m 33. (a) 0.12 m ; (b) 0.36 J ; (c) -0.36 J ; (d) 0.060 m ; (e) 0.090 J 35. (a) 0; (b) 0 37. (a) 42 J ; (b) 30 J ; (c) 12 J ; (d) 6.5 m/s , $+x$ axis; (e) 5.5 m/s , $+x$ axis; (f) 3.5 m/s , $+x$ axis 39. 4.00 N/m 41. $5.3 \times 10^2 \text{ J}$ 43. (a) 0.83 J ; (b) 2.5 J ; (c) 4.2 J ; (d) 5.0 W 45. $4.9 \times 10^2 \text{ W}$ 47. (a) $1.0 \times 10^2 \text{ J}$; (b) 8.4 W 49. $7.4 \times 10^2 \text{ W}$ 51. (a) 32.0 J ; (b) 8.00 W ; (c) 78.2° 53. (a) 1.20 J ; (b) 1.10 m/s 55. (a) $1.8 \times 10^5 \text{ ft} \cdot \text{lb}$; (b) 0.55 hp 57. (a) 797 N ; (b) 0; (c) -1.55 kJ ; (d) 0; (e) 1.55 kJ ; (f) F varies during displacement 59. (a) 11 J ; (b) -21 J 61. -6 J 63. (a) 314 J ; (b) -155 J ; (c) 0; (d) 158 J 65. (a) 98 N ; (b) 4.0 cm ; (c) 3.9 J ; (d) -3.9 J 67. (a) 23 mm ; (b) 45 N 69. 165 kW 71. -37 J 73. (a) 13 J ; (b) 13 J 75. 235 kW 77. (a) 6 J ; (b) 6.0 J 79. (a) 0.6 J ; (b) 0; (c) -0.6 J 81. (a) 3.35 m/s ; (b) 22.5 J ; (c) 0; (d) 0; (e) 0.212 m 83. (a) $-5.20 \times 10^{-2} \text{ J}$; (b) -0.160 J 85. 6.63 m/s

Chapter 8

- CP** 1. no (consider round trip on the small loop) 2. 3, 1, 2 (see Eq. 8-6) 3. (a) all tie; (b) all tie 4. (a) *CD, AB, BC* (0) (check slope magnitudes); (b) positive direction of *x* 5. all tie
Q 1. (a) 3, 2, 1; (b) 1, 2, 3 3. (a) 12 J ; (b) -2 J 5. (a) increasing; (b) decreasing; (c) decreasing; (d) constant in *AB* and *BC*, decreasing in *CD* 7. $+30 \text{ J}$ 9. 2, 1, 3 11. -40 J
P 1. 89 N/cm 3. (a) 167 J ; (b) -167 J ; (c) 196 J ; (d) 29 J ; (e) 167 J ; (f) -167 J ; (g) 296 J ; (h) 129 J 5. (a) 4.31 mJ ; (b) -4.31 mJ ; (c) 4.31 mJ ; (d) -4.31 mJ ; (e) all increase 7. (a) 13.1 J ; (b) -13.1 J ; (c) 13.1 J ; (d) all increase 9. (a) 17.0 m/s ; (b) 26.5 m/s ; (c) 33.4 m/s ; (d) 56.7 m/s ; (e) all the same 11. (a) 2.08 m/s ; (b) 2.08 m/s ; (c) increase 13. (a) 0.98 J ; (b) -0.98 J ; (c) 3.1 N/cm 15. (a) $2.6 \times 10^2 \text{ m}$; (b) same; (c) decrease 17. (a) 2.5 N ; (b) 0.31 N ; (c) 30 cm 19. (a) 784 N/m ; (b) 62.7 J ; (c) 62.7 J ; (d) 80.0 cm 21. (a) 8.35 m/s ; (b) 4.33 m/s ; (c) 7.45 m/s ; (d) both decrease 23. (a) 4.85 m/s ; (b) 2.42 m/s 25. $-3.2 \times 10^2 \text{ J}$ 27. (a) no; (b) $9.3 \times 10^2 \text{ N}$ 29. (a) 35 cm ; (b) 1.7 m/s 31. (a) 39.2 J ; (b) 39.2 J ; (c) 4.00 m 33. (a) 2.40 m/s ; (b) 4.19 m/s 35. (a) 39.6 cm ; (b) 3.64 cm 37. -18 mJ 39. (a) 2.1 m/s ; (b) 10 N ; (c) $+x$ direction; (d) 5.7 m ; (e) 30 N ; (f) $-x$ direction 41. (a) -3.7 J ; (c) 1.3 m ; (d) 9.1 m ; (e) 2.2 J ; (f) 4.0 m ; (g) $(4 - x)e^{-x/4}$; (h) 4.0 m 43. (a) 5.6 J ; (b) 3.5 J 45. (a) 30.1 J ; (b) 30.1 J ; (c) 0.225 J 47. 0.53 J 49. (a) -2.9 kJ ; (b) $3.9 \times 10^2 \text{ J}$; (c) $2.1 \times 10^2 \text{ N}$ 51. (a) 1.5 MJ ; (b) 0.51 MJ ; (c) 1.0 MJ ; (d) 63 m/s 53. (a) 67 J ; (b) 67 J ; (c) 46 cm 55. (a) -0.90 J ; (b) 0.46 J ; (c) 1.0 m/s 57. 1.2 m 59. (a) 19.4 m ; (b) 19.0 m/s 61. (a) $1.5 \times 10^{-2} \text{ N}$; (b) $(3.8 \times 10^2)g$ 63. (a) 7.4 m/s ; (b) 90 cm ; (c) 2.8 m ; (d) 15 m 65. 20 cm 67. (a) 7.0 J ; (b) 22 J 69. 3.7 J 71. 4.33 m/s 73. 25 J 75. (a) 4.9 m/s ; (b) 4.5 N ; (c) 71° ; (d) same 77. (a) 4.8 N ; (b) $+x$ direction; (c) 1.5 m ; (d) 13.5 m ; (e) 3.5 m/s 79. (a) 24 kJ ; (b) $4.7 \times 10^2 \text{ N}$ 81. (a) 5.00 J ; (b) 9.00 J ; (c) 11.0 J ; (d) 3.00 J ; (e) 12.0 J ; (f) 2.00 J ; (g) 13.0 J ; (h) 1.00 J ; (i) 13.0 J ; (j) 1.00 J ; (l) 11.0 J ; (m) 10.8 m ; (n) It returns to $x = 0$ and stops. 83. (a) 6.0 kJ ; (b) $6.0 \times 10^2 \text{ W}$; (c) $3.0 \times 10^2 \text{ W}$;

- (d) $9.0 \times 10^2 \text{ W}$ 85. 880 MW 87. (a) $v_0 = (2gL)^{0.5}$; (b) $5mg$; (c) $-mgL$; (d) $-2mgL$ 89. (a) 109 J ; (b) 60.3 J ; (c) 68.2 J ; (d) 41.0 J 91. (a) 2.7 J ; (b) 1.8 J ; (c) 0.39 m 93. (a) 10 m ; (b) 49 N ; (c) 4.1 m ; (d) $1.2 \times 10^2 \text{ N}$ 95. (a) 5.5 m/s ; (b) 5.4 m ; (c) same 97. 80 mJ 99. 24 W 101. -12 J 103. (a) 8.8 m/s ; (b) 2.6 kJ ; (c) 1.6 kW 105. (a) $7.4 \times 10^2 \text{ J}$; (b) $2.4 \times 10^2 \text{ J}$ 107. 15 J 109. (a) $2.35 \times 10^3 \text{ J}$; (b) 352 J 111. 738 m 113. (a) -3.8 kJ ; (b) 31 kN 115. (a) 300 J ; (b) 93.8 J ; (c) 6.38 m 117. (a) 5.6 J ; (b) 12 J ; (c) 13 J 119. (a) 1.2 J ; (b) 11 m/s ; (c) no; (d) no 121. (a) $2.1 \times 10^6 \text{ kg}$; (b) $(100 + 1.5t)^{0.5}$ m/s; (c) $(1.5 \times 10^6)/(100 + 1.5t)^{0.5} \text{ N}$; (d) 6.7 km 123. 54% 125. (a) $2.7 \times 10^9 \text{ J}$; (b) $2.7 \times 10^9 \text{ W}$; (c) $\$2.4 \times 10^8$ 127. 5.4 kJ 129. $3.1 \times 10^{11} \text{ W}$ 131. because your force on the cabbage (as you lower it) does work 135. (a) 8.6 kJ ; (b) $8.6 \times 10^2 \text{ W}$; (c) $4.3 \times 10^2 \text{ W}$; (d) 1.3 kW

Chapter 9

- CP** 1. (a) origin; (b) fourth quadrant; (c) on *y* axis below origin; (d) origin; (e) third quadrant; (f) origin 2. (a) – (c) at the center of mass, still at the origin (their forces are internal to the system and cannot move the center of mass) 3. (Consider slopes and Eq. 9-23.) (a) 1, 3, and then 2 and 4 tie (zero force); (b) 3 4. (a) unchanged; (b) unchanged (see Eq. 9-32); (c) decrease (Eq. 9-35) 5. (a) zero; (b) positive (initial p_y down *y*; final p_y up *y*); (c) positive direction of *y* 6. (No net external force; \vec{P} conserved.) (a) 0; (b) no; (c) $-x$ 7. (a) $10 \text{ kg} \cdot \text{m/s}$; (b) $14 \text{ kg} \cdot \text{m/s}$; (c) $6 \text{ kg} \cdot \text{m/s}$ 8. (a) $4 \text{ kg} \cdot \text{m/s}$; (b) $8 \text{ kg} \cdot \text{m/s}$; (c) 3 J 9. (a) $2 \text{ kg} \cdot \text{m/s}$ (conserve momentum along *x*); (b) $3 \text{ kg} \cdot \text{m/s}$ (conserve momentum along *y*) 10. (a) 2 N, rightward; (b) 2 N, rightward; (c) greater than 2 N, rightward 3. b, c, a 5. (a) x yes, y no; (b) x yes, y no; (c) x no, y yes 7. (a) c , kinetic energy cannot be negative; d , total kinetic energy cannot increase; (b) a ; (c) b 9. (a) one was stationary; (b) 2; (c) 5; (d) equal (pool player's result) 11. (a) *C*; (b) *B*; (c) 3
P 1. (a) -1.50 m ; (b) -1.43 m 3. (a) -6.5 cm ; (b) 8.3 cm ; (c) 1.4 cm 5. (a) -0.45 cm ; (b) -2.0 cm 7. (a) 0; (b) $3.13 \times 10^{-11} \text{ m}$ 9. (a) 28 cm ; (b) 2.3 m/s 11. $(-4.0 \text{ m})\hat{i} + (4.0 \text{ m})\hat{j}$ 13. 53 m 15. (a) $(2.35\hat{i} - 1.57\hat{j}) \text{ m/s}^2$; (b) $(2.35\hat{i} - 1.57\hat{j})t \text{ m/s}$, with *t* in seconds; (d) straight, at downward angle 34° 17. 4.2 m 19. (a) $7.5 \times 10^4 \text{ J}$; (b) $3.8 \times 10^4 \text{ kg} \cdot \text{m/s}$; (c) 39° south of due east 21. (a) $5.0 \text{ kg} \cdot \text{m/s}$; (b) $10 \text{ kg} \cdot \text{m/s}$ 23. 1.0×10^3 to $1.2 \times 10^3 \text{ kg} \cdot \text{m/s}$ 25. (a) $42 \text{ N} \cdot \text{s}$; (b) 2.1 kN 27. (a) 67 m/s ; (b) $-x$; (c) 1.2 kN ; (d) $-x$ 29. 5 N 31. (a) $2.39 \times 10^3 \text{ N} \cdot \text{s}$; (b) $4.78 \times 10^5 \text{ N}$; (c) $1.76 \times 10^3 \text{ N} \cdot \text{s}$; (d) $3.52 \times 10^5 \text{ N}$ 33. (a) $5.86 \text{ kg} \cdot \text{m/s}$; (b) 59.8° ; (c) 2.93 kN ; (d) 59.8° 35. $9.9 \times 10^2 \text{ N}$ 37. (a) $9.0 \text{ kg} \cdot \text{m/s}$; (b) 3.0 kN ; (c) 4.5 kN ; (d) 20 m/s 39. 3.0 mm/s 41. (a) $-(0.15 \text{ m/s})\hat{i}$; (b) 0.18 m 43. 55 cm 45. (a) $(1.00\hat{i} - 0.167\hat{j}) \text{ km/s}$; (b) 3.23 MJ 47. (a) 14 m/s ; (b) 45° 49. $3.1 \times 10^2 \text{ m/s}$ 51. (a) 721 m/s ; (b) 937 m/s 53. (a) 33%; (b) 23%; (c) decreases 55. (a) $+2.0 \text{ m/s}$; (b) -1.3 J ; (c) $+40 \text{ J}$; (d) system got energy from some source, such as a small explosion 57. (a) 4.4 m/s ; (b) 0.80 59. 25 cm 61. (a) 99 g ; (b) 1.9 m/s ; (c) 0.93 m/s 63. (a) 3.00 m/s ; (b) 6.00 m/s 65. (a) 1.2 kg ; (b) 2.5 m/s 67. -28 cm 69. (a) 0.21 kg ; (b) 7.2 m 71. (a) $4.15 \times 10^5 \text{ m/s}$; (b) $4.84 \times 10^5 \text{ m/s}$ 73. 120° 75. (a) 433 m/s ; (b) 250 m/s 77. (a) 46 N ; (b) none 79. (a) $1.57 \times 10^6 \text{ N}$; (b) $1.35 \times 10^5 \text{ kg}$; (c) 2.08 km/s 81. (a) 7290 m/s ; (b) 8200 m/s ; (c) $1.271 \times 10^{10} \text{ J}$; (d) $1.275 \times 10^{10} \text{ J}$ 83. (a) 1.92 m ; (b) 0.640 m 85. (a) 1.78 m/s ; (b) less; (c) less; (d) greater 87. (a) 3.7 m/s ; (b) $1.3 \text{ N} \cdot \text{s}$; (c) $1.8 \times 10^2 \text{ N}$ 89. (a) $(7.4 \times 10^3 \text{ N} \cdot \text{s})\hat{i}$; (b) $(-7.4 \times 10^3 \text{ N} \cdot \text{s})\hat{i}$; (c) $2.3 \times 10^3 \text{ N}$; (d) $2.1 \times 10^4 \text{ N}$; (e) -45° 91. $+4.4 \text{ m/s}$ 93. $1.18 \times 10^4 \text{ kg}$ 95. (a) 1.9 m/s ; (b) -30° ; (c) elastic 97. (a) 6.9 m/s ; (b) 30° ; (c) 6.9 m/s ; (d) -30° ; (e) 2.0 m/s ; (f) -180° 99. (a) 25 mm ; (b) 26 mm ; (c) down; (d) $1.6 \times 10^{-2} \text{ m/s}^2$ 101. 29 J 103. 2.2 kg 105. 5.0 kg 107. (a) 50 kg/s ; (b) $1.6 \times 10^2 \text{ kg/s}$ 109. (a) $4.6 \times 10^3 \text{ km}$; (b) 73% 111. 190 m/s

- 113.** 28.8 N **115.** (a) 0.745 mm; (b) 153° ; (c) 1.67 mJ **117.** (a) $(2.67 \text{ m/s})\hat{i} + (-3.00 \text{ m/s})\hat{j}$; (b) 4.01 m/s; (c) 48.4° **119.** (a) -0.50 m ; (b) -1.8 cm ; (c) 0.50 m **121.** 0.22% **123.** 36.5 km/s **125.** (a) $(-1.00 \times 10^{-19}\hat{i} + 0.67 \times 10^{-19}\hat{j}) \text{ kg} \cdot \text{m/s}$; (b) $1.19 \times 10^{-12} \text{ J}$ **127.** 2.2×10^{-3}

Chapter 10

- CP** **1.** b and c **2.** (a) and (d) ($\alpha = d^2\theta/dt^2$ must be a constant) **3.** (a) yes; (b) no; (c) yes; (d) yes **4.** all tie **5.** 1, 2, 4, 3 (see Eq. 10-36) **6.** (see Eq. 10-40) 1 and 3 tie, 4, then 2 and 5 tie (zero) **7.** (a) downward in the figure ($\tau_{\text{net}} = 0$); (b) less (consider moment arms) **Q** **1.** (a) *c, a*, then *b* and *d* tie; (b) *b*, then *a* and *c* tie, then *d* **3.** all tie **5.** (a) decrease; (b) clockwise; (c) counterclockwise **7.** larger **9.** *c, a, b* **11.** less **P** **1.** 14 rev **3.** (a) 4.0 rad/s; (b) 11.9 rad/s **5.** 11 rad/s **7.** (a) 4.0 m/s; (b) no **9.** (a) 3.00 s; (b) 18.9 rad **11.** (a) 30 s; (b) $1.8 \times 10^3 \text{ rad}$ **13.** (a) $3.4 \times 10^2 \text{ s}$; (b) $-4.5 \times 10^{-3} \text{ rad/s}^2$; (c) 98 s **15.** 8.0 s **17.** (a) 44 rad; (b) 5.5 s; (c) 32 s; (d) -2.1 s ; (e) 40 s **19.** (a) $2.50 \times 10^{-3} \text{ rad/s}$; (b) 20.2 m/s^2 ; (c) 0 **21.** $6.9 \times 10^{-13} \text{ rad/s}$ **23.** (a) 20.9 rad/s; (b) 12.5 m/s ; (c) 800 rev/min²; (d) 600 rev **25.** (a) $7.3 \times 10^{-5} \text{ rad/s}$; (b) $3.5 \times 10^2 \text{ m/s}$; (c) $7.3 \times 10^{-5} \text{ rad/s}$; (d) $4.6 \times 10^2 \text{ m/s}$ **27.** (a) 73 cm/s^2 ; (b) 0.075; (c) 0.11 **29.** (a) $3.8 \times 10^3 \text{ rad/s}$; (b) $1.9 \times 10^2 \text{ m/s}$ **31.** (a) 40 s; (b) 2.0 rad/s^2 **33.** $12.3 \text{ kg} \cdot \text{m}^2$ **35.** (a) 1.1 kJ; (b) 9.7 kJ **37.** $0.097 \text{ kg} \cdot \text{m}^2$ **39.** (a) 49 MJ; (b) $1.0 \times 10^2 \text{ min}$ **41.** (a) 0.023 kg · m²; (b) 1.1 mJ **43.** $4.7 \times 10^{-4} \text{ kg} \cdot \text{m}^2$ **45.** $-3.85 \text{ N} \cdot \text{m}$ **47.** $4.6 \text{ N} \cdot \text{m}$ **49.** (a) 28.2 rad/s^2 ; (b) $338 \text{ N} \cdot \text{m}$ **51.** (a) 6.00 cm/s^2 ; (b) 4.87 N; (c) 4.54 N; (d) 1.20 rad/s^2 ; (e) $0.0138 \text{ kg} \cdot \text{m}^2$ **53.** 0.140 N **55.** $2.51 \times 10^{-4} \text{ kg} \cdot \text{m}^2$ **57.** (a) $4.2 \times 10^2 \text{ rad/s}^2$; (b) $5.0 \times 10^2 \text{ rad/s}$ **59.** 396 N · m **61.** (a) -19.8 kJ ; (b) 1.32 kW **63.** 5.42 m/s **65.** (a) 5.32 m/s²; (b) 8.43 m/s²; (c) 41.8° **67.** 9.82 rad/s **69.** $6.16 \times 10^{-5} \text{ kg} \cdot \text{m}^2$ **71.** (a) 31.4 rad/s^2 ; (b) 0.754 m/s^2 ; (c) 56.1 N; (d) 55.1 N **73.** (a) $4.81 \times 10^5 \text{ N}$; (b) $1.12 \times 10^4 \text{ N} \cdot \text{m}$; (c) $1.25 \times 10^6 \text{ J}$ **75.** (a) 2.3 rad/s^2 ; (b) 1.4 rad/s^2 **77.** (a) -67 rev/min^2 ; (b) 8.3 rev **81.** 3.1 rad/s **83.** (a) 1.57 m/s^2 ; (b) 4.55 N; (c) 4.94 N **85.** 30 rev **87.** $0.054 \text{ kg} \cdot \text{m}^2$ **89.** $1.4 \times 10^2 \text{ N} \cdot \text{m}$ **91.** (a) 10 J; (b) 0.27 m **93.** 4.6 rad/s^2 **95.** 2.6 J **97.** (a) $5.92 \times 10^4 \text{ m/s}^2$; (b) $4.39 \times 10^4 \text{ s}^{-2}$ **99.** (a) $0.791 \text{ kg} \cdot \text{m}^2$; (b) $1.79 \times 10^{-2} \text{ N} \cdot \text{m}$ **101.** (a) $1.5 \times 10^2 \text{ cm/s}$; (b) 15 rad/s; (c) 15 rad/s; (d) 75 cm/s; (e) 3.0 rad/s **103.** (a) $7.0 \text{ kg} \cdot \text{m}^2$; (b) 7.2 m/s; (c) 71° **105.** (a) 0.32 rad/s; (b) $1.0 \times 10^2 \text{ km/h}$ **107.** (a) $1.4 \times 10^2 \text{ rad}$; (b) 14 s

Chapter 11

- CP** **1.** (a) same; (b) less **2.** less (consider the transfer of energy from rotational kinetic energy to gravitational potential energy) **3.** (draw the vectors, use right-hand rule) (a) $\pm z$; (b) $+y$; (c) $-x$ **4.** (see Eq. 11-21) (a) 1 and 3 tie; then 2 and 4 tie, then 5 (zero); (b) 2 and 3 **5.** (see Eqs. 11-23 and 11-16) (a) 3, 1; then 2 and 4 tie (zero); (b) 3 **6.** (a) all tie (same τ , same t , thus same ΔL); (b) sphere, disk, hoop (reverse order of I) **7.** (a) decreases; (b) same ($\tau_{\text{net}} = 0$, so L is conserved); (c) increases **Q** **1.** *a, then b and c tie, then e, d (zero)* **3.** (a) spins in place; (b) rolls toward you; (c) rolls away from you **5.** (a) 1, 2, 3 (zero); (b) 1 and 2 tie, then 3; (c) 1 and 3 tie, then 2 **7.** (a) same; (b) increase; (c) decrease; (d) same, decrease, increase **9.** *D, B, then A and C tie* **11.** (a) same; (b) same **P** **1.** (a) 0; (b) $(22 \text{ m/s})\hat{i}$; (c) $(-22 \text{ m/s})\hat{i}$; (d) 0; (e) $1.5 \times 10^3 \text{ m/s}^2$; (f) $1.5 \times 10^3 \text{ m/s}^2$; (g) $(22 \text{ m/s})\hat{i}$; (h) $(44 \text{ m/s})\hat{i}$; (i) 0; (j) 0; (k) $1.5 \times 10^3 \text{ m/s}^2$; (l) $1.5 \times 10^3 \text{ m/s}^2$ **3.** -3.15 J **5.** 0.020 **7.** (a) 63 rad/s; (b) 4.0 m **9.** 4.8 m **11.** (a) $(-4.0 \text{ N})\hat{i}$; (b) $0.60 \text{ kg} \cdot \text{m}^2$ **13.** 0.50 **15.** (a) $-(0.11 \text{ m})\omega$; (b) -2.1 m/s^2 ; (c) -47 rad/s^2 ; (d) 1.2 s; (e) 8.6 m; (f) 6.1 m/s **17.** (a) 13 cm/s^2 ; (b) 4.4 s; (c) 55 cm/s; (d) 18 mJ; (e) 1.4 J; (f) 27 rev/s **19.** $(-2.0 \text{ N} \cdot \text{m})\hat{i}$ **21.** (a) $(6.0 \text{ N} \cdot \text{m})\hat{j} + (8.0 \text{ N} \cdot \text{m})\hat{k}$; (b)

- ($-22 \text{ N} \cdot \text{m})\hat{i}$ **23.** (a) $(-1.5 \text{ N} \cdot \text{m})\hat{i} - (4.0 \text{ N} \cdot \text{m})\hat{j} - (1.0 \text{ N} \cdot \text{m})\hat{k}$; (b) $(-1.5 \text{ N} \cdot \text{m})\hat{i} - (4.0 \text{ N} \cdot \text{m})\hat{j} - (1.0 \text{ N} \cdot \text{m})\hat{k}$ **25.** (a) $(50 \text{ N} \cdot \text{m})\hat{k}$; (b) 90° **27.** (a) 0; (b) $(8.0 \text{ N} \cdot \text{m})\hat{i} + (8.0 \text{ N} \cdot \text{m})\hat{k}$ **29.** (a) $9.8 \text{ kg} \cdot \text{m}^2/\text{s}$; (b) $+z$ direction **31.** (a) 0; (b) $-22.6 \text{ kg} \cdot \text{m}^2/\text{s}$; (c) $-7.84 \text{ N} \cdot \text{m}$; (d) $-7.84 \text{ N} \cdot \text{m}$ **33.** (a) $(-1.7 \times 10^2 \text{ kg} \cdot \text{m}^2/\text{s})\hat{k}$; (b) $(+56 \text{ N} \cdot \text{m})\hat{k}$; (c) $(+56 \text{ kg} \cdot \text{m}^2/\text{s}^2)\hat{k}$ **35.** (a) $48 \text{ kN} \cdot \text{m}$; (b) increasing **37.** (a) $4.6 \times 10^{-3} \text{ kg} \cdot \text{m}^2$; (b) $1.1 \times 10^{-3} \text{ kg} \cdot \text{m}^2/\text{s}$; (c) $3.9 \times 10^{-3} \text{ kg} \cdot \text{m}^2/\text{s}$ **39.** (a) $1.47 \text{ N} \cdot \text{m}$; (b) 20.4 rad ; (c) -29.9 J ; (d) 19.9 W **41.** (a) $1.6 \text{ kg} \cdot \text{m}^2/\text{s}^2$; (b) $4.0 \text{ kg} \cdot \text{m}^2/\text{s}^2$ **43.** (a) 1.5 m; (b) 0.93 rad/s; (c) 98 J; (d) 8.4 rad/s; (e) $8.8 \times 10^2 \text{ J}$; (f) internal energy of the skaters **45.** (a) 3.6 rev/s; (b) 3.0; (c) forces on the bricks from the man transferred energy from the man's internal energy to kinetic energy **47.** 0.17 rad/s **49.** (a) 750 rev/min; (b) 450 rev/min; (c) clockwise **51.** (a) 267 rev/min; (b) 0.667 **53.** $1.3 \times 10^3 \text{ m/s}$ **55.** 3.4 rad/s **57.** (a) 18 rad/s; (b) 0.92 **59.** 11.0 m/s **61.** 1.5 rad/s **63.** 0.070 rad/s **65.** (a) 0.148 rad/s; (b) 0.0123; (c) 181° **67.** (a) 0.180 m; (b) clockwise **69.** 0.041 rad/s **71.** (a) 1.6 m/s^2 ; (b) 16 rad/s^2 ; (c) $(4.0 \text{ N})\hat{i}$ **73.** (a) 0; (b) 0; (c) $-30\hat{i}\hat{k}$ $\text{kg} \cdot \text{m}^2/\text{s}$; (d) $-90\hat{r}\hat{k} \text{ N} \cdot \text{m}$; (e) $30\hat{r}\hat{k} \text{ kg} \cdot \text{m}^2/\text{s}$; (f) $90\hat{r}\hat{k} \text{ N} \cdot \text{m}$ **75.** (a) 149 kg · m²; (b) 158 kg · m²/s; (c) 0.744 rad/s **77.** (a) $6.65 \times 10^{-5} \text{ kg} \cdot \text{m}^2/\text{s}$; (b) no; (c) 0; (d) yes **79.** (a) 0.333; (b) 0.111 **81.** (a) 58.8 J; (b) 39.2 J **83.** (a) 61.7 J; (b) 3.43 m; (c) no **85.** (a) $mvR/(I + MR^2)$; (b) $mvR^2/(I + MR^2)$

Chapter 12

- CP** **1.** *c, e, f* **2.** (a) no; (b) at site of \vec{F}_1 , perpendicular to plane of figure; (c) 45 N **3.** *d* **Q** **1.** (a) 1 and 3 tie, then 2; (b) all tie; (c) 1 and 3 tie, then 2 (zero) **3.** *a* and *c* (forces and torques balance) **5.** (a) 12 kg; (b) 3 kg; (c) 1 kg **7.** (a) at *C* (to eliminate forces there from a torque equation); (b) plus; (c) minus; (d) equal **9.** increase **11.** *A* and *B*, then *C* **P** **1.** (a) 1.00 m; (b) 2.00 m; (c) 0.987 m; (d) 1.97 m **3.** (a) 9.4 N; (b) 4.4 N **5.** 7.92 kN **7.** (a) $2.8 \times 10^2 \text{ N}$; (b) $8.8 \times 10^2 \text{ N}$; (c) 71° **9.** 74.4 g **11.** (a) 1.2 kN; (b) down; (c) 1.7 kN; (d) up; (e) left; (f) right **13.** (a) 2.7 kN; (b) up; (c) 3.6 kN; (d) down **15.** (a) 5.0 N; (b) 30 N; (c) 1.3 m **17.** (a) 0.64 m; (b) increased **19.** 8.7 N **21.** (a) 6.63 kN; (b) 5.74 kN; (c) 5.96 kN **23.** (a) 192 N; (b) 96.1 N; (c) 55.5 N **25.** 13.6 N **27.** (a) 1.9 kN; (b) up; (c) 2.1 kN; (d) down **29.** (a) $(-80 \text{ N})\hat{i} + (1.3 \times 10^2 \text{ N})\hat{j}$; (b) $(80 \text{ N})\hat{i} + (1.3 \times 10^2 \text{ N})\hat{j}$ **31.** 2.20 m **33.** (a) 60.0°; (b) 300 N **35.** (a) 445 N; (b) 0.50; (c) 315 N **37.** 0.34 **39.** (a) 207 N; (b) 539 N; (c) 315 N **41.** (a) slides; (b) 31°; (c) tips; (d) 34° **43.** (a) $6.5 \times 10^6 \text{ N/m}^2$; (b) $1.1 \times 10^{-5} \text{ m}$ **45.** (a) 0.80; (b) 0.20; (c) 0.25 **47.** (a) $1.4 \times 10^9 \text{ N}$; (b) 75 **49.** (a) 866 N; (b) 143 N; (c) 0.165 **51.** (a) $1.2 \times 10^2 \text{ N}$; (b) 68 N **53.** (a) $1.8 \times 10^7 \text{ N}$; (b) $1.4 \times 10^7 \text{ N}$; (c) 16 **55.** 0.29 **57.** 76 N **59.** (a) 8.01 kN; (b) 3.65 kN; (c) 5.66 kN **61.** 71.7 N **63.** (a) $L/2$; (b) $L/4$; (c) $L/6$; (d) $L/8$; (e) $25L/24$ **65.** (a) 88 N; (b) $(30\hat{i} + 97\hat{j}) \text{ N}$ **67.** $2.4 \times 10^9 \text{ N/m}^2$ **69.** 60° **71.** (a) $\mu < 0.57$; (b) $\mu > 0.57$ **73.** (a) $(35\hat{i} + 200\hat{j}) \text{ N}$; (b) $(-45\hat{i} + 200\hat{j}) \text{ N}$; (c) $1.9 \times 10^2 \text{ N}$ **75.** (a) *BC, CD, DA*; (b) 535 N; (c) 757 N **77.** (a) 1.38 kN; (b) 180 N **79.** (a) $a_1 = L/2$, $a_2 = 5L/8$, $h = 9L/8$; (b) $b_1 = 2L/3$, $b_2 = L/2$, $h = 7L/6$ **81.** $L/4$ **83.** (a) 106 N; (b) 64.0° **85.** $1.8 \times 10^2 \text{ N}$ **87.** (a) -24.4 N ; (b) 1.60 N; (c) -3.75°

Chapter 13

- CP** **1.** all tie **2.** (a) 1, tie of 2 and 4, then 3; (b) line *d* **3.** (a) increase; (b) negative **4.** (a) 2; (b) 1 **5.** (a) path 1 (decreased E (more negative) gives decreased a); (b) less (decreased a gives decreased T) **Q** **1.** $3GM^2/d^2$, leftward **3.** Gm^2/r^2 , upward **5.** *b* and *c* tie, then *a* (zero) **7.** 1, tie of 2 and 4, then 3 **9.** (a) positive *y*; (b) yes, rotates

counterclockwise until it points toward particle *B* **11.** *b, d, and f all tie, then e, c, a*

- P** **1.** $\frac{1}{2}$ **3.** 19 m **5.** 0.8 m **7.** $-5.00d$ **9.** 2.60×10^5 km **11.** (a) $M = m$; (b) 0 **13.** 8.31×10^{-9} N **15.** (a) $-1.88d$; (b) $-3.90d$; (c) $0.489d$ **17.** (a) 17 N; (b) 2.4 **19.** 2.6×10^6 m **21.** 5×10^{24} kg **23.** (a) 7.6 m/s^2 ; (b) 4.2 m/s^2 **25.** (a) $(3.0 \times 10^{-7} \text{ N/kg})m$; (b) $(3.3 \times 10^{-7} \text{ N/kg})m$; (c) $(6.7 \times 10^{-7} \text{ N/kg} \cdot \text{m})mr$ **27.** (a) 9.83 m/s^2 ; (b) 9.84 m/s^2 ; (c) 9.79 m/s^2 **29.** 5.0×10^9 J **31.** (a) 0.74; (b) 3.8 m/s^2 ; (c) 5.0 km/s **33.** (a) 0.0451; (b) 28.5 **35.** -4.82×10^{-13} J **37.** (a) 0.50 pJ; (b) -0.50 pJ **39.** (a) 1.7 km/s; (b) 2.5×10^5 m; (c) 1.4 km/s **41.** (a) 82 km/s; (b) 1.8×10^4 km/s **43.** (a) 7.82 km/s; (b) 87.5 min **45.** 6.5×10^{23} kg **47.** 5×10^{10} stars **49.** (a) 1.9×10^{13} m; (b) $6.4R_p$ **51.** (a) 6.64×10^3 km; (b) 0.0136 **53.** 5.8×10^6 m **57.** 0.71 y **59.** $(GM/L)^{0.5}$ **61.** (a) 3.19×10^3 km; (b) lifting **63.** (a) 2.8 y; (b) 1.0×10^{-4} **65.** (a) $r^{1.5}$; (b) r^{-1} ; (c) $r^{0.5}$; (d) $r^{-0.5}$ **67.** (a) 7.5 km/s; (b) 97 min; (c) 4.1×10^2 km; (d) 7.7 km/s; (e) 93 min; (f) 3.2×10^{-3} N; (g) no; (h) yes **69.** 1.1 s **71.** (a) $GMmx(x^2 + R^2)^{-3/2}$; (b) $[2GM(R^{-1} - (R^2 + x^2)^{-1/2})]^{1/2}$ **73.** (a) 1.0×10^3 kg; (b) 1.5 km/s **75.** 3.2×10^{-7} N **77.** $0.037\hat{j}$ μN **79.** $2\pi r^{1.5}G^{-0.5}(M + m/4)^{-0.5}$ **81.** (a) 2.2×10^{-7} rad/s; (b) 89 km/s **83.** (a) 2.15×10^4 s; (b) 12.3 km/s; (c) 12.0 km/s; (d) 2.17×10^{11} J; (e) -4.53×10^{11} J; (f) -2.35×10^{11} J; (g) 4.04×10^7 m; (h) 1.22×10^3 s; (i) elliptical **85.** 2.5×10^4 km **87.** (a) 1.4×10^6 m/s; (b) 3×10^6 m/s² **89.** (a) 0; (b) 1.8×10^{32} J; (c) 1.8×10^{32} J; (d) 0.99 km/s **91.** (a) Gm^2/R_i ; (b) $Gm^2/2R_i$; (c) $(Gm/R_i)^{0.5}$; (d) $2(Gm/R_i)^{0.5}$; (e) Gm^2/R_i ; (f) $(2Gm/R_i)^{0.5}$; (g) The center-of-mass frame is an inertial frame, and in it the principle of conservation of energy may be written as in Chapter 8; the reference frame attached to body *A* is noninertial, and the principle cannot be written as in Chapter 8. Answer (d) is correct. **93.** 2.4×10^4 m/s **95.** $-0.044\hat{j}$ μN **97.** $GM_{\text{E}}/12R_{\text{E}}$ **99.** 1.51×10^{-12} N **101.** 3.4×10^5 km

Chapter 14

CP **1.** all tie **2.** (a) all tie (the gravitational force on the penguin is the same); (b) $0.95\rho_0, \rho_0, 1.1\rho_0$ **3.** $13 \text{ cm}^3/\text{s}$, outward

- 4.** (a) all tie; (b) 1, then 2 and 3 tie, 4 (wider means slower); (c) 4, 3, 2, 1 (wider and lower mean more pressure)

Q **1.** (a) moves downward; (b) moves downward **3.** (a) downward; (b) downward; (c) same **5.** *b*, then *a* and *d* tie (zero), then *c* **7.** (a) 1 and 4; (b) 2; (c) 3 **9.** *B, C, A*

- P** **1.** 0.074 **3.** 1.1×10^5 Pa **5.** 2.9×10^4 N **7.** (b) 26 kN **9.** (a) 1.0×10^3 torr; (b) 1.7×10^3 torr **11.** (a) 94 torr; (b) 4.1×10^2 torr; (c) 3.1×10^2 torr **13.** 1.08×10^3 atm **15.** -2.6×10^4 Pa **17.** 7.2×10^5 N **19.** 4.69×10^5 N **21.** 0.635 J **23.** 44 km **25.** 739.26 torr **27.** (a) 7.9 km; (b) 16 km **29.** 8.50 kg **31.** (a) $6.7 \times 10^2 \text{ kg/m}^3$; (b) $7.4 \times 10^2 \text{ kg/m}^3$ **33.** (a) $2.04 \times 10^{-2} \text{ m}^3$; (b) 1.57 kN **35.** five **37.** 57.3 cm **39.** (a) 1.2 kg; (b) 1.3×10^3 kg/m³ **41.** (a) 0.10; (b) 0.083 **43.** (a) 637.8 cm^3 ; (b) 5.102 m³; (c) 5.102×10^3 kg **45.** 0.126 m³ **47.** (a) 1.80 m^3 ; (b) 4.75 m³ **49.** (a) 3.0 m/s; (b) 2.8 m/s **51.** 8.1 m/s **53.** 66 W **55.** 1.4×10^5 J **57.** (a) $1.6 \times 10^{-3} \text{ m}^3/\text{s}$; (b) 0.90 m **59.** (a) 2.5 m/s; (b) 2.6×10^5 Pa **61.** (a) 3.9 m/s; (b) 88 kPa **63.** 1.1×10^2 m/s **65.** (b) 2.0×10^{-2} m³/s **67.** (a) 74 N; (b) 1.5×10^2 m³ **69.** (a) $0.0776 \text{ m}^3/\text{s}$; (b) 69.8 kg/s **71.** (a) 35 cm; (b) 30 cm; (c) 20 cm **73.** 1.5 g/cm^3 **75.** 5.11×10^{-7} kg **77.** 44.2 g **79.** $6.0 \times 10^2 \text{ kg/m}^3$ **81.** 45.3 cm³ **83.** (a) 3.2 m/s; (b) 9.2×10^4 Pa; (c) 10.3 m **85.** 1.07×10^3 g **87.** 26.3 m² **89.** (a) 5.66×10^9 N; (b) 25.4 atm

Chapter 15

CP **1.** (sketch *x* versus *t*) (a) $-x_m$; (b) $+x_m$; (c) 0 **2.** *c* (*a* must have the form of Eq. 15-8) **3.** *a* (*F* must have the form of Eq. 15-10)

- 4.** (a) 5 J; (b) 2 J; (c) 5 J **5.** all tie (in Eq. 15-29, *m* is included in *I*) **6.** 1, 2, 3 (the ratio *m/b* matters; *k* does not)

- Q** **1.** *a* and *b* **3.** (a) 2; (b) positive; (c) between 0 and $+x_m$ **5.** (a) between *D* and *E*; (b) between $3\pi/2$ rad and 2π rad **7.** (a) all tie; (b) 3, then 1 and 2 tie; (c) 1, 2, 3 (zero); (d) 1, 2, 3 (zero); (e) 1, 3, 2 **9.** *b* (infinite period, does not oscillate), *c, a* **11.** (a) greater; (b) same; (c) same; (d) greater; (e) greater **P** **1.** (a) 0.50 s; (b) 2.0 Hz; (c) 18 cm **3.** 37.8 m/s^2 **5.** (a) 1.0 mm; (b) 0.75 m/s; (c) $5.7 \times 10^2 \text{ m/s}^2$ **7.** (a) 498 Hz; (b) greater **9.** (a) 3.0 m; (b) -49 m/s ; (c) $-2.7 \times 10^2 \text{ m/s}^2$; (d) 20 rad; (e) 1.5 Hz; (f) 0.67 s **11.** 39.6 Hz **13.** (a) 0.500 s; (b) 2.00 Hz; (c) 12.6 rad/s; (d) 79.0 N/m; (e) 4.40 m/s; (f) 27.6 N **15.** (a) 0.18*A*; (b) same direction **17.** (a) 5.58 Hz; (b) 0.325 kg; (c) 0.400 m **19.** (a) 25 cm; (b) 2.2 Hz **21.** 54 Hz **23.** 3.1 cm **25.** (a) 0.525 m; (b) 0.686 s **27.** (a) 0.75; (b) 0.25; (c) $2^{-0.5}x_m$ **29.** 37 mJ **31.** (a) 2.25 Hz; (b) 125 J; (c) 250 J; (d) 86.6 cm **33.** (a) 1.1 m/s; (b) 3.3 cm **35.** (a) 3.1 ms; (b) 4.0 m/s; (c) 0.080 J; (d) 80 N; (e) 40 N **37.** (a) 2.2 Hz; (b) 56 cm/s; (c) 0.10 kg; (d) 20.0 cm **39.** (a) 39.5 rad/s; (b) 34.2 rad/s; (c) 124 rad/s² **41.** (a) $0.205 \text{ kg}\cdot\text{m}^2$; (b) 47.7 cm; (c) 1.50 s **43.** (a) 1.64 s; (b) equal **45.** 8.77 s **47.** 0.366 s **49.** (a) 0.845 rad; (b) 0.0602 rad **51.** (a) 0.53 m; (b) 2.1 s **53.** 0.0653 s **55.** (a) 2.26 s; (b) increases; (c) same **57.** 6.0% **59.** (a) 14.3 s; (b) 5.27 **61.** (a) $F_m/b\omega$; (b) F_m/b **63.** 5.0 cm **65.** (a) $2.8 \times 10^3 \text{ rad/s}$; (b) 2.1 m/s; (c) 5.7 km/s^2 **67.** (a) 1.1 Hz; (b) 5.0 cm **69.** 7.2 m/s **71.** (a) 7.90 N/m; (b) 1.19 cm; (c) 2.00 Hz **73.** (a) $1.3 \times 10^2 \text{ N/m}$; (b) 0.62 s; (c) 1.6 Hz; (d) 5.0 cm; (e) 0.51 m/s **75.** (a) 16.6 cm; (b) 1.23% **77.** (a) 1.2 J; (b) 50 **79.** 1.53 m **81.** (a) 0.30 m; (b) 0.28 s; (c) $1.5 \times 10^2 \text{ m/s}^2$; (d) 11 J **83.** (a) 1.23 kN/m; (b) 76.0 N **85.** 1.6 kg **87.** (a) $0.735 \text{ kg}\cdot\text{m}^2$; (b) 0.0240 N·m; (c) 0.181 rad/s **89.** (a) 3.5 m; (b) 0.75 s **91.** (a) 0.35 Hz; (b) 0.39 Hz; (c) 0 (no oscillation) **93.** (a) 245 N/m; (b) 0.284 s **95.** 0.079 kg·m² **97.** (a) $8.11 \times 10^{-5} \text{ kg}\cdot\text{m}^2$; (b) 3.14 rad/s **99.** 14.0° **101.** (a) 3.2 Hz; (b) 0.26 m; (c) $x = (0.26 \text{ m}) \cos(20t - \pi/2)$, with *t* in seconds **103.** (a) 0.44 s; (b) 0.18 m **105.** (a) 0.45 s; (b) 0.10 m above and 0.20 m below; (c) 0.15 m; (d) 2.3 J **107.** $7 \times 10^2 \text{ N/m}$ **109.** 0.804 m **111.** (a) 0.30 m; (b) 30 m/s^2 ; (c) 0; (d) 4.4 s **113.** (a) F/m ; (b) $2F/mL$; (c) 0 **115.** 2.54 m

Chapter 16

CP **1.** a, 2; b, 3; c, 1 (compare with the phase in Eq. 16-2, then see Eq. 16-5) **2.** (a) 2, 3, 1 (see Eq. 16-12); (b) 3, then 1 and 2 tie (find amplitude of *dy/dt*) **3.** (a) same (independent of *f*); (b) decrease ($\lambda = v/f$); (c) increase; (d) increase **4.** 0.20 and 0.80 tie, then 0.60, 0.45 **5.** (a) 1; (b) 3; (c) 2 **6.** (a) 75 Hz; (b) 525 Hz

- Q** **1.** (a) 1, 4, 2, 3; (b) 1, 4, 2, 3 **3.** *a*, upward; *b*, upward; *c*, downward; *d*, downward; *e*, downward; *f*, downward; *g*, upward; *h*, upward **5.** intermediate (closer to fully destructive) **7.** (a) 0, 0.2 wavelength, 0.5 wavelength (zero); (b) $4P_{\text{avg},1}$ **9.** *d* **11.** *c, a, b*

- P** **1.** 1.1 ms **3.** (a) 3.49 m^{-1} ; (b) 31.5 m/s **5.** (a) 0.680 s; (b) 1.47 Hz; (c) 2.06 m/s **7.** (a) 64 Hz; (b) 1.3 m; (c) 4.0 cm; (d) 5.0 m^{-1} ; (e) $4.0 \times 10^2 \text{ s}^{-1}$; (f) $\pi/2$ rad; (g) minus **9.** (a) 3.0 mm; (b) 16 m^{-1} ; (c) $2.4 \times 10^2 \text{ s}^{-1}$; (d) minus **11.** (a) negative; (b) 4.0 cm; (c) 0.31 cm⁻¹; (d) 0.63 s⁻¹; (e) π rad; (f) minus; (g) 2.0 cm/s; (h) -2.5 cm/s **13.** (a) 11.7 cm; (b) π rad **15.** (a) 0.12 mm; (b) 141 m⁻¹; (c) 628 s⁻¹; (d) plus **17.** (a) 15 m/s; (b) 0.036 N **19.** 129 m/s **21.** 2.63 m **23.** (a) 5.0 cm; (b) 40 cm; (c) 12 m/s; (d) 0.033 s; (e) 9.4 m/s; (f) 16 m^{-1} ; (g) $1.9 \times 10^2 \text{ s}^{-1}$; (h) 0.93 rad; (i) plus **27.** 3.2 mm **29.** 0.20 m/s **31.** $1.41y_m$ **33.** (a) 9.0 mm; (b) 16 m^{-1} ; (c) $1.1 \times 10^3 \text{ s}^{-1}$; (d) 2.7 rad; (e) plus **35.** 5.0 cm **37.** (a) 3.29 mm; (b) 1.55 rad; (c) 1.55 rad **39.** 84° **41.** (a) 82.0 m/s; (b) 16.8 m; (c) 4.88 Hz **43.** (a) 7.91 Hz; (b) 15.8 Hz; (c) 23.7 Hz **45.** (a) 105 Hz; (b) 158 m/s **47.** 260 Hz **49.** (a) 144 m/s; (b) 60.0 cm; (c) 241 Hz **51.** (a) 0.50 cm;

- (b) 3.1 m^{-1} ; (c) $3.1 \times 10^2 \text{ s}^{-1}$; (d) minus **53.** (a) 0.25 cm ; (b) $1.2 \times 10^2 \text{ cm/s}$; (c) 3.0 cm ; (d) 0.50 cm **55.** 0.25 m **57.** (a) 2.00 Hz ; (b) 2.00 m ; (c) 4.00 m/s ; (d) 50.0 cm ; (e) 150 cm ; (f) 250 cm ; (g) 0 ; (h) 100 cm ; (i) 200 cm **59.** (a) 324 Hz ; (b) eight **61.** 36 N **63.** (a) 75 Hz ; (b) 13 ms **65.** (a) 2.0 mm ; (b) 95 Hz ; (c) $+30 \text{ m/s}$; (d) 31 cm ; (e) 1.2 m/s **67.** (a) 0.31 m ; (b) 1.64 rad ; (c) 2.2 mm **69.** (a) $0.83y_i$; (b) 37° **71.** (a) 3.77 m/s ; (b) 12.3 N ; (c) 0 ; (d) 46.4 W ; (e) 0 ; (f) 0 ; (g) $\pm 0.50 \text{ cm}$ **73.** 1.2 rad **75.** (a) 300 m/s ; (b) no **77.** (a) $[k \Delta\ell(\ell + \Delta\ell)/m]^{0.5}$ **79.** (a) 144 m/s ; (b) 3.00 m ; (c) 1.50 m ; (d) 48.0 Hz ; (e) 96.0 Hz **81.** (a) 1.00 cm ; (b) $3.46 \times 10^3 \text{ s}^{-1}$; (c) 10.5 m^{-1} ; (d) plus **83.** (a) $2\pi y_m/\lambda$; (b) no **85.** (a) 240 cm ; (b) 120 cm ; (c) 80 cm **87.** (a) 1.33 m/s ; (b) 1.88 m/s ; (c) 16.7 m/s^2 ; (d) 23.7 m/s^2 **89.** (a) 0.52 m ; (b) 40 m/s ; (c) 0.40 m **91.** (a) 0.16 m ; (b) $2.4 \times 10^2 \text{ N}$; (c) $y(x, t) = (0.16 \text{ m}) \sin[(1.57 \text{ m}^{-1})x] \sin[(31.4 \text{ s}^{-1})t]$ **93.** (c) 2.0 m/s ; (d) $-x$ **95.** (a) ∞ ; (b) 1.0 ; (c) 4.0%

Chapter 17

- CP** **1.** beginning to decrease (example: mentally move the curves of Fig. 17-6 rightward past the point at $x = 42 \text{ cm}$) **2.** (a) 1 and 2 tie, then 3 (see Eq. 17-28); (b) 3, then 1 and 2 tie (see Eq. 17-26) **3.** second (see Eqs. 17-39 and 17-41) **4.** *a*, greater; *b*, less; *c*, can't tell; *d*, can't tell; *e*, greater; *f*, less

- Q** **1.** (a) $0, 0.2 \text{ wavelength}, 0.5 \text{ wavelength (zero)}$; (b) $4P_{\text{avg},1}$ **3.** *C*, then *A* and *B* tie **5.** *E, A, D, C, B* **7.** $1, 4, 3, 2$ **9.** 150 Hz and 450 Hz **11.** $505, 507, 508 \text{ Hz}$ or $501, 503, 508 \text{ Hz}$ **P** **1.** (a) 79 m ; (b) 41 m ; (c) 89 m **3.** (a) 2.6 km ; (b) $2.0 \times 10^2 \text{ } 5.1.9 \times 10^3 \text{ km}$ **7.** 40.7 m **9.** 0.23 ms **11.** (a) $76.2 \mu\text{m}$; (b) 0.333 mm **13.** 960 Hz **15.** (a) $2.3 \times 10^2 \text{ Hz}$; (b) higher **17.** (a) 143 Hz ; (b) 3; (c) 5; (d) 286 Hz ; (e) 2; (f) 3 **19.** (a) 14; (b) 14 **21.** (a) 343 Hz ; (b) 3; (c) 5; (d) 686 Hz ; (e) 2; (f) 3 **23.** (a) 0; (b) fully constructive; (c) increase; (d) 128 m; (e) 63.0 m ; (f) 41.2 m **25.** 36.8 nm **27.** (a) 1.0×10^3 ; (b) 32 **29.** 15.0 mW **31.** $2 \mu\text{W}$ **33.** $0.76 \mu\text{m}$ **35.** (a) $5.97 \times 10^{-5} \text{ W/m}^2$; (b) 4.48 nW **37.** (a) 0.34 nW ; (b) 0.68 nW ; (c) 1.4 nW ; (d) 0.88 nW ; (e) 0 **39.** (a) 405 m/s ; (b) 596 N ; (c) 44.0 cm ; (d) 37.3 cm **41.** (a) 833 Hz ; (b) 0.418 m **43.** (a) 3; (b) 1129 Hz ; (c) 1506 Hz **45.** (a) 2; (b) 1 **47.** 12.4 m **49.** 45.3 N **51.** 2.25 ms **53.** 0.020 **55.** (a) 526 Hz ; (b) 555 Hz **57.0** **59.** (a) 1.022 kHz ; (b) 1.045 kHz **61.** 41 kHz **63.** 155 Hz **65.** (a) 2.0 kHz ; (b) 2.0 kHz **67.** (a) 485.8 Hz ; (b) 500.0 Hz ; (c) 486.2 Hz ; (d) 500.0 Hz **69.** (a) 42° ; (b) 11 s **71.** 1 cm **73.** 2.1 m **75.** (a) $39.7 \mu\text{W/m}^2$; (b) 171 nm ; (c) 0.893 Pa **77.** 0.25 **79.** (a) 2.10 m ; (b) 1.47 m **81.** (a) 59.7 ; (b) 2.81×10^{-4} **83.** (a) rightward; (b) 0.90 m/s ; (c) less **85.** (a) 11 ms ; (b) 3.8 m **87.** (a) $9.7 \times 10^2 \text{ Hz}$; (b) 1.0 kHz ; (c) 60 Hz , no **89.** (a) 21 nm ; (b) 35 cm ; (c) 24 nm ; (d) 35 cm **91.** (a) 7.70 Hz ; (b) 7.70 Hz **93.** (a) 5.2 kHz ; (b) 2 **95.** (a) 10 W ; (b) 0.032 W/m^2 ; (c) 99 dB **97.** (a) 0; (b) 0.572 m ; (c) 1.14 m **99.** 171 m **101.** (a) $3.6 \times 10^2 \text{ m/s}$; (b) 150 Hz **103.** 400 Hz **105.** (a) 14; (b) 12 **107.** 821 m/s **109.** (a) 39.3 Hz ; (b) 118 Hz **111.** $4.8 \times 10^2 \text{ Hz}$

Chapter 18

- CP** **1.** (a) all tie; (b) $50^\circ\text{X}, 50^\circ\text{Y}, 50^\circ\text{W}$ **2.** (a) 2 and 3 tie, then 1, then 4; (b) 3, 2, then 1 and 4 tie (from Eqs. 18-9 and 18-10, assume that change in area is proportional to initial area) **3.** *A* (see Eq. 18-14) **4.** *c* and *e* (maximize area enclosed by a clockwise cycle) **5.** (a) all tie (ΔE_{int} depends on *i* and *f*, not on path); (b) 4, 3, 2, 1 (compare areas under curves); (c) 4, 3, 2, 1 (see Eq. 18-26) **6.** (a) zero (closed cycle); (b) negative (W_{net} is negative; see Eq. 18-26) **7.** *b* and *d* tie, then *a*, *c* (P_{cond} identical; see Eq. 18-32) **Q** **1.** *c*, then the rest tie **3.** *B*, then *A* and *C* tie **5.** (a) *f*, because ice temperature will not rise to freezing point and then drop; (b) *b* and *c* at freezing point, *d* above, *e* below; (c) in *b* liquid partly freezes and no ice melts; in *c* no liquid freezes and no ice melts; in *d*

no liquid freezes and ice fully melts; in *e* liquid fully freezes and no ice melts **7.** (a) both clockwise; (b) both clockwise **9.** (a) greater; (b) 1, 2, 3; (c) 1, 3, 2; (d) 1, 2, 3; (e) 2, 3, 1 **11.** *c, b, a*

- P** **1.** 1.366 **3.** 348 K **5.** (a) 320°F ; (b) -12.3°F **7.** -92.1°X **9.** 2.731 cm **11.** 49.87 cm^3 **13.** 29 cm^3 **15.** 360°C **17.** 0.26 cm^3 **19.** 0.13 mm **21.** 7.5 cm **23.** 160 s **25.** 94.6 L **27.** 42.7 kJ **29.** 33 m^2 **31.** 33 g **33.** 3.0 min **35.** 13.5 C° **37.** (a) 5.3°C ; (b) 0; (c) 0°C ; (d) 60 g **39.** 742 kJ **41.** (a) 0°C ; (b) 2.5°C **43.** (a) $1.2 \times 10^2 \text{ J}$; (b) 75 J ; (c) 30 J **45.** -30 J **47.** (a) 6.0 cal ; (b) -43 cal ; (c) 40 cal ; (d) 18 cal ; (e) 18 cal **49.** 60 J **51.** (a) 1.23 kW ; (b) 2.28 kW ; (c) 1.05 kW **53.** 1.66 kJ/s **55.** (a) 16 J/s ; (b) 0.048 g/s **57.** (a) $1.7 \times 10^4 \text{ W/m}^2$; (b) 18 W/m^2 **59.** 0.50 min **61.** 0.40 cm/h **63.** -4.2°C **65.** 1.1 m **67.** 10% **69.** (a) 80 J ; (b) 80 J **71.** $4.5 \times 10^2 \text{ J/kg-K}$ **73.** 0.432 cm^3 **75.** $3.1 \times 10^2 \text{ J}$ **77.** 79.5°C **79.** 23 J **81.** (a) $11p_1V_1$; (b) $6p_1V_1$ **83.** $4.83 \times 10^{-2} \text{ cm}^3$ **85.** 10.5°C **87.** (a) 90 W ; (b) $2.3 \times 10^2 \text{ W}$; (c) $3.3 \times 10^2 \text{ W}$ **89.** (a) 1.87×10^4 ; (b) 10.4 h **91.** 333 J **93.** 8.6 J **95.** (a) -45 J ; (b) $+45 \text{ J}$ **97.** $4.0 \times 10^3 \text{ min}$ **99.** -6.1 nW **101.** 1.17 C° **103.** $8.0 \times 10^{-3} \text{ m}^2$ **105.** (a) too fast; (b) 0.79 s/h **107.** 1.9

Chapter 19

- CP** **1.** all but *c* **2.** (a) all tie; (b) 3, 2, 1 **3.** *gas A* **4.** 5 (greatest change in *T*), then tie of 1, 2, 3, and 4 **5.** 1, 2, 3 ($Q_3 = 0$, Q_2 goes into work W_2 , but Q_1 goes into greater work W_1 and increases gas temperature)

- Q** **1.** *d*, then *a* and *b* tie, then *c* **3.** 20 J **5.** (a) 3; (b) 1; (c) 4; (d) 2; (e) yes **7.** (a) 1, 2, 3, 4; (b) 1, 2, 3 **9.** constant-volume process **P** **1.** 0.933 kg **3.** (a) 0.0388 mol ; (b) 220°C **5.** $25 \text{ molecules/cm}^3$ **7.** (a) $3.14 \times 10^3 \text{ J}$; (b) from **9.** 186 kPa **11.** 5.60 kJ **13.** (a) 1.5 mol ; (b) $1.8 \times 10^3 \text{ K}$; (c) $6.0 \times 10^2 \text{ K}$; (d) 5.0 kJ **15.** 360 K **17.** $2.0 \times 10^5 \text{ Pa}$ **19.** (a) 511 m/s ; (b) -200°C ; (c) 899°C **21.** $1.8 \times 10^2 \text{ m/s}$ **23.** 1.9 kPa **25.** (a) $5.65 \times 10^{-21} \text{ J}$; (b) $7.72 \times 10^{-21} \text{ J}$; (c) 3.40 kJ ; (d) 4.65 kJ **27.** (a) $6.76 \times 10^{-20} \text{ J}$; (b) 10.7 **29.** (a) $6 \times 10^9 \text{ km}$ **31.** (a) $3.27 \times 10^{10} \text{ molecules/cm}^3$; (b) 172 m **33.** (a) 6.5 km/s ; (b) 7.1 km/s **35.** (a) 420 m/s ; (b) 458 m/s ; (c) yes **37.** (a) 0.67 ; (b) 1.2; (c) 1.3; (d) 0.33 **39.** (a) $1.0 \times 10^4 \text{ K}$; (b) $1.6 \times 10^5 \text{ K}$; (c) $4.4 \times 10^2 \text{ K}$; (d) $7.0 \times 10^3 \text{ K}$; (e) no; (f) yes **41.** (a) 7.0 km/s ; (b) $2.0 \times 10^{-8} \text{ cm}$; (c) $3.5 \times 10^{10} \text{ collisions/s}$ **43.** (a) 3.49 kJ ; (b) 2.49 kJ ; (c) 997 J ; (d) 1.00 kJ **45.** (a) $6.6 \times 10^{-26} \text{ kg}$; (b) 40 g/mol **47.** (a) 0; (b) $+374 \text{ J}$; (c) $+374 \text{ J}$; (d) $+3.11 \times 10^{-22} \text{ J}$ **49.** $15.8 \text{ J/mol}\cdot\text{K}$ **51.** 8.0 kJ **53.** (a) 6.98 kJ ; (b) 4.99 kJ ; (c) 1.99 kJ ; (d) 2.99 kJ **55.** (a) 14 atm; (b) $6.2 \times 10^2 \text{ K}$ **57.** (a) diatomic; (b) 446 K ; (c) 8.10 mol **59.** -15 J **61.** -20 J **63.** (a) 3.74 kJ ; (b) 3.74 kJ ; (c) 0; (d) 0; (e) -1.81 kJ ; (f) 1.81 kJ ; (g) -3.22 kJ ; (h) -1.93 kJ ; (i) -1.29 kJ ; (j) 520 J ; (k) 0; (l) 520 J ; (m) 0.0246 m^3 ; (n) 2.00 atm ; (o) 0.0373 m^3 ; (p) 1.00 atm **65.** (a) monatomic; (b) $2.7 \times 10^4 \text{ K}$; (c) $4.5 \times 10^4 \text{ mol}$; (d) 3.4 kJ ; (e) $3.4 \times 10^2 \text{ kJ}$; (f) 0.010 **67.** (a) 2.00 atm ; (b) 333 J ; (c) 0.961 atm ; (d) 236 J **69.** 349 K **71.** (a) -374 J ; (b) 0; (c) $+374 \text{ J}$; (d) $+3.11 \times 10^{-22} \text{ J}$ **73.** $7.03 \times 10^9 \text{ s}^{-1}$ **75.** (a) 900 cal ; (b) 0; (c) 900 cal ; (d) 450 cal ; (e) 1200 cal ; (f) 300 cal ; (g) 900 cal ; (h) 450 cal ; (i) 0; (j) -900 cal ; (k) 900 cal ; (l) 450 cal **77.** (a) $3/v_0^3$; (b) $0.750v_0$; (c) $0.775v_0$ **79.** (a) -2.37 kJ ; (b) 2.37 kJ **81.** (b) 125 J ; (c) to **83.** (a) 8.0 atm ; (b) 300 K ; (c) 4.4 kJ ; (d) 3.2 atm ; (e) 120 K ; (f) 2.9 kJ ; (g) 4.6 atm ; (h) 170 K ; (i) 3.4 kJ **85.** (a) 38 L ; (b) 71 g **87.** -3.0 J **89.** 22.8 m **95.** 1.40 **97.** 4.71

Chapter 20

- CP** **1.** a, b, c **2.** smaller (*Q* is smaller) **3.** c, b, a **4.** a, d, c, b **5.** b **Q** **1.** b, a, c, d **3.** unchanged **5.** a and c tie, then b and d tie **7.** (a) same; (b) increase; (c) decrease **9.** A, first; B, first and second; C, second; D, neither

- P** 1. (a) 9.22 kJ; (b) 23.1 J/K; (c) 0 3. 14.4 J/K 5. (a) 5.79×10^4 J; (b) 173 J/K 7. (a) 320 K; (b) 0; (c) +1.72 J/K 9. +0.76 J/K
11. (a) 57.0°C; (b) -22.1 J/K; (c) +24.9 J/K; (d) +2.8 J/K
13. (a) -710 mJ/K; (b) +710 mJ/K; (c) +723 mJ/K; (d) -723 mJ/K; (e) +13 mJ/K; (f) 0 15. (a) -943 J/K; (b) +943 J/K; (c) yes
17. (a) 0.333; (b) 0.215; (c) 0.644; (d) 1.10; (e) 1.10; (f) 0; (g) 1.10; (h) 0; (i) -0.889; (j) -0.889; (k) -1.10; (l) -0.889; (m) 0; (n) 0.889; (o) 0 19. (a) 0.693; (b) 4.50; (c) 0.693; (d) 0; (e) 4.50; (f) 23.0 J/K; (g) -0.693; (h) 7.50; (i) -0.693; (j) 3.00; (k) 4.50; (l) 23.0 J/K
21. -1.18 J/K 23. 97 K 25. (a) 266 K; (b) 341 K 27. (a) 23.6%; (b) 1.49×10^4 J 29. (a) 2.27 kJ; (b) 14.8 kJ; (c) 15.4%; (d) 75.0%; (e) greater 31. (a) 33 kJ; (b) 25 kJ; (c) 26 kJ; (d) 18 kJ
33. (a) 1.47 kJ; (b) 554 J; (c) 918 J; (d) 62.4% 35. (a) 3.00; (b) 1.98; (c) 0.660; (d) 0.495; (e) 0.165; (f) 34.0% 37. 440 W 39. 20 J
41. 0.25 hp 43. 2.03 47. (a) $W = N!/(n_1! n_2! n_3!)$; (b) $[(N/2)! (N/2)!]/[(N/3)! (N/3)! (N/3)!]$; (c) 4.2×10^{16} 49. 0.141 J/K·s
51. (a) 87 m/s; (b) 1.2×10^2 m/s; (c) 22 J/K 53. (a) 78%; (b) 82 kg/s
55. (a) 40.9°C; (b) -27.1 J/K; (c) 30.3 J/K; (d) 3.18 J/K 57. +3.59 J/K 59. 1.18×10^3 J/K 63. (a) 0; (b) 0; (c) -23.0 J/K; (d) 23.0 J/K
65. (a) 25.5 kJ; (b) 4.73 kJ; (c) 18.5% 67. (a) 1.95 J/K; (b) 0.650 J/K; (c) 0.217 J/K; (d) 0.072 J/K; (e) decrease 69. (a) 4.45 J/K; (b) no
71. (a) 1.26×10^{14} ; (b) 4.71×10^{13} ; (c) 0.37; (d) 1.01×10^{29} ; (e) 1.37×10^{28} ; (f) 0.14; (g) 9.05×10^{58} ; (h) 1.64×10^{57} ; (i) 0.018; (j) decrease 73. (a) 42.6 kJ; (b) 7.61 kJ 75. (a) 1; (b) 1; (c) 3; (d) 10; (e) 1.5×10^{-23} J/K; (f) 3.2×10^{-23} J/K 77. $e = (1 + K)^{-1}$
79. 6.7

Chapter 21

- CP** 1. C and D attract; B and D attract 2. (a) leftward; (b) leftward; (c) leftward 3. (a) a, c, b; (b) less than $-15e$ (net charge of $-30e$ is equally shared)
Q 1. 3, 1, 2, 4 (zero) 3. a and b 5. $2kq^2/r^2$, up the page
7. b and c tie, then a (zero) 9. (a) same; (b) less than; (c) cancel; (d) add; (e) adding components; (f) positive direction of y; (g) negative direction of y; (h) positive direction of x; (i) negative direction of x 11. (a) +4e; (b) -2e upward; (c) -3e upward; (d) -12e upward
P 1. 0.500 3. 1.39 m 5. 2.81 N 7. -4.00 9. (a) -1.00 μ C; (b) 3.00 μ C 11. (a) 0.17 N; (b) -0.046 N 13. (a) -14 cm; (b) 0
15. (a) 35 N; (b) -10°; (c) -8.4 cm; (d) +2.7 cm 17. (a) 1.60 N; (b) 2.77 N 19. (a) 3.00 cm; (b) 0; (c) -0.444 21. 3.8×10^{-8} C
23. (a) 0; (b) 12 cm; (c) 0; (d) 4.9×10^{-26} N 25. 6.3×10^{11}
27. (a) 3.2×10^{-19} C; (b) 2 29. (a) -6.05 cm; (b) 6.05 cm
31. 122 mA 33. 1.3×10^7 C 35. (a) 0; (b) 1.9×10^{-9} N
37. (a) ${}^9\text{B}$; (b) ${}^{13}\text{N}$; (c) ${}^{12}\text{C}$ 39. 1.31×10^{-22} N 41. (a) 5.7×10^{13} C; (b) cancels out; (c) 6.0×10^5 kg 43. (b) 3.1 cm 45. 0.19 MC
47. -45 μ C 49. 3.8 N 51. (a) 2.00×10^{10} electrons; (b) 1.33×10^{10} electrons 53. (a) 8.99×10^9 N; (b) 8.99 kN 55. (a) 0.5; (b) 0.15; (c) 0.85 57. 1.7×10^8 N 59. -1.32×10^{13} C 61. (a) $(0.829 \text{ N})\hat{i}$; (b) $(-0.621 \text{ N})\hat{j}$ 63. 2.2×10^{-6} kg 65. 4.68×10^{-19} N
67. (a) $2.72L$; (b) 0 69. (a) 5.1×10^2 N; (b) 7.7×10^{28} m/s²
71. (a) 0; (b) 3.43×10^9 m/s² 73. (a) 2.19×10^6 m/s; (b) 1.09×10^6 m/s; (c) decrease 75. 4.16×10^{42}

Chapter 22

- CP** 1. (a) rightward; (b) leftward; (c) leftward; (d) rightward (p and e have same charge magnitude, and p is farther)
2. (a) toward positive y; (b) toward positive x; (c) toward negative y
3. (a) leftward; (b) leftward; (c) decrease 4. (a) all tie; (b) 1 and 3 tie, then 2 and 4 tie
Q 1. a, b, c 3. (a) yes; (b) toward; (c) no (the field vectors are not along the same line); (d) cancel; (e) add; (f) adding components;

- (g) toward negative y 5. (a) to their left; (b) no 7. (a) 4, 3, 1, 2; (b) 3, then 1 and 4 tie, then 2 9. a, b, c 11. e, b, then a and c tie, then d (zero) 13. a, b, c
P 3. (a) 3.07×10^{21} N/C; (b) outward 5. 56 pC 7. $(1.02 \times 10^5 \text{ N/C})\hat{j}$ 9. (a) 1.38×10^{-10} N/C; (b) 180° 11. -30 cm
13. (a) 3.60×10^{-6} N/C; (b) 2.55×10^{-6} N/C; (c) 3.60×10^{-4} N/C; (d) 7.09×10^{-7} N/C; (e) As the proton nears the disk, the forces on it from electrons e_s more nearly cancel. 15. (a) 160 N/C; (b) 45°
17. (a) -90°; (b) +2.0 μ C; (c) -1.6 μ C 19. (a) $qd/4\pi\epsilon_0 r^3$; (b) -90°
23. 0.506 25. (a) 1.62×10^6 N/C; (b) -45° 27. (a) 23.8 N/C; (b) -90° 29. 1.57 31. (a) -5.19×10^{-14} C/m; (b) 1.57×10^{-3} N/C; (c) -180°; (d) 1.52×10^{-8} N/C; (e) 1.52×10^{-8} N/C 35. 0.346 m
37. 28% 39. -5e 41. (a) 1.5×10^3 N/C; (b) 2.4×10^{-16} N; (c) up; (d) 1.6×10^{-26} N; (e) 1.5×10^{10} 43. 3.51×10^{15} m/s²
45. 6.6×10^{-15} N 47. (a) 1.92×10^{12} m/s²; (b) 1.96×10^5 m/s
49. (a) 0.245 N; (b) -11.3°; (c) 108 m; (d) -21.6 m 51. 2.6×10^{-10} N; (b) 3.1×10^{-8} N; (c) moves to stigma 53. $27 \mu\text{m}$ 55. (a) 2.7×10^6 m/s; (b) 1.0 kN/C 57. (a) 9.30×10^{-15} C·m; (b) 2.05×10^{-11} J
59. 1.22×10^{-23} J 61. $(1/2\pi)(pE/I)^{0.5}$ 63. (a) 8.87×10^{-15} N; (b) 120 65. 217° 67. 61 N/C 69. (a) 47 N/C; (b) 27 N/C
71. 38 N/C 73. (a) -1.0 cm; (b) 0; (c) 10 pC 75. +1.00 μ C
77. (a) 6.0 mm; (b) 180° 79. 9.30 81. (a) -0.029 C; (b) repulsive forces would explode the sphere 83. (a) -1.49×10^{-26} J; (b) $(-1.98 \times 10^{-26} \text{ N}\cdot\text{m})\hat{k}$; (c) 3.47×10^{-26} J 85. (a) top row: 4, 8, 12; middle row: 5, 10, 14; bottom row: 7, 11, 16; (b) 1.63×10^{-19} C
87. (a) $(-1.80 \text{ N/C})\hat{i}$; (b) $(43.2 \text{ N/C})\hat{i}$; (c) $(-6.29 \text{ N/C})\hat{i}$

Chapter 23

- CP** 1. (a) $+EA$; (b) $-EA$; (c) 0; (d) 0 2. (a) 2; (b) 3; (c) 1
3. (a) equal; (b) equal; (c) equal 4. 3 and 4 tie, then 2, 1
Q 1. (a) $8 \text{ N}\cdot\text{m}^2/\text{C}$; (b) 0 3. all tie 5. all tie 7. a, c, then b and d tie (zero) 9. (a) 2, 1, 3; (b) all tie (+4q) 11. (a) impossible; (b) $-3q_0$; (c) impossible
P 1. $-0.015 \text{ N}\cdot\text{m}^2/\text{C}$ 3. (a) 0; (b) $-3.92 \text{ N}\cdot\text{m}^2/\text{C}$; (c) 0; (d) 0
5. $3.01 \text{ nN}\cdot\text{m}^2/\text{C}$ 7. $2.0 \times 10^5 \text{ N}\cdot\text{m}^2/\text{C}$ 9. (a) $8.23 \text{ N}\cdot\text{m}^2/\text{C}$; (b) 72.9 pC; (c) $8.23 \text{ N}\cdot\text{m}^2/\text{C}$; (d) 72.9 pC 11. -1.70 nC
13. $3.54 \mu\text{C}$ 15. (a) 0; (b) 0.0417 17. (a) $37 \mu\text{C}$; (b) $4.1 \times 10^6 \text{ N}\cdot\text{m}^2/\text{C}$
19. (a) $4.5 \times 10^{-7} \text{ C}/\text{m}^2$; (b) $5.1 \times 10^4 \text{ N/C}$ 21. (a) -3.0×10^{-6} C; (b) $+1.3 \times 10^{-5}$ C 23. (a) 0.32 μ C; (b) 0.14 μ C 25. 5.0 μ C/m
27. $3.8 \times 10^{-8} \text{ C}/\text{m}^2$ 29. (a) 0.214 N/C ; (b) inward; (c) 0.855 N/C ; (d) outward; (e) -3.40×10^{-12} C; (f) -3.40×10^{-12} C 31. (a) $2.3 \times 10^6 \text{ N/C}$; (b) outward; (c) $4.5 \times 10^5 \text{ N/C}$; (d) inward 33. (a) 0; (b) 0; (c) $(-7.91 \times 10^{-11} \text{ N/C})\hat{i}$ 35. -1.5 37. (a) $5.3 \times 10^7 \text{ N/C}$; (b) 60 N/C 39. $5.0 \text{ nC}/\text{m}^2$ 41. 0.44 mm 43. (a) 0; (b) $1.31 \mu\text{N/C}$; (c) $3.08 \mu\text{N/C}$; (d) $3.08 \mu\text{N/C}$ 45. (a) $2.50 \times 10^4 \text{ N/C}$; (b) $1.35 \times 10^4 \text{ N/C}$ 47. -7.5 nC 49. (a) 0; (b) 56.2 mN/C ; (c) 112 mN/C ; (d) 49.9 mN/C ; (e) 0; (f) 0; (g) -5.00 fC; (h) 0 51. $1.79 \times 10^{-11} \text{ C}/\text{m}^2$
53. (a) 7.78 fC ; (b) 0; (c) 5.58 mN/C ; (d) 22.3 mN/C 55. $6K\epsilon_0 r^3$
57. (a) 0; (b) $2.88 \times 10^4 \text{ N/C}$; (c) 200 N/C 59. (a) 5.4 N/C ; (b) 6.8 N/C 61. (a) 0; (b) $q_a/4\pi\epsilon_0 r^2$; (c) $(q_a + q_b)/4\pi\epsilon_0 r^2$
63. -1.04 nC 65. (a) 0.125; (b) 0.500 67. (a) +2.0 nC; (b) -1.2 nC; (c) +1.2 nC; (d) +0.80 nC 69. $(5.65 \times 10^4 \text{ N/C})\hat{i}$
71. (a) $-2.53 \times 10^{-2} \text{ N}\cdot\text{m}^2/\text{C}$; (b) $+2.53 \times 10^{-2} \text{ N}\cdot\text{m}^2/\text{C}$
75. 3.6 nC 77. (a) +4.0 μ C; (b) -4.0 μ C 79. (a) 693 kg/s; (b) 693 kg/s; (c) 347 kg/s; (d) 347 kg/s; (e) 575 kg/s 81. (a) 0.25R; (b) 2.0R

Chapter 24

- CP** 1. (a) negative; (b) increase; (c) positive; (d) higher
2. (a) rightward; (b) 1, 2, 3, 5; positive; 4, negative; (c) 3, then 1, 2, and 5 tie, then 4 3. all tie 4. a, c (zero), b 5. (a) 2, then 1 and 3 tie; (b) 3; (c) accelerate leftward

- Q** **1.** $-4q/4\pi\epsilon_0 d$ **3.** (a) 1 and 2; (b) none; (c) no; (d) 1 and 2, yes; 3 and 4, no **5.** (a) higher; (b) positive; (c) negative; (d) all tie **7.** (a) 0; (b) 0; (c) 0; (d) all three quantities still 0 **9.** (a) 3 and 4 tie, then 1 and 2 tie; (b) 1 and 2, increase; 3 and 4, decrease **11.** *a, b, c* **P** **1.** (a) $3.0 \times 10^5 \text{ C}$; (b) $3.6 \times 10^6 \text{ J}$ **3.** 2.8×10^5 **5.** 8.8 mm **7.** -32.0 V **9.** (a) $1.87 \times 10^{-21} \text{ J}$; (b) -11.7 mV **11.** (a) -0.268 mV; (b) -0.681 mV **13.** (a) 3.3 nC; (b) 12 nC/m² **15.** (a) 0.54 mm; (b) 790 V **17.** 0.562 mV **19.** (a) 6.0 cm; (b) -12.0 cm **21.** 16.3 μV **23.** (a) 24.3 mV; (b) 0 **25.** (a) -2.30 V; (b) -1.78 V **27.** 13 kV **29.** 32.4 mV **31.** 47.1 μV **33.** 18.6 mV **35.** $(-12 \text{ V/m})\hat{i} + (12 \text{ V/m})\hat{j}$ **37.** 150 N/C **39.** $(-4.0 \times 10^{-16} \text{ N})\hat{i} + (1.6 \times 10^{-16} \text{ N})\hat{j}$ **41.** (a) 0.90 J; (b) 4.5 J **43.** -0.192 pJ **45.** 2.5 km/s **47.** 22 km/s **49.** 0.32 km/s **51.** (a) $+6.0 \times 10^4 \text{ V}$; (b) $-7.8 \times 10^5 \text{ V}$; (c) 2.5 J; (d) increase; (e) same; (f) same **53.** (a) 0.225 J; (b) A 45.0 m/s², B 22.5 m/s²; (c) A 7.75 m/s, B 3.87 m/s **55.** $1.6 \times 10^{-9} \text{ m}$ **57.** (a) 3.0 J; (b) -8.5 m **59.** (a) proton; (b) 65.3 km/s **61.** (a) 12; (b) 2 **63.** (a) $-1.8 \times 10^2 \text{ V}$; (b) 2.9 kV; (c) -8.9 kV **65.** $2.5 \times 10^{-8} \text{ C}$ **67.** (a) 12 kN/C; (b) 1.8 kV; (c) 5.8 cm **69.** (a) 64 N/C; (b) 2.9 V; (c) 0 **71.** $p/2\pi\epsilon_0 r^3$ **73.** (a) $3.6 \times 10^5 \text{ V}$; (b) no **75.** $6.4 \times 10^8 \text{ V}$ **77.** 2.90 kV **79.** $7.0 \times 10^5 \text{ m/s}$ **81.** (a) 1.8 cm; (b) $8.4 \times 10^5 \text{ m/s}$; (c) $2.1 \times 10^{-17} \text{ N}$; (d) positive; (e) $1.6 \times 10^{-17} \text{ N}$; (f) negative **83.** (a) $+7.19 \times 10^{-10} \text{ V}$; (b) $+2.30 \times 10^{-28} \text{ J}$; (c) $+2.43 \times 10^{-29} \text{ J}$ **85.** $2.30 \times 10^{-28} \text{ J}$ **87.** 2.1 days **89.** $2.30 \times 10^{-22} \text{ J}$ **91.** $1.48 \times 10^7 \text{ m/s}$ **93.** -1.92 MV **95.** (a) $Q/4\pi\epsilon_0 r$; (b) $(\rho/3\epsilon_0)(1.5r_2^2 - 0.50r^2 - r_1^2r^{-1})$, $\rho = Q/[(4\pi/3)(r_2^3 - r_1^3)]$; (c) $(\rho/2\epsilon_0)(r_2^2 - r_1^2)$, with ρ as in (b); (d) yes **97.** (a) 38 s; (b) 2.7×10^2 days **101.** (a) 0.484 MeV; (b) 0 **103.** -1.7

Chapter 25

- CP** **1.** (a) same; (b) same **2.** (a) decreases; (b) increases; (c) decreases **3.** (a) $V, q/2$; (b) $V/2, q$ **Q** **1.** *a, 2; b, 1; c, 3* **3.** (a) no; (b) yes; (c) all tie **5.** (a) same; (b) same; (c) more; (d) more **7.** *a, series; b, parallel; c, parallel* **9.** (a) increase; (b) same; (c) increase; (d) increase; (e) increase; (f) increase **11.** parallel, C_1 alone, C_2 alone, series **P** **1.** (a) 3.5 pF; (b) 3.5 pF; (c) 57 V **3.** (a) 144 pF; (b) 17.3 nC **5.** 0.280 pF **7.** $6.79 \times 10^{-4} \text{ F/m}^2$ **9.** 315 mC **11.** 3.16 μF **13.** 43 pF **15.** (a) 3.00 μF ; (b) 60.0 μC ; (c) 10.0 V; (d) 30.0 μC ; (e) 10.0 V; (f) 20.0 μC ; (g) 5.00 V; (h) 20.0 μC **17.** (a) 789 μC ; (b) 78.9 V **19.** (a) 4.0 μF ; (b) 2.0 μF **21.** (a) 50 V; (b) $5.0 \times 10^{-5} \text{ C}$; (c) $1.5 \times 10^{-4} \text{ C}$ **23.** (a) 4.5×10^{14} ; (b) 1.5×10^{14} ; (c) 3.0×10^{14} ; (d) 4.5×10^{14} ; (e) up; (f) up **25.** 3.6 pC **27.** (a) 9.00 μC ; (b) 16.0 μC ; (c) 9.00 μC ; (d) 16.0 μC ; (e) 8.40 μC ; (f) 16.8 μC ; (g) 10.8 μC ; (h) 14.4 μC **29.** 72 F **31.** 0.27 J **33.** 0.11 J/m³ **35.** (a) $9.16 \times 10^{-18} \text{ J/m}^3$; (b) $9.16 \times 10^{-6} \text{ J/m}^3$; (c) $9.16 \times 10^6 \text{ J/m}^3$; (d) $9.16 \times 10^{18} \text{ J/m}^3$; (e) ∞ **37.** (a) 16.0 V; (b) 45.1 pJ; (c) 120 pJ; (d) 75.2 pJ **39.** (a) 190 V; (b) 95 mJ **41.** 81 pF/m **43.** Pyrex **45.** 66 μJ **47.** 0.63 m² **49.** 17.3 pF **51.** (a) 10 kV/m; (b) 5.0 nC; (c) 4.1 nC **53.** (a) 89 pF; (b) 0.12 nF; (c) 11 nC; (d) 11 nC; (e) 10 kV/m; (f) 2.1 kV/m; (g) 88 V; (h) -0.17 μJ **55.** (a) 0.107 nF; (b) 7.79 nC; (c) 7.45 nC **57.** 45 μC **59.** 16 μC **61.** (a) 7.20 μC ; (b) 18.0 μC ; (c) Battery supplies charges only to plates to which it is connected; charges on other plates are due to electron transfers between plates, in accord with new distribution of voltages across the capacitors. So the battery does not directly supply charge on capacitor 4. **63.** (a) 10 μC ; (b) 20 μC **65.** 1.06 nC **67.** (a) 2.40 μF ; (b) 0.480 mC; (c) 80 V; (d) 0.480 mC; (e) 120 V **69.** 4.9% **71.** (a) 0.708 pF; (b) 0.600; (c) $1.02 \times 10^{-9} \text{ J}$; (d) sucked in **73.** 5.3 V **75.** 40 μF **77.** (a) 200 kV/m; (b) 200 kV/m; (c) 1.77 $\mu\text{C/m}^2$; (d) 4.60 $\mu\text{C/m}^2$; (e) -2.83 $\mu\text{C/m}^2$ **79.** (a) $q^2/2\epsilon_0 A$

Chapter 26

- CP** **1.** 8 A, rightward **2.** (a)-(c) rightward **3.** *a and c tie, then b 4. device 2* **5.** (a) and (b) tie, then (d), then (c) **Q** **1.** tie of *A, B, and C*, then tie of *A + B* and *B + C*, then *A + B + C* **3.** (a) top-bottom, front-back, left-right; (b) top-bottom, front-back, left-right; (c) top-bottom, front-back, left-right; (d) top-bottom, front-back, left-right **5.** *a, b, and c all tie, then d* **7.** (a) *B, A, C*; (b) *B, A, C* **9.** (a) *C, B, A*; (b) all tie; (c) *A, B, C*; (d) all tie **11.** (a) *a and c tie, then b (zero)*; (b) *a, b, c*; (c) *a and b tie, then c* **P** **1.** (a) 1.2 kC; (b) 7.5×10^{21} **3.** 6.7 $\mu\text{C/m}^2$ **5.** (a) 6.4 A/m²; (b) north; (c) cross-sectional area **7.** 0.38 mm **9.** 18.1 μA **11.** (a) 1.33 A; (b) 0.666 A; (c) J_a **13.** 13 min **15.** 2.4 Ω **17.** $2.0 \times 10^6 (\Omega \cdot \text{m})^{-1}$ **19.** $2.0 \times 10^{-8} \Omega \cdot \text{m}$ **21.** $(1.8 \times 10^3)^\circ\text{C}$ **23.** $8.2 \times 10^{-8} \Omega \cdot \text{m}$ **25.** 54 Ω **27.** 3.0 **29.** $3.35 \times 10^{-7} \text{ C}$ **31.** (a) 6.00 mA; (b) $1.59 \times 10^{-8} \text{ V}$; (c) 21.2 n Ω **33.** (a) 38.3 mA; (b) 109 A/m²; (c) 1.28 cm/s; (d) 227 V/m **35.** 981 k Ω **39.** 150 s **41.** (a) 1.0 kW; (b) US\$0.25 **43.** 0.135 W **45.** (a) 10.9 A; (b) 10.6 Ω ; (c) 4.50 MJ **47.** (a) 5.85 m; (b) 10.4 m **49.** (a) US\$4.46; (b) 144 Ω ; (c) 0.833 A **51.** (a) 5.1 V; (b) 10 V; (c) 10 W; (d) 20 W **53.** (a) 28.8 Ω ; (b) $2.60 \times 10^{19} \text{ s}^{-1}$ **55.** 660 W **57.** 28.8 kC **59.** (a) silver; (b) 51.6 n Ω **61.** (a) 2.3×10^{12} ; (b) 5.0×10^3 ; (c) 10 MV **63.** 2.4 kW **65.** (a) 1.37; (b) 0.730 **67.** (a) -8.6%; (b) smaller **69.** 146 kJ **71.** (a) 250°C; (b) yes **73.** $3.0 \times 10^6 \text{ J/kg}$ **75.** 560 W **77.** 0.27 m/s **79.** (a) 10 A/cm²; (b) eastward **81.** (a) $9.4 \times 10^{13} \text{ s}^{-1}$; (b) $2.40 \times 10^2 \text{ W}$ **83.** 113 min **85.** (a) 225 μC ; (b) 60.0 μA ; (c) 0.450 mW

Chapter 27

- CP** **1.** (a) rightward; (b) all tie; (c) *b*, then *a* and *c* tie; (d) *b*, then *a* and *c* tie **2.** (a) all tie; (b) R_1, R_2, R_3 **3.** (a) less; (b) greater; (c) equal **4.** (a) $V/2, i$; (b) $V, i/2$ **5.** (a) 1, 2, 4, 3; (b) 4, tie of 1 and 2, then 3 **Q** **1.** (a) equal; (b) more **3.** parallel, R_2, R_1 , series **5.** (a) series; (b) parallel; (c) parallel **7.** (a) less; (b) less; (c) more **9.** (a) parallel; (b) series **11.** (a) same; (b) same; (c) less; (d) more **13.** (a) all tie; (b) 1, 3, 2 **P** **1.** (a) 0.50 A; (b) 1.0 W; (c) 2.0 W; (d) 6.0 W; (e) 3.0 W; (f) supplied; (g) absorbed **3.** (a) 14 V; (b) $1.0 \times 10^2 \text{ W}$; (c) $6.0 \times 10^2 \text{ W}$; (d) 10 V; (e) $1.0 \times 10^2 \text{ W}$ **5.** 11 kJ **7.** (a) 80 J; (b) 67 J; (c) 13 J **9.** (a) 12.0 eV; (b) 6.53 W **11.** (a) 50 V; (b) 48 V; (c) negative **13.** (a) 6.9 km; (b) 20 Ω **15.** 8.0 Ω **17.** (a) 0.004 Ω ; (b) 1 **19.** (a) 4.00 Ω ; (b) parallel **21.** 5.56 A **23.** (a) 50 mA; (b) 60 mA; (c) 9.0 V **25.** 3d **27.** $3.6 \times 10^3 \text{ A}$ **29.** (a) 0.333 A; (b) right; (c) 720 J **31.** (a) -11 V; (b) -9.0 V **33.** 48.3 V **35.** (a) 5.25 V; (b) 1.50 V; (c) 5.25 V; (d) 6.75 V **37.** 1.43 Ω **39.** (a) 0.150 Ω ; (b) 240 W **41.** (a) 0.709 W; (b) 0.050 W; (c) 0.346 W; (d) 1.26 W; (e) -0.158 W **43.** 9 **45.** (a) 0.67 A; (b) down; (c) 0.33 A; (d) up; (e) 0.33 A; (f) up; (g) 3.3 V **47.** (a) 1.11 A; (b) 0.893 A; (c) 126 m **49.** (a) 0.45 A **51.** (a) 55.2 mA; (b) 4.86 V; (c) 88.0 Ω ; (d) decrease **53.** -3.0% **57.** 0.208 ms **59.** 4.61 **61.** (a) 2.41 μs ; (b) 161 pF **63.** (a) 1.1 mA; (b) 0.55 mA; (c) 0.55 mA; (d) 0.82 mA; (e) 0.82 mA; (f) 0; (g) $4.0 \times 10^2 \text{ V}$; (h) $6.0 \times 10^2 \text{ V}$ **65.** 411 μA **67.** 0.72 M Ω **69.** (a) 0.955 $\mu\text{C/s}$; (b) 1.08 μW ; (c) 2.74 μW ; (d) 3.82 μW **71.** (a) 3.00 A; (b) 3.75 A; (c) 3.94 A **73.** (a) $1.32 \times 10^7 \text{ A/m}^2$; (b) 8.90 V; (c) copper; (d) $1.32 \times 10^7 \text{ A/m}^2$; (e) 51.1 V; (f) iron **75.** (a) 3.0 kV; (b) 10 s; (c) 11 G Ω **77.** (a) 85.0 Ω ; (b) 915 Ω **81.** 4.0 V **83.** (a) 24.8 Ω ; (b) 14.9 k Ω **85.** the cable **87.** -13 μC **89.** 20 Ω **91.** (a) 3.00 A; (b) down; (c) 1.60 A; (d) down; (e) supply; (f) 55.2 W; (g) supply; (h) 6.40 W **93.** (a) 1.0 V; (b) 50 m Ω **95.** 3 **99.** (a) 1.5 mA; (b) 0; (c) 1.0 mA **101.** 7.50 V

- 103.** (a) 60.0 mA; (b) down; (c) 180 mA; (d) left; (e) 240 mA; (f) up **105.** (a) 4.0 A; (b) up; (c) 0.50 A; (d) down; (e) 64 W; (f) 16 W; (g) supplied; (h) absorbed

Chapter 28

- CP 1.** $a, +z; b, -x; c, \vec{F}_B = 0$ **2.** (a) 2, then tie of 1 and 3 (zero); (b) 4 **3.** (a) electron; (b) clockwise **4.** $-y$ **5.** (a) all tie; (b) 1 and 4 tie, then 2 and 3 tie **Q 1.** (a) no, because \vec{v} and \vec{F}_B must be perpendicular; (b) yes; (c) no, because \vec{B} and \vec{F}_B must be perpendicular **3.** (a) $+z$ and $-z$ tie, then $+y$ and $-y$ tie, then $+x$ and $-x$ tie (zero); (b) $+y$ **5.** (a) \vec{F}_E ; (b) \vec{F}_B **7.** (a) \vec{B}_1 ; (b) \vec{B}_1 into page, \vec{B}_2 out of page; (c) less **9.** (a) positive; (b) $2 \rightarrow 1$ and $2 \rightarrow 4$ tie, then $2 \rightarrow 3$ (which is zero) **11.** (a) negative; (b) equal; (c) equal; (d) half-circle **P 1.** (a) 400 km/s; (b) 835 eV **3.** (a) $(6.2 \times 10^{-14} \text{ N})\hat{k}$; (b) $(-6.2 \times 10^{-14} \text{ N})\hat{k}$ **5.** -2.0 T **7.** $(-11.4 \text{ V/m})\hat{i} - (6.00 \text{ V/m})\hat{j} + (4.80 \text{ V/m})\hat{k}$ **9.** $-(0.267 \text{ mT})\hat{k}$ **11.** 0.68 MV/m **13.** $7.4 \mu\text{V}$ **15.** (a) $(-600 \text{ mV/m})\hat{k}$; (b) 1.20 V **17.** (a) $2.60 \times 10^6 \text{ m/s}$; (b) $0.109 \mu\text{s}$; (c) 0.140 MeV ; (d) 70.0 kV **19.** $1.2 \times 10^{-9} \text{ kg/C}$ **21.** (a) $2.05 \times 10^7 \text{ m/s}$; (b) $467 \mu\text{T}$; (c) 13.1 MHz ; (d) 76.3 ns **23.** $21.1 \mu\text{T}$ **25.** (a) 0.978 MHz ; (b) 96.4 cm **27.** (a) 495 mT ; (b) 22.7 mA ; (c) 8.17 MJ **29.** 65.3 km/s **31.** 5.07 ns **33.** (a) 0.358 ns ; (b) 0.166 mm ; (c) 1.51 mm **35.** (a) 200 eV ; (b) 20.0 keV ; (c) 0.499% **37.** $2.4 \times 10^2 \text{ m}$ **39.** (a) 28.2 N ; (b) horizontally west **41.** (a) 467 mA ; (b) right **43.** (a) 0; (b) 0.138 N ; (c) 0.138 N ; (d) 0 **45.** $(-2.50 \text{ mN})\hat{j} + (0.750 \text{ mN})\hat{k}$ **47.** (a) 0.10 T ; (b) 31° **49.** $(-4.3 \times 10^{-3} \text{ N}\cdot\text{m})\hat{j}$ **51.** 2.45 A **55.** (a) $2.86 \text{ A}\cdot\text{m}^2$; (b) $1.10 \text{ A}\cdot\text{m}^2$ **57.** (a) 12.7 A ; (b) $0.0805 \text{ N}\cdot\text{m}$ **59.** (a) $0.30 \text{ A}\cdot\text{m}^2$; (b) $0.024 \text{ N}\cdot\text{m}$ **61.** (a) $-72.0 \mu\text{J}$; (b) $(96.0\hat{i} + 48.0\hat{k}) \mu\text{N}\cdot\text{m}$ **63.** (a) $(-9.7 \times 10^{-4} \text{ N}\cdot\text{m})\hat{i} - (7.2 \times 10^{-4} \text{ N}\cdot\text{m})\hat{j} + (8.0 \times 10^{-4} \text{ N}\cdot\text{m})\hat{k}$; (b) $-6.0 \times 10^{-4} \text{ J}$ **65.** (a) 90° ; (b) 1; (c) $1.28 \times 10^{-7} \text{ N}\cdot\text{m}$ **67.** (a) 20 min ; (b) $5.9 \times 10^{-2} \text{ N}\cdot\text{m}$ **69.** 8.2 mm **71.** 127 u **73.** (a) $6.3 \times 10^{14} \text{ m/s}^2$; (b) 3.0 mm **75.** (a) 1.4 ; (b) 1.0 **77.** $(-500 \text{ V/m})\hat{j}$ **79.** (a) 0.50 ; (b) 0.50 ; (c) 14 cm ; (d) 14 cm **81.** $(0.80\hat{j} - 1.1\hat{k}) \text{ mN}$ **83.** -40 mC **85.** (a) $(12.8\hat{i} + 6.4\hat{j}) \times 10^{-22} \text{ N}$; (b) 90° ; (c) 173° **87.** (a) up the conducting path; (b) rim; (c) 47.1 V ; (d) 47.1 V ; (e) 2.36 kW **89.** $(mV/2ed^2)^{0.5}$ **91.** $n = JB/eE$

Chapter 29

- CP 1.** b, c, a **2.** d , tie of a and c , then b **3.** d, a , tie of b and c (zero) **Q 1.** c, a, b **3.** c, d , then a and b tie (zero) **5.** a, c, b **7.** c and d tie, then b, a **9.** b, a, d, c (zero) **11.** (a) 1, 3, 2; (b) less **P 1.** (a) $3.3 \mu\text{T}$; (b) yes **3.** (a) 16 A ; (b) east **5.** (a) 1.0 mT ; (b) out; (c) 0.80 mT ; (d) out **7.** (a) $0.102 \mu\text{T}$; (b) out **9.** (a) opposite; (b) 30 A **11.** (a) 4.3 A ; (b) out **13.** 50.3 nT **15.** (a) $1.7 \mu\text{T}$; (b) into; (c) $6.7 \mu\text{T}$; (d) into **17.** 132 nT **19.** $5.0 \mu\text{T}$ **21.** 256 nT **23.** $(-7.75 \times 10^{-23} \text{ N})\hat{i}$ **25.** 2.00 rad **27.** 61.3 mA **29.** $(80 \mu\text{T})\hat{j}$ **31.** (a) $20 \mu\text{T}$; (b) into **33.** $(22.3 \text{ pT})\hat{j}$ **35.** 88.4 pN/m **37.** $(-125 \mu\text{N/m})\hat{i} + (41.7 \mu\text{N/m})\hat{j}$ **39.** 800 nN/m **41.** $(3.20 \text{ mN})\hat{j}$ **43.** (a) 0; (b) 0.850 mT ; (c) 1.70 mT ; (d) 0.850 mT **45.** (a) $-2.5 \mu\text{T}\cdot\text{m}$; (b) 0 **47.** (a) 0; (b) $0.10 \mu\text{T}$; (c) $0.40 \mu\text{T}$ **49.** (a) $533 \mu\text{T}$; (b) $400 \mu\text{T}$ **51.** 0.30 mT **53.** 0.272 A **55.** (a) 4.77 cm ; (b) $35.5 \mu\text{T}$ **57.** (a) $2.4 \text{ A}\cdot\text{m}^2$; (b) 46 cm **59.** $0.47 \text{ A}\cdot\text{m}^2$ **61.** (a) $79 \mu\text{T}$; (b) $1.1 \times 10^{-6} \text{ N}\cdot\text{m}$ **63.** (a) $(0.060 \text{ A}\cdot\text{m}^2)\hat{j}$; (b) $(96 \text{ pT})\hat{j}$ **65.** 1.28 mm **69.** (a) 15 A ; (b) $-z$ **71.** 7.7 mT **73.** (a) $15.3 \mu\text{T}$ **75.** (a) $(0.24\hat{i}) \text{ nT}$; (b) 0; (c) $(-43\hat{k}) \text{ pT}$; (d) $(0.14\hat{k}) \text{ nT}$ **79.** (a) 4.8 mT ; (b) 0.93 mT ; (c) 0 **83.** $(-0.20 \text{ mT})\hat{k}$ **87.** (a) $\mu_0 ir/2\pi c^2$; (b) $\mu_0 l/2\pi r$; (c) $\mu_0 i(a^2 - r^2)/2\pi(a^2 - b^2)r$; (d) 0

Chapter 30

- CP 1.** b , then d and e tie, and then a and c tie (zero) **2.** a and b tie, then c (zero) **3.** c and d tie, then a and b tie **4.** b , out; c , out; d ,

into; e , into **5.** d and e **6.** (a) 2, 3, 1 (zero); (b) 2, 3, 1

7. a and b tie, then c

- Q 1.** out **3.** (a) all tie (zero); (b) 2, then 1 and 3 tie (zero) **5.** d and c tie, then b, a **7.** (a) more; (b) same; (c) same; (d) same (zero) **9.** (a) all tie (zero); (b) 1 and 2 tie, then 3; (c) all tie (zero) **11.** b

- P 1.** 0 **3.** 30 mA **5.** 0 **7.** (a) 31 mV ; (b) left **9.** 0.198 mV **11.** (b) 0.796 m^2 **13.** 29.5 mC **15.** (a) 21.7 V ; (b) counterclockwise **17.** (a) $1.26 \times 10^{-4} \text{ T}$; (b) 0; (c) $1.26 \times 10^{-4} \text{ T}$; (d) yes; (e) $5.04 \times 10^{-8} \text{ V}$ **19.** 5.50 kV **21.** (a) 40 Hz ; (b) 3.2 mV **23.** (a) $\mu_0 R^2 \pi r^2 / 2x^3$; (b) $3\mu_0 i \pi R^2 r^2 v / 2x^4$; (c) counterclockwise **25.** (a) $13 \mu\text{Wb/m}$; (b) 17%; (c) 0 **27.** (a) $80 \mu\text{V}$; (b) clockwise **29.** (a) 48.1 mV ; (b) 2.67 mA ; (c) 0.129 mW **31.** $3.68 \mu\text{W}$ **33.** (a) $240 \mu\text{V}$; (b) 0.600 mA ; (c) $0.144 \mu\text{W}$; (d) $2.87 \times 10^{-8} \text{ N}$; (e) $0.144 \mu\text{W}$ **35.** (a) 0.60 V ; (b) up; (c) 1.5 A ; (d) clockwise; (e) 0.90 W ; (f) 0.18 N ; (g) 0.90 W **37.** (a) $71.5 \mu\text{V/m}$; (b) $143 \mu\text{V/m}$ **39.** 0.15 V/m **41.** (a) 2.45 mWb ; (b) 0.645 mH **43.** $1.81 \mu\text{H/m}$ **45.** (a) decreasing; (b) 0.68 mH **47.** (b) $L_{eq} = \sum L_j$, sum from $j = 1$ to $j = N$ **49.** 59.3 mH **51.** 46Ω **53.** (a) 8.45 ns ; (b) 7.37 mA **55.** 6.91 **57.** (a) 1.5 s **59.** (a) $i[1 - \exp(-Rt/L)]$; (b) $(L/R) \ln 2$ **61.** (a) 97.9 H ; (b) 0.196 mJ **63.** 25.6 ms **65.** (a) 18.7 J ; (b) 5.10 J ; (c) 13.6 J **67.** (a) 34.2 J/m^3 ; (b) 49.4 mJ **69.** $1.5 \times 10^8 \text{ V/m}$ **71.** (a) 1.0 J/m^3 ; (b) $4.8 \times 10^{-15} \text{ J/m}^3$ **73.** (a) 1.67 mH ; (b) 6.00 mWb **75.** $13 \mu\text{H}$ **77.** (b) have the turns of the two solenoids wrapped in opposite directions **79.** (a) 2.0 A ; (b) 0; (c) 2.0 A ; (d) 0; (e) 10 V ; (f) 2.0 A/s ; (g) 2.0 A ; (h) 1.0 A ; (i) 3.0 A ; (j) 10 V ; (k) 0; (l) 0 **81.** (a) $10 \mu\text{T}$; (b) out; (c) $3.3 \mu\text{T}$; (d) out **83.** 0.520 ms **85.** (a) $(4.4 \times 10^7 \text{ m/s}^2)\hat{i}$; (b) 0; (c) $(-4.4 \times 10^7 \text{ m/s}^2)\hat{i}$ **87.** (a) 0.40 V ; (b) 20 A **89.** (a) 10 A ; (b) $1.0 \times 10^2 \text{ J}$ **91.** (a) 0; (b) $8.0 \times 10^2 \text{ A/s}$; (c) 1.8 mA ; (d) $4.4 \times 10^2 \text{ A/s}$; (e) 4.0 mA ; (f) 0 **93.** 1.15 W **95.** (a) 20 A/s ; (b) 0.75 A **97.** 12 A/s **99.** $3 \times 10^{36} \text{ J}$ **101.** (a) 13.9 H ; (b) 120 mA

Chapter 31

- CP 1.** (a) $T/2$; (b) T ; (c) $T/2$; (d) $T/4$ **2.** (a) 5 V ; (b) $150 \mu\text{J}$ **3.** (a) remains the same; (b) remains the same **4.** (a) C, B, A ; (b) 1, $A; 2, B; 3, S; 4, C$; (c) A **5.** (a) remains the same; (b) increases; (c) remains the same; (d) decreases **6.** (a) 1, lags; 2, leads; 3, in phase; (b) 3 ($\omega_d = \omega$ when $X_L = X_C$) **7.** (a) increase (circuit is mainly capacitive; increase C to decrease X_C to be closer to resonance for maximum P_{avg}); (b) closer **8.** (a) greater; (b) step-up **Q 1.** b, a, c **3.** (a) $T/4$; (b) $T/4$; (c) $T/2$; (d) $T/2$ **5.** c, b, a **7.a** inductor; **b** resistor; **c** capacitor **9.** (a) positive; (b) decreased (to decrease X_L and get closer to resonance); (c) decreased (to increase X_C and get closer to resonance) **11.** (a) rightward, increase (X_L increases, closer to resonance); (b) rightward, increase (X_C decreases, closer to resonance); (c) rightward, increase (ω_d/ω increases, closer to resonance) **13.** (a) inductor; (b) decrease **P 1.** (a) $1.17 \mu\text{J}$; (b) 5.58 mA **3.** (a) $6.00 \mu\text{s}$; (b) 167 kHz ; (c) $3.00 \mu\text{s}$ **5.** 45.2 mA **7.** (a) 1.25 kg ; (b) 372 N/m ; (c) $1.75 \times 10^{-4} \text{ m}$; (d) 3.02 mm/s **9.** $7.0 \times 10^{-4} \text{ s}$ **11.** (a) 6.0 ; (b) 36 pF ; (c) 0.22 mH **13.** (a) 0.180 mC ; (b) $70.7 \mu\text{s}$; (c) 66.7 W **15.** (a) 3.0 nC ; (b) 1.7 mA ; (c) 4.5 nJ **17.** (a) 275 Hz ; (b) 365 mA **21.** (a) $356 \mu\text{s}$; (b) 2.50 mH ; (c) 3.20 mJ **23.** (a) $1.98 \mu\text{J}$; (b) $5.56 \mu\text{C}$; (c) 12.6 mA ; (d) -46.9° ; (e) $+46.9^\circ$ **25.** $8.66 \text{ m}\Omega$ **29.** (a) 95.5 mA ; (b) 11.9 mA **31.** (a) 0.65 kHz ; (b) 24Ω **33.** (a) 6.73 ms ; (b) 11.2 ms ; (c) inductor; (d) 138 mH **35.** 89Ω **37.** 7.61 A **39.** (a) 267Ω ; (b) -41.5° ; (c) 135 mA **41.** (a) 206Ω ; (b) 13.7° ; (c) 175 mA **43.** (a) 218Ω ; (b) 23.4° ; (c) 165 mA **45.** (a) yes; (b) 1.0 kV **47.** (a) 224 rad/s ; (b) 6.00 A ; (c) 219 rad/s ; (d) 228 rad/s ; (e) 0.040 **49.** (a) 796 Hz ; (b) no change; (c) decreased; (d) increased **53.** (a) 12.1Ω ; (b) 1.19 kW

- 55.** 1.84 A **57.** (a) $117\text{ }\mu\text{F}$; (b) 0 ; (c) 90.0 W ; (d) 0° ; (e) 1 ; (f) 0 ; (g) -90° ; (h) 0 **59.** (a) 2.59 A ; (b) 38.8 V ; (c) 159 V ; (d) 224 V ; (e) 64.2 V ; (f) 75.0 V ; (g) 100 W ; (h) 0 ; (i) 0 **61.** (a) 0.743 ; (b) lead; (c) capacitive; (d) no; (e) yes; (f) no; (g) yes; (h) 33.4 W **63.** (a) 2.4 V ; (b) 3.2 mA ; (c) 0.16 A **65.** (a) 1.9 V ; (b) 5.9 W ; (c) 19 V ; (d) $5.9 \times 10^2\text{ W}$; (e) 0.19 kW ; (f) 59 kW **67.** (a) 6.73 ms ; (b) 2.24 ms ; (c) capacitor; (d) $59.0\text{ }\mu\text{F}$ **69.** (a) -0.405 rad ; (b) 2.76 A ; (c) capacitive **71.** (a) $64.0\text{ }\Omega$; (b) $50.9\text{ }\Omega$; (c) capacitive **73.** (a) $2.41\text{ }\mu\text{H}$; (b) 21.4 pJ ; (c) 82.2 nC **75.** (a) $39.1\text{ }\Omega$; (b) $21.7\text{ }\Omega$; (c) capacitive **79.** (a) 0.577 Q ; (b) 0.152 **81.** (a) 45.0° ; (b) $70.7\text{ }\Omega$ **83.** 1.84 kHz **85.** (a) $0.689\text{ }\mu\text{H}$; (b) 17.9 pJ ; (c) $0.110\text{ }\mu\text{C}$ **87.** (a) $165\text{ }\Omega$; (b) 313 mH ; (c) $14.9\text{ }\mu\text{F}$ **93.** (a) 36.0 V ; (b) 29.9 V ; (c) 11.9 V ; (d) -5.85 V

Chapter 32

- CP** **1.** d, b, c, a (zero) **2.** a, c, b, d (zero) **3.** tie of b, c , and d , then a **4.** (a) 2 ; (b) 1 **5.** (a) away; (b) away; (c) less **6.** (a) toward; (b) toward; (c) less

- Q** **1.** 1 $a, 2$ $b, 3$ c and d **3.** a , decreasing; b , decreasing **5.** supplied **7.** (a) a and b tie, then c, d ; (b) none (because plate lacks circular symmetry, \vec{B} not tangent to any circular loop); (c) none **9.** (a) 1 up, 2 up, 3 down; (b) 1 down, 2 up, 3 zero **11.** (a) $1, 3, 2$; (b) 2

- P** **1.** $+3\text{ Wb}$ **3.** (a) $47.4\text{ }\mu\text{Wb}$; (b) inward **5.** $2.4 \times 10^{13}\text{ V/m}\cdot\text{s}$ **7.** (a) $1.18 \times 10^{-19}\text{ T}$; (b) $1.06 \times 10^{-19}\text{ T}$ **9.** (a) $5.01 \times 10^{-22}\text{ T}$; (b) $4.51 \times 10^{-22}\text{ T}$ **11.** (a) 1.9 pT **13.** $7.5 \times 10^5\text{ V/s}$ **17.** (a) 0.324 V/m ; (b) $2.87 \times 10^{-16}\text{ A}$; (c) 2.87×10^{-18} **19.** (a) 75.4 nT ; (b) 67.9 nT **21.** (a) 27.9 nT ; (b) 15.1 nT **23.** (a) 2.0 A ; (b) $2.3 \times 10^{11}\text{ V/m}\cdot\text{s}$; (c) 0.50 A ; (d) $0.63\text{ }\mu\text{T}\cdot\text{m}$ **25.** (a) $0.63\text{ }\mu\text{T}$; (b) $2.3 \times 10^{12}\text{ V/m}\cdot\text{s}$ **27.** (a) 0.71 A ; (b) 0 ; (c) 2.8 A **29.** (a) $7.60\text{ }\mu\text{A}$; (b) $859\text{ kV}\cdot\text{m/s}$; (c) 3.39 mm ; (d) 5.16 pT **31.** $55\text{ }\mu\text{T}$ **33.** (a) 0 ; (b) 0 ; (c) 0 ; (d) $\pm 3.2 \times 10^{-25}\text{ J}$; (e) $-3.2 \times 10^{-34}\text{ J}\cdot\text{s}$; (f) $2.8 \times 10^{-23}\text{ J/T}$; (g) $-9.7 \times 10^{-25}\text{ J}$; (h) $\pm 3.2 \times 10^{-25}\text{ J}$ **35.** (a) $-9.3 \times 10^{-24}\text{ J/T}$; (b) $1.9 \times 10^{-23}\text{ J/T}$ **37.** (b) $+x$; (c) clockwise; (d) $+x$ **39.** yes **41.** 20.8 mJ/T **43.** (b) K_i/B ; (c) $-z$; (d) 0.31 kA/m **47.** (a) $1.8 \times 10^2\text{ km}$; (b) 2.3×10^{-5} **49.** (a) $3.0\text{ }\mu\text{T}$; (b) $5.6 \times 10^{-10}\text{ eV}$ **51.** $5.15 \times 10^{-24}\text{ A}\cdot\text{m}^2$ **53.** (a) 0.14 A ; (b) $79\text{ }\mu\text{C}$ **55.** (a) $6.3 \times 10^8\text{ A}$; (b) yes; (c) no **57.** 0.84 kJ/T **59.** (a) $(1.2 \times 10^{-13}\text{ T}) \exp[-t/(0.012\text{ s})]$; (b) $5.9 \times 10^{-15}\text{ T}$ **63.** (a) 27.5 mm ; (b) 110 mm **65.** 8.0 A **67.** (a) $-8.8 \times 10^{15}\text{ V/m}\cdot\text{s}$; (b) $5.9 \times 10^{-7}\text{ T}\cdot\text{m}$ **69.** (b) sign is minus; (c) no, because there is compensating positive flux through open end nearer to magnet **71.** (b) $-x$; (c) counterclockwise; (d) $-x$ **73.** (a) 7 ; (b) 7 ; (c) $3h/2\pi$; (d) $3eh/4\pi m$; (e) $3.5h/2\pi$; (f) 8 **75.** (a) 9 ; (b) $3.71 \times 10^{-23}\text{ J/T}$; (c) $+9.27 \times 10^{-24}\text{ J}$; (d) $-9.27 \times 10^{-24}\text{ J}$

Chapter 33

- CP** **1.** (a) (Use Fig. 33-5.) On right side of rectangle, \vec{E} is in negative y direction; on left side, $\vec{E} + d\vec{E}$ is greater and in same direction; (b) \vec{E} is downward. On right side, \vec{B} is in negative z direction; on left side, $\vec{B} + d\vec{B}$ is greater and in same direction. **2.** positive direction of x **3.** (a) same; (b) decrease **4.** a, d, b, c (zero) **5.** a

- Q** **1.** (a) positive direction of z ; (b) x **3.** (a) same; (b) increase; (c) decrease **5.** (a) and (b) $A = 1, n = 4, \theta = 30^\circ$ **7.** a, b, c **9.** B **11.** none

- P** **1.** 7.49 GHz **3.** (a) 515 nm ; (b) 610 nm ; (c) 555 nm ; (d) $5.41 \times 10^{14}\text{ Hz}$; (e) $1.85 \times 10^{-15}\text{ s}$ **5.** $5.0 \times 10^{-21}\text{ H}$ **7.** 1.2 MW/m^2 **9.** 0.10 MJ **11.** (a) 6.7 nT ; (b) y ; (c) negative direction of y **13.** (a) 1.03 kV/m ; (b) $3.43\text{ }\mu\text{T}$ **15.** (a) 87 mV/m ; (b) 0.29 nT ;

- (c) 6.3 kW **17.** (a) 6.7 nT ; (b) 5.3 mW/m^2 ; (c) 6.7 W **19.** $1.0 \times 10^7\text{ Pa}$

- 21.** $5.9 \times 10^{-8}\text{ Pa}$ **23.** (a) $4.68 \times 10^{11}\text{ W}$; (b) any chance disturbance could move sphere from directly above source—the two force vectors no longer along the same axis **27.** (a) $1.0 \times 10^8\text{ Hz}$; (b) $6.3 \times 10^8\text{ rad/s}$; (c) 2.1 m^{-1} ; (d) $1.0\text{ }\mu\text{T}$; (e) z ; (f) $1.2 \times 10^2\text{ W/m}^2$; (g) $8.0 \times 10^{-7}\text{ N}$; (h) $4.0 \times 10^{-7}\text{ Pa}$ **29.** 1.9 mm/s **31.** (a) $0.17\text{ }\mu\text{m}$; (b) toward the Sun **33.** 3.1% **35.** 4.4 W/m^2 **37.** (a) 2 sheets; (b) 5 sheets **39.** (a) 1.9 V/m ; (b) $1.7 \times 10^{-11}\text{ Pa}$ **41.** 20° or 70° **43.** 0.67 **45.** 1.26 **47.** 1.48 **49.** 180° **51.** (a) 56.9° ; (b) 35.3°

- 55.** 1.07 m **57.** 182 cm **59.** (a) 48.9° ; (b) 29.0° **61.** (a) 26.8° ; (b) yes **63.** (a) $(1 + \sin^2 \theta)^{0.5}$; (b) $2^{0.5}$; (c) yes; (d) no **65.** 23.2°

- 67.** (a) 1.39 ; (b) 28.1° ; (c) no **69.** 49.0° **71.** (a) 0.50 ms ; (b) 8.4 min ; (c) 2.4 h ; (d) 5446 B.C. **73.** (a) $(16.7\text{ nT}) \sin[(1.00 \times 10^6\text{ m}^{-1})z + (3.00 \times 10^{14}\text{ s}^{-1})t]$; (b) $6.28\text{ }\mu\text{m}$; (c) 20.9 fs ; (d) 33.2 mW/m^2 ; (e) x ; (f) infrared **75.** 1.22 **77.** (c) 137.6° ; (d) 139.4° ; (e) 1.7°

- 81.** (a) z axis; (b) $7.5 \times 10^{14}\text{ Hz}$; (c) 1.9 kW/m^2 **83.** (a) white; (b) white dominated by red end; (c) no refracted light

- 85.** $1.5 \times 10^{-9}\text{ m/s}^2$ **87.** (a) $3.5\text{ }\mu\text{W/m}^2$; (b) $0.78\text{ }\mu\text{W}$; (c) $1.5 \times 10^{-17}\text{ W/m}^2$; (d) $1.1 \times 10^{-7}\text{ V/m}$; (e) 0.25 fT **89.** (a) 55.8° ; (b) 55.5° **91.** (a) 83 W/m^2 ; (b) 1.7 MW **93.** 35° **97.** $\cos^{-1}(p/50)^{0.5}$

- 99.** $8RI/3c$ **101.** 0.034 **103.** $9.43 \times 10^{-10}\text{ T}$ **105.** (a) $-y$; (b) z ; (c) 1.91 kW/m^2 ; (d) $E_z = (1.20\text{ kV/m}) \sin[(6.67 \times 10^6\text{ m}^{-1})y + (2.00 \times 10^{15}\text{ s}^{-1})t]$; (e) 942 nm ; (f) infrared **107.** (a) 1.60 ; (b) 58.0°

Chapter 34

- CP** **1.** $0.2d, 1.8d, 2.2d **2.** (a) real; (b) inverted; (c) same **3.** (a) e ; (b) virtual, same **4.** virtual, same as object, diverging$

- Q** **1.** (a) a ; (b) c **3.** (a) a and c ; (b) three times; (c) you **5.** convex **7.** (a) all but variation 2; (b) 1, 3, 4: right, inverted; 5, 6: left, same **9.** d (infinite), tie of a and b , then c **11.** (a) x ; (b) no; (c) no; (d) the direction you are facing

- P** **1.** 9.10 m **3.** 1.11 **5.** 351 cm **7.** 10.5 cm **9.** (a) $+24\text{ cm}$; (b) $+36\text{ cm}$; (c) -2.0 ; (d) R ; (e) I ; (f) same **11.** (a) -20 cm ; (b) -4.4 cm ; (c) $+0.56$; (d) V ; (e) NI ; (f) opposite **13.** (a) $+36\text{ cm}$; (b) -36 cm ; (c) $+3.0$; (d) V ; (e) NI ; (f) opposite **15.** (a) -16 cm ; (b) -4.4 cm ; (c) $+0.44$; (d) V ; (e) NI ; (f) opposite **17.** (b) plus; (c) $+40\text{ cm}$; (e) -20 cm ; (f) $+2.0$; (g) V ; (h) NI ; (i) opposite **19.** (a) convex; (b) -20 cm ; (d) $+20\text{ cm}$; (f) $+0.50$; (g) V ; (h) NI ; (i) opposite **21.** (a) concave; (c) $+40\text{ cm}$; (e) $+60\text{ cm}$; (f) -2.0 ; (g) R ; (h) I ; (i) same **23.** (a) convex; (b) minus; (c) -60 cm ; (d) $+1.2\text{ m}$; (e) -24 cm ; (g) V ; (h) NI ; (i) opposite **25.** (a) concave; (b) $+8.6\text{ cm}$; (c) $+17\text{ cm}$; (e) $+12\text{ cm}$; (f) minus; (g) R ; (i) same **27.** (a) convex; (c) -60 cm ; (d) $+30\text{ cm}$; (f) $+0.50$; (g) V ; (h) NI ; (i) opposite **29.** (b) -20 cm ; (c) minus; (d) $+5.0\text{ cm}$; (e) minus; (f) $+0.80$; (g) V ; (h) NI ; (i) opposite **31.** (b) 0.56 cm/s ; (c) 11 m/s ; (d) 6.7 cm/s **33.** (c) -33 cm ; (e) V ; (f) same **35.** (d) -26 cm ; (e) V ; (f) same **37.** (c) $+30\text{ cm}$; (e) V ; (f) same **39.** (a) 2.00 ; (b) none **41.** (a) $+40\text{ cm}$; (b) ∞ **43.** 5.0 mm **45.** 1.86 mm **47.** (a) 45 mm ; (b) 90 mm **49.** 22 cm **51.** (a) -48 cm ; (b) $+4.0$; (c) V ; (d) NI ; (e) same **53.** (a) -4.8 cm ; (b) $+0.60$; (c) V ; (d) NI ; (e) same **55.** (a) -8.6 cm ; (b) $+0.39$; (c) V ; (d) NI ; (e) same **57.** (a) $+36\text{ cm}$; (b) -0.80 ; (c) R ; (d) I ; (e) opposite **59.** (a) $+55\text{ cm}$; (b) -0.74 ; (c) R ; (d) I ; (e) opposite **61.** (a) -18 cm ; (b) $+0.76$; (c) V ; (d) NI ; (e) same **63.** (a) -30 cm ; (b) $+0.86$; (c) V ; (d) NI ; (e) same **65.** (a) -7.5 cm ; (b) $+0.75$; (c) V ; (d) NI ; (e) same **67.** (a) $+84\text{ cm}$; (b) -1.4 ; (c) R ; (d) I ; (e) opposite **69.** (a) C ; (d) -10 cm ; (e) $+2.0$; (f) V ; (g) NI ; (h) same **71.** (a) D ; (b) -5.3 cm ; (d) -4.0 cm ; (f) V ; (g) NI ; (h) same **73.** (a) C ; (b) $+3.3\text{ cm}$; (d) $+5.0\text{ cm}$; (f) R ; (g) I ; (h) opposite **75.** (a) D ; (b) minus; (d) -3.3 cm ; (e) $+0.67$; (f) V ; (g) NI **77.** (a) C ; (b) $+80\text{ cm}$; (d) -20 cm ; (f) V ; (g) NI ; (h) same **79.** (a) C ; (b) plus; (d) -13 cm ; (e) $+1.7$; (f) V ; (g) NI ; (h) same

- 81.** (a) +24 cm; (b) +6.0; (c) R; (d) NI; (e) opposite
83. (a) +3.1 cm; (b) -0.31; (c) R; (d) I; (e) opposite **85.** (a) -4.6 cm;
(b) +0.69; (c) V; (d) NI; (e) same **87.** (a) -5.5 cm; (b) +0.12; (c) V;
(d) NI; (e) same **89.** (a) 13.0 cm; (b) 5.23 cm; (c) -3.25; (d) 3.13;
(e) -10.2 **91.** (a) 2.35 cm; (b) decrease **93.** (a) 3.5; (b) 2.5
95. (a) +8.6 cm; (b) +2.6; (c) R; (d) NI; (e) opposite
97. (a) +7.5 cm; (b) -0.75; (c) R; (d) I; (e) opposite **99.** (a) +24 cm;
(b) -0.58; (c) R; (d) I; (e) opposite **105.** (a) 3.00 cm; (b) 2.33 cm
107. (a) 40 cm; (b) 20 cm; (c) -40 cm; (d) 40 cm **109.** (a) 20 cm;
(b) 15 cm **111.** (a) 6.0 mm; (b) 1.6 kW/m²; (c) 4.0 cm **113.** 100 cm
115. 2.2 mm² **119.** (a) -30 cm; (b) not inverted; (c) virtual; (d) 1.0
121. (a) -12 cm **123.** (a) 80 cm; (b) 0 to 12 cm **127.** (a) 8.0 cm;
(b) 16 cm; (c) 48 cm **129.** (a) $\alpha = 0.500 \text{ rad}$: 7.799 cm; $\alpha = 0.100 \text{ rad}$:
8.544 cm; $\alpha = 0.0100 \text{ rad}$: 8.571 cm; mirror equation: 8.571 cm;
(b) $\alpha = 0.500 \text{ rad}$: -13.56 cm; $\alpha = 0.100 \text{ rad}$: -12.05 cm; $\alpha = 0.0100 \text{ rad}$:
-12.00 cm; mirror equation: -12.00 cm **131.** 42 mm
133. (b) P_n **135.** (a) $(0.5)(2-n)r/(n-1)$; (b) right **137.** 2.67 cm
139. (a) 3.33 cm; (b) left; (c) virtual; (d) not inverted
141. (a) $1 + (25 \text{ cm})/f$; (b) $(25 \text{ cm})/f$; (c) 3.5; (d) 2.5

Chapter 35

- CP** **1.** b (least n), c, a **2.** (a) top; (b) bright intermediate illumination (phase difference is 2.1 wavelengths) **3.** (a) 3λ , 3; (b) 2.5λ , 2.5
4. a and d tie (amplitude of resultant wave is $4E_0$), then b and c tie (amplitude of resultant wave is $2E_0$) **5.** (a) 1 and 4; (b) 1 and 4
Q **1.** (a) decrease; (b) decrease; (c) decrease; (d) blue **3.** (a) 2d;
(b) (odd number) $\lambda/2$; (c) $\lambda/4$ **5.** (a) intermediate closer to maximum, $m = 2$; (b) minimum, $m = 3$; (c) intermediate closer to maximum, $m = 2$; (d) maximum, $m = 1$ **7.** (a) maximum;
(b) minimum; (c) alternates **9.** (a) peak; (b) valley **11.** c, d **13.** c
P **1.** (a) 155 nm; (b) 310 nm **3.** (a) $3.60 \mu\text{m}$; (b) intermediate closer to fully constructive **5.** $4.55 \times 10^7 \text{ m/s}$ **7.** 1.56
9. (a) $1.55 \mu\text{m}$; (b) $4.65 \mu\text{m}$ **11.** (a) 1.70; (b) 1.70; (c) 1.30;
(d) all tie **13.** (a) 0.833; (b) intermediate closer to fully constructive **15.** 648 nm **17.** 16 **19.** 2.25 mm **21.** 7.2 μm
23. 0 **25.** 7.88 μm **27.** 6.64 μm **29.** 2.65 **31.** $27 \sin(\omega t + 8.5^\circ)$
33. $(17.1 \mu\text{V}/\text{m}) \sin[(2.0 \times 10^{14} \text{ rad/s})t]$ **35.** 120 nm **37.** 70.0 nm
39. (a) $0.117 \mu\text{m}$; (b) $0.352 \mu\text{m}$ **41.** 161 nm **43.** 560 nm
45. 478 nm **47.** 509 nm **49.** 273 nm **51.** 409 nm **53.** 338 nm
55. (a) 552 nm; (b) 442 nm **57.** 608 nm **59.** 528 nm **61.** 455 nm
63. 248 nm **65.** 339 nm **67.** 329 nm **69.** 1.89 μm **71.** 0.012°
73. 140 **75.** $[(m + \frac{1}{2})\lambda R]^{0.5}$, for $m = 0, 1, 2, \dots$ **77.** 1.00 m
79. 588 nm **81.** 1.00030 **83.** (a) 50.0 nm; (b) 36.2 nm **85.** 0.23°
87. (a) 1500 nm; (b) 2250 nm; (c) 0.80 **89.** $x = (D/2a)(m + 0.5)\lambda$, for $m = 0, 1, 2, \dots$ **91.** (a) 22°; (b) refraction reduces θ **93.** 600 nm **95.** (a) $1.75 \mu\text{m}$; (b) 4.8 mm **97.** $I_m \cos^2(2\pi x/\lambda)$ **99.** (a) 42.0 ps; (b) 42.3 ps; (c) 43.2 ps; (d) 41.8 ps; (e) 4 **101.** 33 μm
103. (a) bright; (b) 594 nm; (c) Primary reason: the colored bands begin to overlap too much to be distinguished. Secondary reason: the two reflecting surfaces are too separated for the light reflecting from them to be coherent.

Chapter 36

- CP** **1.** (a) expand; (b) expand **2.** (a) second side maximum; (b) 2.5 **3.** (a) red; (b) violet **4.** diminish **5.** (a) left; (b) less
Q **1.** (a) $m = 5$ minimum; (b) (approximately) maximum between the $m = 4$ and $m = 5$ minima **3.** (a) A, B, C; (b) A, B, C
5. (a) 1 and 3 tie, then 2 and 4 tie; (b) 1 and 2 tie, then 3 and 4 tie
7. (a) larger; (b) red **9.** (a) decrease; (b) same; (c) remain in place
11. (a) A; (b) left; (c) left; (d) right **13.** (a) 1 and 2 tie, then 3; (b) yes; (c) no

- P** **1.** (a) 2.5 mm; (b) $2.2 \times 10^{-4} \text{ rad}$ **3.** (a) 70 cm; (b) 1.0 mm
5. (a) 700 nm; (b) 4; (c) 6 **7.** $6.04 \mu\text{m}$ **9.** 1.77 mm **11.** 160°
13. (a) 0.18° ; (b) 0.46 rad; (c) 0.93 **15.** (d) 52.5° ; (e) 10.1° ; (f) 5.06°
17. (b) 0; (c) -0.500; (d) 4.493 rad; (e) 0.930; (f) 7.725 rad; (g) 1.96
19. (a) 19 cm; (b) larger **21.** (a) $1.1 \times 10^4 \text{ km}$; (b) 11 km
23. (a) $1.3 \times 10^{-4} \text{ rad}$; (b) 10 km **25.** 50 m **27.** $1.6 \times 10^3 \text{ km}$
29. (a) $8.8 \times 10^{-7} \text{ rad}$; (b) $8.4 \times 10^7 \text{ km}$; (c) 0.025 mm **31.** (a) 0.346°; (b) 0.97° **33.** (a) 17.1 m; (b) 1.37×10^{-10} **35.** 5 **37.** 3
39. (a) $5.0 \mu\text{m}$; (b) $20 \mu\text{m}$ **41.** (a) 7.43×10^{-3} ; (b) between the $m = 6$ minimum (the seventh one) and the $m = 7$ maximum (the seventh side maximum); (c) between the $m = 3$ minimum (the third one) and the $m = 4$ minimum (the fourth one)
43. (a) 9; (b) 0.255 **45.** (a) 62.1° ; (b) 45.0° ; (c) 32.0° **47.** 3
49. (a) $6.0 \mu\text{m}$; (b) $1.5 \mu\text{m}$; (c) 9; (d) 7; (e) 6 **51.** (a) 2.1° ; (b) 21° ; (c) 11 **53.** (a) 470 nm; (b) 560 nm **55.** 3.65×10^3
57. (a) $0.032^\circ/\text{nm}$; (b) 4.0×10^4 ; (c) $0.076^\circ/\text{nm}$; (d) 8.0×10^4 ; (e) $0.24^\circ/\text{nm}$; (f) 1.2×10^5 **59.** 0.15 nm **61.** (a) $10 \mu\text{m}$; (b) 3.3 mm
63. $1.09 \times 10^3 \text{ rulings/mm}$ **65.** (a) 0.17 nm; (b) 0.13 nm
67. (a) 25 pm; (b) 38 pm **69.** 0.26 nm **71.** (a) 15.3° ; (b) 30.6° ; (c) 3.1° ; (d) 37.8° **73.** (a) $0.7071a_0$; (b) $0.4472a_0$; (c) $0.3162a_0$; (d) $0.2774a_0$; (e) $0.2425a_0$ **75.** (a) 625 nm; (b) 500 nm; (c) 416 nm
77. 3.0 mm **83.** (a) 13; (b) 6 **85.** 59.5 pm **87.** 4.9 km **89.** 1.36×10^4
91. 2 **93.** 4.7 cm **97.** 36 cm **99.** (a) fourth; (b) seventh
103. (a) $2.4 \mu\text{m}$; (b) $0.80 \mu\text{m}$; (c) 2 **107.** 9

Chapter 37

- CP** **1.** (a) same (speed of light postulate); (b) no (the start and end of the flight are spatially separated); (c) no (because his measurement is not a proper time) **2.** (a) Eq. 2; (b) $+0.90c$; (c) 25 ns; (d) -7.0 m **3.** (a) right; (b) more **4.** (a) equal; (b) less
Q **1.** c **3.** b **5.** (a) C'_1 ; (b) C'_1 **7.** (a) 4 s; (b) 3 s; (c) 5 s; (d) 4 s; (e) 10 s **9.** (a) a tie of 3, 4, and 6, then a tie of 1, 2, and 5; (b) 1, then a tie of 2 and 3, then 4, then a tie of 5 and 6; (c) 1, 2, 3, 4, 5, 6; (d) 2 and 4; (e) 1, 2, 5 **11.** (a) 3, tie of 1 and 2, then 4; (b) 4, tie of 1 and 2, then 3; (c) 1, 4, 2, 3
P **1.** 0.99050 **3.** (a) 0.999 999 50 **5.** 0.446 ps **7.** $2.68 \times 10^3 \text{ y}$
9. (a) 87.4 m; (b) 394 ns **11.** 1.32 m **13.** (a) 26.26 y; (b) 52.26 y; (c) 3.705 y **15.** (a) 0.999 999 15; (b) 30 ly
17. (a) 138 km; (b) -374 μs **19.** (a) $25.8 \mu\text{s}$; (b) small flash
21. (a) $\gamma[1.00 \mu\text{s} - \beta(400 \text{ m})/(2.998 \times 10^8 \text{ m/s})]$; (d) 0.750; (e) $0 < \beta < 0.750$; (f) $0.750 < \beta < 1$; (g) no **23.** (a) 1.25; (b) 0.800 μs
25. (a) 0.480; (b) negative; (c) big flash; (d) 4.39 μs **27.** 0.81c
29. (a) 0.35; (b) 0.62 **31.** 1.2 μs **33.** (a) 1.25 y; (b) 1.60 y; (c) 4.00 y
35. 22.9 MHz **37.** 0.13c **39.** (a) 550 nm; (b) yellow
41. (a) 196.695; (b) 0.999 987 **43.** (a) 1.0 keV; (b) 1.1 MeV
45. 110 km **47.** $1.01 \times 10^7 \text{ km}$ **49.** (a) 0.222 cm; (b) 701 ps; (c) 7.40 ps **51.** 2.83mc **53.** $\gamma(2\pi n/lq|B|)$; (b) no; (c) 4.85 mm; (d) 15.9 mm; (e) 16.3 ps; (f) 0.334 ns **55.** (a) 0.707; (b) 1.41; (c) 0.414 **57.** 1.18 smu/y **59.** (a) 2.08 MeV; (b) -1.21 MeV
61. (d) 0.801 **63.** (a) $vt \sin \theta$; (b) $t[1 - (v/c) \cos \theta]$; (c) 3.24c
67. (b) $+0.44c$ **69.** (a) 1.93 m; (b) 6.00 m; (c) 13.6 ns; (d) 13.6 ns; (e) 0.379 m; (f) 30.5 m; (g) -101 ns; (h) no; (i) 2; (k) no; (l) both
71. (a) $5.4 \times 10^4 \text{ km/h}$; (b) 6.3×10^{-10} **73.** 189 MeV
75. $8.7 \times 10^{-3} \text{ ly}$ **77.** 7 **79.** 2.46 MeV/c **81.** 0.27c
83. (a) 5.71 GeV; (b) 6.65 GeV; (c) 6.58 GeV/c; (d) 3.11 MeV; (e) 3.62 MeV; (f) 3.59 MeV/c **85.** 0.95c **87.** (a) 256 kV; (b) 0.745c
89. (a) 0.858c; (b) 0.185c **91.** 0.500c **93.** (a) 119 MeV; (b) 64.0 MeV/c; (c) 81.3 MeV; (d) 64.0 MeV/c **95.** 4.00 u, probably a helium nucleus **97.** (a) 534; (b) 0.999 998 25; (c) 2.23 T
99. (a) 415 nm; (b) blue **101.** (a) 88 kg; (b) no **103.** (a) 3×10^{-18} ; (b) 2×10^{-12} ; (c) 8.2×10^{-8} ; (d) 6.4×10^{-6} ; (e) 1.1×10^{-6} ; (f) 3.7×10^{-5} ; (g) 9.9×10^{-5} ; (h) 0.10

Chapter 38

- CP** 1. b, a, d, c 2. (a) lithium, sodium, potassium, cesium; (b) all tie 3. (a) same; (b)–(d) x rays 4. (a) proton; (b) same; (c) proton 5. same
- Q** 1. (a) greater; (b) less 3. potassium 5. only e 7. none 9. (a) decreases by a factor of $(1/2)^{0.5}$; (b) decreases by a factor of $1/2$ 11. amplitude of reflected wave is less than that of incident wave 13. electron, neutron, alpha particle 15. all tie
- P** 1. (a) $2.1 \mu\text{m}$; (b) infrared 3. 1.0×10^{45} photons/s 5. 2.047 eV 7. $1.1 \times 10^{-10} \text{ W}$ 9. (a) 2.96×10^{20} photons/s; (b) $4.86 \times 10^7 \text{ m}$; (c) 5.89×10^{18} photons/ $\text{m}^2 \cdot \text{s}$ 11. (a) infrared; (b) 1.4×10^{21} photons/s 13. 4.7×10^{26} photons 15. 170 nm 17. 676 km/s 19. 1.3 V ; (b) $6.8 \times 10^2 \text{ km/s}$ 21. (a) 3.1 keV ; (b) 14 keV 23. (a) 2.00 eV ; (b) 0; (c) 2.00 V ; (d) 295 nm 25. (a) 382 nm ; (b) 1.82 eV 27. (a) 2.73 pm ; (b) 6.05 pm 29. (a) $8.57 \times 10^{18} \text{ Hz}$; (b) $3.55 \times 10^4 \text{ eV}$; (c) $35.4 \text{ keV}/c$ 31. 300% 33. (a) $-8.1 \times 10^{-9}\%$; (b) $-4.9 \times 10^{-4}\%$; (c) -8.9% ; (d) -66% 35. (a) 2.43 pm ; (b) 1.32 fm ; (c) 0.511 MeV ; (d) 939 MeV 37. (a) 41.8 keV ; (b) 8.2 keV 39. 44° 41. (a) 2.43 pm ; (b) 4.11×10^{-6} ; (c) $-8.67 \times 10^{-6} \text{ eV}$; (d) 2.43 pm ; (e) 9.78×10^{-2} ; (f) -4.45 keV 43. (a) $2.9 \times 10^{-10} \text{ m}$; (b) x ray; (c) $2.9 \times 10^{-8} \text{ m}$; (d) ultraviolet 45. (a) $9.35 \mu\text{m}$; (b) $1.47 \times 10^{-5} \text{ W}$; (c) 6.93×10^{14} photons/s; (d) $2.33 \times 10^{-37} \text{ W}$; (e) 5.87×10^{-19} photons/s 47. 7.75 pm 49. (a) $1.9 \times 10^{-21} \text{ kg} \cdot \text{m/s}$; (b) 346 fm 51. $4.3 \mu\text{eV}$ 53. (a) $1.24 \mu\text{m}$; (b) 1.22 nm ; (c) 1.24 fm 55. (a) 15 keV ; (b) 120 keV 57. neutron 59. (a) $3.96 \times 10^6 \text{ m/s}$; (b) 81.7 kV 67. $2.1 \times 10^{-24} \text{ kg} \cdot \text{m/s}$ 71. (a) $1.45 \times 10^{11} \text{ m}^{-1}$; (b) $7.25 \times 10^{10} \text{ m}^{-1}$; (c) 0.111 ; (d) 5.56×10^4 73. 4.81 mA 75. (a) 9.02×10^{-6} ; (b) 3.0 MeV ; (c) 3.0 MeV ; (d) 7.33×10^{-8} ; (e) 3.0 MeV ; (f) 3.0 MeV 77. (a) -20% ; (b) -10% ; (c) $+15\%$ 79. (a) no; (b) plane wave-fronts of infinite extent, perpendicular to x axis 83. (a) 38.8 meV ; (b) 146 pm 85. (a) $4.14 \times 10^{-15} \text{ eV} \cdot \text{s}$; (b) 2.31 eV 89. (a) no; (b) 544 nm ; (c) green

Chapter 39

- CP** 1. b, a, c 2. (a) all tie; (b) a, b, c 3. a, b, c, d 4. $E_{1,1}$ (neither n_x nor n_y can be zero) 5. (a) 5; (b) 7
- Q** 1. a, c, b 3. (a) 18; (b) 17 5. equal 7. c 9. (a) decrease; (b) increase 11. $n = 1, n = 2, n = 3$ 13. (a) $n = 3$; (b) $n = 1$; (c) $n = 5$ 15. b, c, and d
- P** 1. 1.41 3. 0.65 eV 5. 0.85 nm 7. 1.9 GeV 9. (a) 72.2 eV ; (b) 13.7 nm ; (c) 17.2 nm ; (d) 68.7 nm ; (e) 41.2 nm ; (g) 68.7 nm ; (h) 25.8 nm 11. (a) 13; (b) 12 13. (a) 0.020 ; (b) 20 15. (a) 0.050 ; (b) 0.10 ; (c) 0.0095 17. 56 eV 19. 109 eV 23. 3.21 eV 25. 1.4×10^{-3} 27. (a) 8; (b) 0.75 ; (c) 1.00 ; (d) 1.25 ; (e) 3.75 ; (f) 3.00 ; (g) 2.25 29. (a) 7; (b) 1.00 ; (c) 2.00 ; (d) 3.00 ; (e) 9.00 ; (f) 8.00 ; (g) 6.00 31. 4.0 33. (a) 12.1 eV ; (b) $6.45 \times 10^{-27} \text{ kg} \cdot \text{m/s}$; (c) 102 nm 35. (a) 291 nm^{-3} ; (b) 10.2 nm^{-1} 41. (a) 0.0037 ; (b) 0.0054 43. (a) 13.6 eV ; (b) -27.2 eV 45. (a) $(r^4/8a^5)[\exp(-r/a)] \cos^2 \theta$; (b) $(r^4/16a^5)[\exp(-r/a)] \sin^2 \theta$ 47. 4.3×10^3 49. (a) 13.6 eV ; (b) 3.40 eV 51. 0.68 59. (b) $(2\pi/h)[2m(U_0 - E)]^{1/2}$ 61. (b) meter $^{-2.5}$ 63. (a) n ; (b) $2\ell + 1$; (c) n^2 65. (a) $nh/\pi md^2$; (b) $n^2 h^2/4\pi^2 md^2$ 67. (a) $3.9 \times 10^{-22} \text{ eV}$; (b) 10^{20} ; (c) $3.0 \times 10^{-18} \text{ K}$ 71. (a) $e^2 r/4\pi\varepsilon_0 a^3$; (b) $e/(4\pi\varepsilon_0 ma_0^3)^{0.5}$ 73. $18.1, 36.2, 54.3, 66.3, 72.4 \mu\text{eV}$

Chapter 40

- CP** 1. 7 2. (a) decrease; (b)–(c) remain the same 3. A, C, B
- Q** 1. (a) 2; (b) 8; (c) 5; (d) 50 3. all true 5. same number (10) 7. $2, -1, 0$, and 1 9. (a) 2; (b) 3 11. (a) n ; (b) n and ℓ 13. In addition to the quantized energy, a helium atom has kinetic energy; its total energy can equal 20.66 eV .

- P** 1. 24.1° 3. (a) $3.65 \times 10^{-34} \text{ J} \cdot \text{s}$; (b) $3.16 \times 10^{-34} \text{ J} \cdot \text{s}$ 5. (a) 3; (b) 3 7. (a) 4; (b) 5; (c) 2 9. (a) 3.46 ; (b) 3.46 ; (c) 3; (d) 3; (e) -3 ; (f) 30.0° ; (g) 54.7° ; (h) 150° 13. 72 km/s 15. (a) 54.7° ; (b) 125° 17. 19 mT 19. 5.35 cm 21. 44 23. 42 25. (a) 51; (b) 53; (c) 56 27. (a) $(2, 0, 0, +\frac{1}{2})$, $(2, 0, 0, -\frac{1}{2})$; (b) $(2, 1, 1, +\frac{1}{2})$, $(2, 1, 1, -\frac{1}{2})$, $(2, 1, 0, +\frac{1}{2})$, $(2, 1, 0, -\frac{1}{2})$, $(2, 1, -1, +\frac{1}{2})$, $(2, 1, -1, -\frac{1}{2})$ 29. g 31. (a) $4p$; (b) $4p$; (c) $4p$; (d) $5p$; (e) $4p$; (f) $6p$ 33. 12.4 kV 35. (a) 35.4 pm ; (b) 56.5 pm ; (c) 49.6 pm 39. 0.563 41. 80.3 pm 43. (a) 69.5 kV ; (b) 17.8 pm ; (c) 21.3 pm ; (d) 18.5 pm 45. (a) 49.6 pm ; (b) 99.2 pm 47. $2.0 \times 10^{16} \text{ s}^{-1}$ 49. 2×10^7 51. 9.0×10^{-7} 53. $7.3 \times 10^{15} \text{ s}^{-1}$ 55. (a) 3.60 mm ; (b) 5.24×10^{17} 57. (a) 0; (b) 68 J 59. 3.0 eV 61. (a) 3.03×10^5 ; (b) 1.43 GHz ; (d) 3.31×10^{-6} 63. 186 65. (a) 2.13 meV ; (b) 18 T 69. (a) no; (b) 140 nm 71. $n > 3$; $\ell = 3$; $m_\ell = +3, +2, +1, 0, -1, -2, -3$; $m_s = \pm\frac{1}{2}$ 73. (a) 6.0; (b) $3.2 \times 10^6 \text{ y}$ 75. argon 79. $(Ze/4\pi\varepsilon_0)(r^{-2} - rR^{-3})$

Chapter 41

- CP** 1. larger 2. a, b, and c
- Q** 1. b, c, d (the latter due to thermal expansion) 3. 8 5. below 7. increase 9. much less than 11. b and d
- P** 3. $8.49 \times 10^{28} \text{ m}^{-3}$ 5. (b) $6.81 \times 10^{27} \text{ m}^{-3} \text{ eV}^{-3/2}$; (c) $1.52 \times 10^{28} \text{ m}^{-3} \text{ eV}^{-1}$ 7. (a) 0; (b) 0.0955 9. (a) $5.86 \times 10^{28} \text{ m}^{-3}$; (b) 5.49 eV ; (c) $1.39 \times 10^3 \text{ km/s}$; (d) 0.522 nm 11. (a) $1.36 \times 10^{28} \text{ m}^{-3} \text{ eV}^{-1}$; (b) $1.68 \times 10^{28} \text{ m}^{-3} \text{ eV}^{-1}$; (c) $9.01 \times 10^{27} \text{ m}^{-3} \text{ eV}^{-1}$; (d) $9.56 \times 10^{26} \text{ m}^{-3} \text{ eV}^{-1}$; (e) $1.71 \times 10^{18} \text{ m}^{-3} \text{ eV}^{-1}$ 13. (a) 6.81 eV ; (b) $1.77 \times 10^{28} \text{ m}^{-3} \text{ eV}^{-1}$; (c) $1.59 \times 10^{28} \text{ m}^{-3} \text{ eV}^{-1}$ 15. (a) $2.50 \times 10^3 \text{ K}$; (b) $5.30 \times 10^3 \text{ K}$ 17. 3 19. (a) 1.0; (b) 0.99; (c) 0.50; (d) 0.014; (e) 2.4×10^{-17} ; (f) $7.0 \times 10^2 \text{ K}$ 21. (a) 0.0055; (b) 0.018 25. (a) 19.7 kJ ; (b) 197 s 27. (a) $1.31 \times 10^{29} \text{ m}^{-3}$; (b) 9.43 eV ; (c) $1.82 \times 10^3 \text{ km/s}$; (d) 0.40 nm 29. 57.1 kJ 31. (a) 226 nm ; (b) ultraviolet 33. (a) 1.5×10^{-6} ; (b) 1.5×10^{-6} 35. $0.22 \mu\text{g}$ 37. (a) 4.79×10^{-10} ; (b) 0.0140 ; (c) 0.824 39. 6.0×10^5 41. 4.20 eV 43. $13 \mu\text{m}$ 47. (a) 109.5° ; (b) 238 pm 49. (b) $1.8 \times 10^{28} \text{ m}^{-3} \text{ eV}^{-1}$ 53. $3.49 \times 10^3 \text{ atm}$

Chapter 42

- CP** 1. ^{90}As and ^{158}Nd 2. a little more than 75 Bq (elapsed time is a little less than three half-lives) 3. ^{206}Pb
- Q** 1. (a) ^{196}Pt ; (b) no 3. yes 5. (a) less; (b) greater 7. ^{240}U 9. no effect 11. yes 13. (a) all except ^{198}Au ; (b) ^{132}Sn and ^{208}Pb 15. d
- P** 1. $1.3 \times 10^{-13} \text{ m}$ 3. 46.6 fm 5. (a) 0.390 MeV ; (b) 4.61 MeV 7. (a) $2.3 \times 10^{17} \text{ kg/m}^3$; (b) $2.3 \times 10^{17} \text{ kg/m}^3$; (d) $1.0 \times 10^{25} \text{ C/m}^3$; (e) $8.8 \times 10^{24} \text{ C/m}^3$ 9. (a) 6; (b) 8 11. (a) 6.2 fm ; (b) yes 13. 13 km 17. 1.0087 u 19. (a) 9.303% ; (b) 11.71% 21. (b) 7.92 MeV/nucleon 25. 5.3×10^{22} 27. (a) 0.250 ; (b) 0.125 29. (a) 64.2 h ; (b) 0.125 ; (c) 0.0749 31. (a) $7.5 \times 10^{16} \text{ s}^{-1}$; (b) $4.9 \times 10^{16} \text{ s}^{-1}$ 33. $1 \times 10^{13} \text{ atoms}$ 37. 265 mg 39. (a) $8.88 \times 10^{10} \text{ s}^{-1}$; (b) 1.19×10^{15} ; (c) $0.111 \mu\text{g}$ 41. $1.12 \times 10^{11} \text{ y}$ 43. $9.0 \times 10^8 \text{ Bq}$ 45. (a) $3.2 \times 10^{12} \text{ Bq}$; (b) 86 Ci 47. (a) 2.0×10^{20} ; (b) $2.8 \times 10^9 \text{ s}^{-1}$ 49. (a) 1.2×10^{-17} ; (b) 0 51. 4.269 MeV 53. 1.21 MeV 55. 0.783 MeV 57. (b) 0.961 MeV 59. 78.3 eV 61. (a) 1.06×10^{19} ; (b) 0.624×10^{19} ; (c) 1.68×10^{19} ; (d) $2.97 \times 10^9 \text{ y}$ 63. 1.7 mg 65. 1.02 mg 67. 2.50 mSv 69. (a) 6.3×10^{18} ; (b) 2.5×10^{11} ; (c) 0.20 J ; (d) 2.3 mGy ; (e) 30 mSv 71. (a) 6.6 MeV ; (b) no 73. (a) 25.4 MeV ; (b) 12.8 MeV ; (c) 25.0 MeV 75. ^{7}Li 77. $3.2 \times 10^4 \text{ y}$ 79. 730 cm^2 81. ^{225}Ac 83. 30 MeV 89. 27 91. (a) 11.906 eV ; (b) 236.2025 eV 93. 600 keV 95. (a) 59.5 d ; (b) 1.18 97. (a) $4.8 \times 10^{-18} \text{ s}^{-1}$; (b) $4.6 \times 10^9 \text{ y}$

Chapter 43**CP** 1.c and d 2.e

- Q** 1.(a) 101; (b) 42 3. ^{239}Np 5. ^{140}I , ^{105}Mo , ^{152}Nd , ^{123}In , ^{115}Pd
 7.increased 9.less than 11.still equal to 1
P 1.(a) 16 day⁻¹; (b) 4.3×10^8 3. 4.8 MeV 5. 1.3×10^3 kg
 $7.3.1 \times 10^{10} \text{ s}^{-1}$ 9. (a) 2.6×10^{24} ; (b) 8.2×10^{13} J; (c) 2.6×10^4 y
 11. -23.0 MeV 13. (a) 251 MeV; (b) typical fission energy is
 200 MeV 15. (a) 84 kg; (b) 1.7×10^{25} ; (c) 1.3×10^{25} 17. (a) ^{153}Nd ;
 (b) 110 MeV; (c) 60 MeV; (d) 1.6×10^7 m/s; (e) 8.7×10^6 m/s
 21. 557 W 23. 0.99938 25. (b) 1.0; (c) 0.89; (d) 0.28; (e) 0.019;
 (f) 8 27. (a) 75 kW; (b) 5.8×10^3 kg 29. 1.7×10^9 y
 31. 170 keV 33. 1.41 MeV 35. 10^{-12} m 37. (a) 4.3×10^9 kg/s;
 (b) 3.1×10^{-4} 41. 1.6×10^8 y 43. (a) 24.9 MeV; (b) 8.65 megatons TNT 45. (a) 1.8×10^{38} s⁻¹; (b) 8.2×10^{28} s⁻¹ 47. (a) 4.1 eV/atom; (b) 9.0 MJ/kg; (c) 1.5×10^3 y 49. 14.4 kW
 51. $^{238}\text{U} + \text{n} \rightarrow ^{239}\text{U} \rightarrow ^{239}\text{Np} + \text{e} + \nu$, $^{239}\text{Np} \rightarrow ^{239}\text{Pu} + \text{e} + \nu$ 55.
 (a) 3.1×10^{31} protons/m³; (b) 1.2×10^6 57. (a) 227 J; (b) 49.3 mg;
 (c) 22.7 kW

Chapter 44**CP** 1.(a) the muon family; (b) a particle; (c) $L_\mu = +1$

- 2.b and e 3.c

Q 1.b,c,d 3.(a) 1; (b) positively charged 5.a,b,c,d 7.d

- 9.c 11.(a) lepton; (b) antiparticle; (c) fermion; (d) yes

P 1. $\pi^- \rightarrow \mu^- + \bar{\nu}$ 3. 2.4 pm 5. 2.4×10^{-43} 7. 7.69 MeV

9. 2.7 cm/s 11. (a) angular momentum, L_e ; (b) charge, L_μ ;

(c) energy, L_μ 15. (a) energy; (b) strangeness; (c) charge

17. (a) yes; (b)-(d) no 19. (a) 0; (b) -1; (c) 0 21. (a) K^+ ; (b) \bar{n} ;

(c) K^0 23. (a) 37.7 MeV; (b) 5.35 MeV; (c) 32.4 MeV 25. (a) $\bar{u}\bar{u}\bar{d}\bar{d}$;

- (b) $\bar{u}\bar{d}\bar{d}$ 27. $s\bar{d}$ 29. (a) Ξ^0 ; (b) Σ^- 31. 2.77×10^8 ly 33. 668 nm

35. 1.4×10^{10} ly 37. (a) 2.6 K; (b) 976 nm 39. (b) 5.7 H atoms/m³

41. 4.57×10^3 43. (a) 121 m/s; (b) 0.00406; (c) 248 y

47. 1.08×10^{42} J 49. (a) 0.785c; (b) 0.993c; (c) C2; (d) C1;

- (e) 51 ns; (f) 40 ns 51. (c) $r\alpha/c + (r\alpha/c)^2 + (r\alpha/c)^3 + \dots$;

(d) $r\alpha/c$; (e) $\alpha = H$; (f) 6.5×10^8 ly; (g) 6.9×10^8 y; (h) 6.5×10^8 y;

- (i) 6.9×10^8 ly; (j) 1.0×10^9 ly; (k) 1.1×10^9 y; (l) 3.9×10^8 ly

53. (a) ssd; (b) $\bar{s}\bar{s}\bar{d}$

This page intentionally left blank

I N D E X

Figures are noted by page numbers in *italics*, tables are indicated by t following the page number.

A

a_g (gravitational acceleration), 360, 360t
absolute pressure, 390
absolute zero, 515
absorption:
 of heat, 522–527, 523
 photon, *see* photon absorption
absorption lines, 1206, 1207
ac (alternating current), 903, 913
acceleration, 20–30, 283t
 average, 20
 centripetal, 76
 constant, 23, 23–27, 24t
 free-fall, 27, 27–28
 graphical integration in motion
 analysis, 29, 29–30
 instantaneous, 20–22, 21, 67–69
 negative, 21–22
 and Newton's first law, 95–98
Newton's laws applied to,
 108–113
and Newton's second law,
 98–101
principle of equivalence (with
 gravitation), 374–375
projectile motion, 70–75
reference particle, 429
relating linear to angular, 269,
 269–270
relative motion in one
 dimension, 79
relative motion in two
 dimensions, 79–80
rockets, 241–243, 242
rolling down ramp, 299,
 299–300
sign of, 21–22
simple harmonic motion, 418,
 418
system of particles, 220–223
two- and three-dimensional
 motion, 79–80
uniform circular motion, 76,
 76–78, 77, 133
as vector quantity, 41
yo-yo, 302

acceleration amplitude, in simple
 harmonic motion, 418
acceleration vectors, 41
accelerators, 818–819, 1334–1336,
 1336
acceptor atoms, 1264
acre-foot, 9
action at a distance, 630
activity, of radioactive sample, 1287
addition:
 of vectors by components, 46,
 46–47, 49

of vectors geometrically, 41,
 41–42, 42, 44
adiabat, 571, 572
adiabatic expansion, 531–532, 532
 ideal gas, 571–575, 572
adiabatic processes:
 first law of thermodynamics
 for, 531–533, 532t
 summarized, 575, 575t
adiabatic wind, 580
air:
 bulk modulus, 480–481
 density, 387t
 dielectric properties at 1 atm,
 732, 732t
 and drag force, 130–132
 effect on projectile motion, 73,
 73–74
 electric breakdown, 646, 646
 index of refraction at STP, 992t
 speed of sound in, 480–481,
 481t
 terminal speeds in, 131t
 thermal conductivity, 535t
 thin-film interference of water
 film in, 1067
air conditioners, 596
airplanes:
 projectile dropped from, 74
 turns by top gun pilots, 77–78
 two-dimensional relative
 motion of, 80–81
 vector components for flight, 44
airspeed, 90
alkali metals, 1235
alpha decay, 1289–1291, 1290
alpha particles, 621, 705, 1277,
 1277–1279, 1289
 binding energy per nucleon,
 1283
 magic nucleon number, 1299
 radiation dosage, 1296–1297
 in thermonuclear fusion,
 1324–1325
alternating current (ac), 903, 913
alternating current circuits,
 903–934
 damped oscillations in RLC,
 910–912, 911
 forced oscillations, 912–920, 914
 inductive load, 919
 LC oscillations, 903–910, 904
 phase and amplitude relation-
 ships, 920t
 power in, 927–929
 resistive load, 915
 series RLC circuits, 921–926,
 922
 in transformers, 930–933

alternating current generator,
 913–914
 with capacitive load,
 916–918, 917
 with inductive load,
 918–919, 919
 with resistive load, 914–916, 915
ammeters, 788, 788
ampere (unit), 614, 746, 843
Ampère, André-Marie, 844
Ampere–Maxwell law, 944–945,
 949t
Ampere's law, 844–850
Amperian loop, 844, 844–848
amplitude:
 alternating current, 920t
 current, 922, 922–923, 926
 of emf in ac, 914
 exponentially decaying in RLC
 circuits, 911
 LC oscillations, 905
 simple harmonic motion,
 416–418, 417
 waves, 447, 447, 448, 448
amplitude ratio, traveling
 electromagnetic waves, 976
amusement park rides:
 roller coasters, 21
 Rotor, 267–268
analyzer, 988
Andromeda Galaxy, 354–355, 355
anechoic chamber, 513
angles, 45
 angle between two vectors, 54
 degrees and radian measures, 45
 vector, 43, 43, 45
angled force, applied to initially
 stationary block, 128
angle of incidence, 991, 991
angle of minimum deviation, 1005,
 1007
angle of reflection, 991, 991
angle of refraction, 991, 991
angular acceleration, 261, 283t
 relating to linear, 269, 269–270
 rolling wheel, 299, 300
 rotation with constant, 266–268
angular amplitude (simple pendu-
 lum), 426
angular displacement, 259, 260, 265
angular frequency:
 circulating charged particle, 815
 damped harmonic oscillator,
 430–432
 driving, 914
 LC oscillations, 908–909
 natural, 433, 914
 simple harmonic motion,
 414–418, 417

simple pendulum, 426
sound waves, 483
waves, 448
angular magnification:
 compound microscope, 1032
 refracting telescope, 1033
 simple magnifying lens, 1031
angular momentum, 305–318, 312t
atoms, 1221, 1221
 conservation of, 312–316,
 313, 314
 defined, 305, 305–316
 at equilibrium, 328
 intrinsic, 953, 954
 Newton's second law in angular
 form, 307–308
 nuclear, 1284
 orbital, 954, 955, 1222–1224,
 1223, 1223t
 rigid body rotating about fixed
 axis, 311, 311–312
sample problems involving, 306,
 308–309, 315–316
spin, 953–954, 1223t, 1224, 1225
system of particles, 310–311
angular motion, 259
angular position, 259, 259–260,
 283t
 relating to linear, 269
angular simple harmonic motion,
 423, 423–424
angular simple harmonic oscilla-
 tor, 423, 423–424
angular speed, 261, 262
 relating to linear, 268–270
 in rolling, 295–297, 296
angular velocity, 260–264, 283t
 average, 260–261
 instantaneous, 260
 vector nature of, 264–265, 265
angular wave number, 447, 1171
sound waves, 483
annihilation:
 electron–positron, 622, 622,
 1338
 particle–antiparticle, 1338
 proton–antiproton, 1339–1340,
 1340t
annular cylinder, rotational inertia
 for, 274t
antenna, 974, 974
antiderivative, 26
antihydrogen, 1338, 1340, 1340t
antimatter, 1310t, 1338–1339
antineutrino, 1292n
antinodes, 465, 466, 467–468
antiparticles, 1338–1341, 1359
antiprotons, 1338
antisolar point, 994, 994

- aphelion distance, 371
apparent weight, 104
 in fluids, 396–397
applied force, work and, 688–689
Archimedes' principle, 394–397,
 395
areas, law of, 369, 369–370
area vector, 661
astronomical Doppler effect,
 1135–1136
astronomical unit, 12
atmosphere (atm), 388
atmospheric pressure, 388t
atmospheric sprites, 637–638
atoms, 1186–1187, 1219–1246.
 See also electrons; neutrons;
 protons
Bohr model, 1203, 1203–1204
exclusion principle in, 1230
formation in early universe,
 1360
and lasers, 1240–1245
magnetic resonance,
 1229–1230, 1230
matter wave interference, 1167,
 1168
and multiple electrons in a
 trap, 1230–1234
and periodic table, 1234–1236
properties of, 1219–1225
Stern–Gerlach experiment,
 1226, 1226–1228
x rays and ordering of
 elements, 1236–1240
atoms, elasticity of, 339, 339
atomic bomb, 1284, 1314–1315,
 1326–1327
atomic clocks, 5–6
atomic clocks, time dilation tests,
 1123–1124
atomic mass, 1280t, 1282–1283
atomic mass units, 7, 1282–1283
atomic number, 621, 1225, 1280
attractive forces, 356, 611
Atwood's machine, 120
aurora, 610
automobile(s). *See also* race cars
 acceleration of motorcycle vs.,
 25–26
 average velocity of truck, 17
 in banked circular turn,
 137–138
 in flat circular turn, 136–137
 magnet applications, 804
 sliding to stop on icy roads,
 129–130
 spark discharge from, 707, 707
 tire pressure, 388t
average acceleration:
 one-dimensional motion, 20
 two- and three-dimensional
 motion, 67–69
average angular acceleration, 261
average angular velocity, 260–261
average force (of collision), 228
average life, radionuclide,
 1287–1288
average power, 166, 197–198
 engines, 594
 traveling wave on stretched
 string, 455
average speed:
 of gas molecules, 561–563
 one-dimensional motion, 16
average velocity:
 constant acceleration, 24
 one-dimensional motion,
 15–17, 16
 two- and three-dimensional
 motion, 65
Avogadro's number, 550, 748
axis(–es):
 rotating, of vectors, 47
 of rotation, 259, 259
 separation of, in Newton's
 second law, 98–99
 of symmetry, 632
- B**
- Babinet's principle, 1109
background noise, 508
ball, motion of, 70–72, 71, 72
ballet dancing:
 grand jeté, 221–222, 222
 tour jeté, 314
ballistic pendulum, 236, 236
balloons, lifting capacity, 581
Balmer series, 1203, 1206, 1207
bands, energy bands in crystalline
 solids, 1254, 1254
band-gap pattern:
 crystalline solid, 1254
 insulator, 1254
 metal, 1255
 semiconductor, 1262
bar magnets:
 Earth as, 950, 950
 magnetic dipole moment of
 small, 826, 826t
 magnetic field, 942, 942
 magnetic field lines, 806–807,
 807
barrel units, 11
barrier tunneling, 1176–1179,
 1177, 1290–1291
baryons, 1338, 1345–1346
 conservation of baryon
 number, 1345
 and eightfold way, 1347–1348,
 1347t
 and quark model, 1349, 1355
baryonic matter, 1358, 1361, 1361
baryon number, conservation
 of, 1345
baseball:
 collision of ball with bat, 226,
 226, 227
 fly ball, air resistance to, 73, 73,
 73t
 time of free-fall flight, 28
base quantities, 2
base standards, 2
basic equations for constant
 acceleration, 23–24
- basilisk lizards, 249, 249
basketball free throws, 62
bats, navigation using ultrasonic
 waves, 502
batteries. *See also* electromotive
 force (emf)
 connected to capacitors, 718,
 718–719, 727–728
 and current, 746, 746–747
 as emf devices, 772–774
 in multiloop circuits, 781,
 781–787
 multiple batteries in multiloop
 circuit, 784–785, 785
 potential difference across,
 777–780, 779
 and power in circuits, 760,
 760–761
 in *RC* circuits, 788–792, 789
 real, 773, 773, 777, 777–778
 rechargeable, 773–774
 recharging, 779
 in *RL* circuits, 883–886
 in single-loop circuits, 774–775
 work and energy, 773, 773–774
beam, 976
beam expander, 1044
beam separation, in
 Stern–Gerlach experiment,
 1228
beam splitter, 1071, 1164, 1164
beats, 496–498, 497
becquerel, 1287
bends, the, 407, 549
Bernoulli's equation, 401–404
beta decay, 627, 1292–1295, 1295,
 1351
beta-minus decay, 1292
beta-plus decay, 1292
bi-concave lens, 1044
bi-convex lens, 1044
bicycle wheels:
 rolling, 295–297, 296–297
 rolling, with friction, 299,
 299–300
bifurcate (term), 58
Big Bang, 1355–1356, 1358–1361,
 1359
billiard balls, Newton's second law
 and motion of, 221
binding energy, *see* nuclear
 binding energy
Biot–Savart law, 837–838, 844,
 852
bivalent atom, 1256
blackbody radiator, 536
black holes, 355
 event horizon, 362
 gravitational lensing caused by,
 375, 376
 miniature, 379
 supermassive, 355
blocks:
 acceleration of falling, 281
 connected to massless-
 frictionless pulleys, 105, 106,
 108, 108–109
 floating, 397
- forces on stationary, 125–126,
 125–126
friction of sliding, 105, 105
hanging and sliding, 108,
 108–109
Newton's laws applied to, 99,
 108–113
normal forces, 104, 104–105
power used in work on, 168, 168
stable static equilibrium,
 328–329, 329, 332–337
third-law force pair, 106,
 106–107
work done by external force
 with friction, 192–193, 193
- block-spring oscillator, 907–908
block-spring systems:
 damped oscillating systems,
 430, 430–431
 and electrical–mechanical
 analogy, 906–907, 906t
kinetic energy, 159, 159–162,
 161
oscillating systems, 420–421
potential energy, 179, 179,
 182–183
blood pressure, normal systolic,
 387t
blue shift, 1135
bob, of pendulum, 425
body armor, 477–478, 478
body diagonal, 58–59
body wave, 512
Bohr, Niels, 1193, 1298, 1312
Bohr magneton, 953–955, 1224
Bohr model, of hydrogen, 629,
 1203, 1203–1204
Bohr radius, 1204, 1211
boiling point, 526
 for selected substances, 526t
 of water, 518t
Boltzmann, Ludwig, 601, 1243
Boltzmann constant, 551, 1165
Bose, Satyendra Nath, 1337
Bose–Einstein condensate, 1337,
 1337
bosons, 1337, 1337
bottomness, 1346
bottom quark, 1350t, 1351
boundary condition, 1175, 1210
Bragg angle, 1106
Bragg's law, 1106
Brahe, Tycho, 369
branches, circuits, 781
breakdown potential, 732
breakeven, in magnetic confinement,
 1328
Brewster angle, 998, 998
Brewster's law, 998
bright fringes:
 double-slit interference, 1055,
 1055, 1056
 single-slit diffraction, 1083,
 1083–1085
British thermal unit (Btu),
 524–525
Brookhaven accelerator, 1335

- Brout, Robert, 1354
 bubble chambers, 622, 622, 806, 806
 gamma ray track, 1169, 1169
 proton-antiproton annihilation event, 1339, 1339–1340
 buildings:
 mile-high, 380
 natural angular frequency, 433
 swaying in wind, 422–424, 468
 bulk modulus, 341, 480–481
 bungee-cord jumping, 178, 178
 buoyant force, 394–397, 395
- C**
 c , *see* speed of light
 Calorie (Cal) (nutritional), 524–525
 calorie (cal) (heat), 524–525
 cameras, 1030
 canal effect, 410
 cancer radiation therapy, 1276
 capacitance, 717–738
 calculating, 719–723
 of capacitors, 717–718
 of capacitors with dielectrics, 731–734
 and dielectrics/Gauss' law, 735, 735–737
 and energy stored in electric fields, 728–730
 LC oscillations, 903–910
 for parallel and series capacitors, 723–728
 parallel circuits, 783t
 RC circuits, 788–792, 789
 RLC circuits, 910–912
 RLC series circuits, 921–926
 series circuits, 783t
 capacitive reactance, 917
 capacitive time constant, for *RC* circuits, 789, 790
 capacitors, 717, 717–719, 718.
 See also parallel-plate capacitors
 with ac generator, 916–918, 917
 capacitance of, 717–718
 charging, 718–719, 727–728, 789, 789–790, 994
 cylindrical, 721, 721–722
 with dielectrics, 731, 731–733
 discharging, 719, 789, 790–792
 displacement current, 947, 947–949
 electric field calculation, 720
 energy density, 730
 Faraday's, 731, 731–732
 induced magnetic field, 944–946
 isolated spherical, 722, 730
 LC oscillations, 904, 905–906
 in parallel, 724, 724, 726–727, 783t
 and phase/amplitude for ac circuits, 920t
 potential difference calculation, 719–723
 RC circuits, 788–792, 789
 in series, 724–727, 725, 783t, 922, 922
 series *RLC* circuits, 922
 variable, 742
 cars, *see* automobiles
 carbon cycle, 1333
 carbon¹⁴ dating, 1295
 carbon dioxide:
 molar specific heat at constant volume, 565t
 RMS speed at room temperature, 556t
 carbon disulfide, index of refraction, 992t
 Carnot cycle, 591, 591, 592
 Carnot engines, 590–593, 591
 efficiency, 592–593, 597–598
 real vs., 597–598
 Carnot refrigerators, 596, 597–598
 carrier charge density, 750. *See also* current density
 cascade, decay process, 1348–1349
 cat, terminal speed of falling, 131, 131–132
 cathode ray tube, 809, 809–810
 cavitation, 508
 Celsius temperature scale, 518, 518–519
 center of curvature:
 spherical mirrors, 1015, 1015
 spherical refracting surfaces, 1020–1021, 1021
 center of gravity, 330–332, 331
 center of mass, 216–219
 and center of gravity, 330–332
 defined, 215
 motion of system's, 220–221
 one-dimensional inelastic collisions, 234–236, 235
 rolling wheel, 296, 296
 sample problems involving, 217–218, 223
 solid bodies, 216–219, 219
 system of particles, 215, 215–216, 220–223
 center of momentum frame, 1151
 center of oscillation (physical pendulum), 427
 centigrade temperature scale, 518–519
 central axis, spherical mirror, 1015, 1016
 central configuration peak, 600
 central diffraction maximum, 1089, 1089
 central interference maximum, 1056
 central line, 1099
 central maximum, diffraction patterns, 1082, 1082, 1086–1087
 centripetal acceleration, 76
 centripetal force, 133–138, 134
 Cerenkov counters, 1366
 Ceres, escape speed for, 367t
 CERN accelerator, 1335, 1353
 antihydrogen, 1338
 pion beam experiments, 1118
 chain-link conversion, of units, 3
 chain reaction:
 of elastic collisions, 239–240
 nuclear, 1315
 characteristic x-ray spectrum, 1237–1238, 1238
 charge, *see* electric charge
 charge carriers, 747
 doped semiconductors, 1263–1265
 silicon vs. copper, 762–763, 762t
 charge density. *See also* current density
 carrier, 750
 linear, 638–639, 639t
 surface, 629, 639t
 volume, 626, 628, 639t
 charged disk:
 electric field due to, 643–644
 electric potential due to, 700, 700
 charged isolated conductor:
 with cavity, 668, 669
 electric potential, 706, 706–707
 in external electric field, 707, 707
 Gauss' law for, 668–670
 charge distributions:
 circular arc, 642
 continuous, 638–639, 698–700, 699, 700
 ring, 638–640, 639, 642
 spherically symmetric, 675–677, 676, 695
 straight line, 642–643
 uniform, 631, 631–632, 632, 642–643
 charged objects, 631
 charged particles, 612
 in cyclotron, 819
 electric field due to, 633, 633–635
 electric potential due to group of, 695–696, 696
 electric potential energy of system, 703–705, 704
 equilibrium of forces on, 618
 helical paths of, 816, 816–817
 magnetic field due to, 804–805
 motion, in electric field, 647
 net force due to, 616–618
 charged rod, electric field of, 641–642
 charge number, 1225
 charge quantum number, 1341
 charging:
 of capacitors, 718–719, 727–728, 789, 789–790, 944
 electrostatic, 611
 charm, 1346
 charm quark, 1350t, 1351, 1352
 chip (integrated circuits), 1271
 chromatic aberration, 1033
 chromatic dispersion, 993, 993–994
 circuits, 718, 719, 771–793, 783t.
 See also alternating current circuits
 ammeter and voltmeter for measuring, 788
 capacitive load, 916–918, 917
 direct-current (dc), 772
 inductive load, 918–919, 919
 integrated, 1270, 1271
 multiloop, 774, 781, 781–787, 782
 oscillating, 903
 parallel capacitors, 724, 724, 726–727, 783t
 parallel resistors, 782, 782–787, 783t
 power in, 760–761
RC, 788–792, 789
 resistive load, 914–916, 915
RL, 882–886, 883, 884
RLC, 910–912, 911, 921–926, 922
 series capacitors, 724–727, 725, 783t
 series resistors, 776, 776–777, 783t
 single-loop, 771–780, 914
 circuit elements, 718
 circular aperture, diffraction patterns, 1090–1094, 1091
 circular arc, current in, 839–841
 circular arc charge distributions, 642
 circular orbits, 373–374
 clocks:
 event measurement with array of, 1119, 1119
 time dilation tests, 1123–1124, 1153
 closed circuit, 776, 776
 closed cycle processes, first law of thermodynamics for, 532, 532t
 closed path, 179–180, 180
 closed-path test, for conservative force, 179–180
 closed shell, 1299
 closed subshell, 1235
 closed surface, electric flux in, 661–664
 closed system, 221
 entropy, 589
 linear momentum conservation, 230–231
 COBE (Cosmic Background Explorer) satellite, 1360, 1361
 coefficient of kinetic friction, 127–130
 coefficient of linear expansion, 521, 521t
 coefficient of performance (refrigerators), 596
 coefficient of static friction, 127–130
 coefficient of volume expansion, 521
 coherence, 1059–1060
 coherence length, 1241
 coherent light, 1059, 1241
 coils, 823–824. *See also* inductors of current loops, 823–824

in ideal transformers, 931, 931
 induced emf, 867–868
 magnetic field, 851–854, 852
 mutual induction, 890–892, 891
 self-induction, 881, 881–882
 cold-weld, 126–127, 127
 collective model, of nucleus, 1298
 collimated slit, 1226
 collimator, 1100, 1226
 collision(s), 226–229
 elastic in one dimension, 237,
 237–240
 glancing, 240, 240–241
 impulse of series of, 227–229,
 229
 impulse of single, 226–227, 227
 inelastic, in one dimension, 234,
 234–236, 235
 momentum and kinetic energy
 in, 233
 two-dimensional, 240, 240–241
 color force, 1354–1355
 color-neutral quarks, 1354–1355
 color-shifting inks, 1048
 compass, 950, 964
 completely inelastic collisions,
 234, 234–236, 235
 components:
 of light, 993–994
 vector, 42–44, 43, 46, 46–47,
 47, 49
 component notation (vectors), 43
 composite slab, conduction
 through, 535, 535
 compound microscope, 1032, 1032
 compound nucleus, 1298, 1300
 compressibility, 342, 388
 compressive stress, 340–341
 Compton scattering, 1159,
 1159–1162, 1160
 Compton shift, 1159, 1159–1162
 Compton wavelength, 1161
 concave lenses, 1044
 concave mirrors, 1013, 1016,
 1017–1018
 concrete:
 coefficient of linear expansion,
 521t
 elastic properties, 341t
 condensing, 526
 conducting devices, 619, 756–757
 conducting path, 612
 conducting plates:
 eddy currents, 874
 Gauss' law, 674, 674–675
 conduction, 534, 535, 535,
 1252–1272
 and electrical properties of
 metals, 1252–1261
 in *p-n* junctions, 1266–1270
 by semiconductors, 1261–1265
 in transistors, 1270–1271
 conduction band, 1262, 1262
 conduction electrons, 612, 746,
 752, 1255–1261
 conduction rate, 534–535
 conductivity, 754, 1257

conductors, 612–613, 746. *See also*
 electric current
 drift speed in, 749–750, 752
 Hall effect for moving, 812–813
 metallic, 746, 762
 Ohm's law, 756–759
 potential difference across,
 812–813
 configurations, in statistical
 mechanics, 599–600
 confinement principle, 1187
 conical pendulum, 146
 conservation of angular momen-
 tum, 312–316, 313, 314
 conservation of baryon number,
 1345
 conservation of electric charge,
 621–622
 conservation of energy, 149,
 195–199, 197
 in electric field, 688
 mechanical and electric
 potential energy, 705
 principle of conservation of
 mechanical energy, 185
 in proton decay, 1348
 sample problems involving,
 186–187, 198–199
 conservation of lepton number,
 1344–1345
 conservation of linear momen-
 tum, 230–232, 236, 242
 conservation of quantum
 numbers, 1348–1349
 conservation of strangeness, 1346
 conservative forces, 179–181,
 180, 685
 constant acceleration (one-dimen-
 sional motion), 23, 23–27, 24t
 constant angular acceleration,
 rotation with, 266–268
 constant linear acceleration, 266
 constant-pressure molar specific
 heat, 566–568
 constant-pressure processes, 529,
 529–530
 summarized, 575, 575t
 work done by ideal gases,
 554–555
 constant-pressure specific heat, 525
 constant-temperature processes:
 summarized, 575, 575t
 work done by ideal gases,
 552–553
 constant-volume gas thermome-
 ter, 516, 516–517
 constant-volume molar specific
 heat, 565–566
 constant-volume processes, 529,
 529–530
 first law of thermodynamics
 for, 532, 532t
 summarized, 575, 575t
 work done by ideal gases, 553
 constant-volume specific heat, 525
 consumption rate, nuclear reactor,
 1319–1320

contact potential difference,
 1266–1267
 continuity, equation of, 398–401,
 400
 continuous bodies, 272
 continuous charge distribution,
 638–639, 698–700, 699, 700
 continuous x-ray spectrum, 1237,
 1237
 contracted length, 1126–1128
 convection, 537
 converging lens, 1023, 1024, 1025
 conversion factors, 3
 convex lenses, 1044
 convex mirrors, 1013, 1016,
 1017–1018
 cooling:
 evaporative, 545
 super, 605
 Coordinated Universal Time
 (UTC), 6
 copper:
 coefficient of linear expansion,
 521t
 conduction electrons, 612
 electric properties of silicon vs.,
 762–763, 762t, 1253t, 1262
 energy levels, 1254, 1254
 Fermi energy, 1255
 Fermi speed, 1255–1256
 heats of transformation, 526t
 mean free time, 759
 resistivity, 754t, 755, 755, 1262
 rubbing rod with wool, 612
 temperature coefficient of
 resistivity, 1262
 unit cell, 1253, 1253
 copper wire:
 as conductor, 612, 612, 746,
 746–747
 drift speed in, 749–750
 magnetic force on current
 carrying, 820, 820–822
 cord (unit of wood), 11
 core (Earth), 380, 380
 density, 360, 360, 388t
 pressure, 388t
 core (Sun):
 density, 387t
 pressure, 388t
 speed distribution of photons
 in, 562
 corner reflectors, 1046
 corn-hog ratio, 12
 corona discharge, 707
 correspondence principle, 1193
 cosine, 45, 45
 cosine-squared rule, for intensity
 of transmitted polarized
 light, 987
 Cosmic Background Explorer
 (COBE) satellite, 1360, 1361
 cosmic background radiation,
 1357–1358, 1360, 1361
 cosmic ray protons, 627
 cosmological red shift, 1367–1368
 cosmology, 1355–1362

background radiation,
 1357–1358
 Big Bang theory, 1358–1361
 dark matter, 1358
 expansion of universe,
 1356–1357
 coulomb (unit), 614
 Coulomb barrier, 1322
 coulomb per second, 746
 Coulomb's law, 609–622
 conductors and insulators,
 612–613
 conservation of charge, 621–622
 electric charge, 610–611
 formulas for, 613–615
 and Gauss' law, 666–667
 quantization of charge, 619–621
 for spherical conductors,
 615–619
 crimp hold, 348
 critical angle, for total internal
 reflection, 996
 crossed magnetic fields:
 and discovery of electrons,
 808–810
 Hall effect in, 810–813, 811
 crossed sheets, polarizers, 988, 988
 cross product, 52–55
 crust (Earth), 360, 380, 380, 387t
 crystals:
 matter waves incident after
 scattering, 1167, 1168, 1168
 polycrystalline solids, 963
 x-ray diffraction, 1105,
 1105–1106
 crystal defects, 627
 crystalline solids:
 electrical properties, 1252–1261,
 1253
 energy bands, 1254, 1254
 crystal planes, 1105, 1105
 curie (unit), 1287
 Curie constant, 960
 Curie's law, 960
 Curie temperature, 962
 curled-straight right-hand rule,
 838
 currency, anti-counterfeiting
 measures, 1048
 current, *see* electric current
 current amplitude:
 alternating current, 926
 series *RLC* circuits, 922,
 922–923, 926
 current-carrying wire:
 energy dissipation in, 761
 magnetic field due to, 837,
 837–842, 838
 magnetic field inside long
 straight, 846, 846
 magnetic field outside long
 straight, 845, 845–846
 magnetic force between
 parallel, 842–843, 843
 magnetic force on, 820, 820–822
 current density, 749, 749–752
 current law, Kirchoff's, 781

- current-length element, 837, 837
 current loops, 746, 746
 electrons, 955, 955–956, 956
 Faraday's law of induction, 865–866
 Lenz's law for finding direction of current, 868, 868–871, 869
 as magnetic dipoles, 851–854, 852
 solenoids and toroids, 848–851
 torque on, 822–824, 823
 curvature of space, 375, 375–376, 1360–1361
 cutoff frequency, photoelectric effect, 1156–1157
 cutoff wavelength:
 continuous x-ray spectrum, 1237
 photoelectric effect, 1156–1157
 cycle:
 engines, 591
 simple harmonic motion, 414
 thermodynamic, 529, 530, 532
 cyclotrons, 818, 818–819
 cylinders:
 of current, 847–848
 rotational inertia, 274t
 tracer study of flow around, 399
 cylindrical capacitor, capacitance of, 721, 721–722
 cylindrical symmetry, Gauss' law, 671, 671–672
- D**
- damped energy, 431
 damped oscillations, 430–431, 431, 910–912
 damped simple harmonic motion, 430, 430–432, 431
 damped simple harmonic oscillator, 430, 430–432
 damping constant, simple harmonic motion, 430–431
 damping force, simple harmonic motion, 430–431
 dark energy, 1361
 dark fringes:
 double-slit interference, 1055, 1055, 1057
 single-slit diffraction, 1083, 1083–1085, 1088–1089
 dark matter, 1358, 1361, 1361
 daughter nuclei, 622, 1302
 day:
 10-hour day, 5
 variations in length of, 6
 dc (direct current), 772, 913
 de Broglie wavelength, 1167, 1171, 1189
 decay, *see* radioactive decay
 decay constant, 1286
 decay rate, 1286–1288
 deceleration, 21
 decibel, 490–492
 decimal places, significant figures with, 4
 dees, cyclotron, 818
 de-excitation, of electrons, 1190
- deformation, 340, 340
 degenerate energy levels, 1200
 degrees of freedom, ideal gas molecules, 568–570
 density:
 defined, 7
 fluids, 387
 kinetic energy density, 402
 linear, of stretched string, 452, 453
 and liquefaction, 7–8
 nuclear matter, 1285
 occupied states, 1259–1260, 1260
 selected engineering materials, 341t
 selected materials and objects, 387t
 states, 1257, 1257–1258
 uniform, for solid bodies, 216–217
 density gradient, 1266
 depletion zone, *p-n* junction, 1266
 derived units, 2
 detection, *see* probability of detection
 deuterium, 1294
 deuterium–tritium fuel pellets, 1328, 1328
 deuterons, 819, 1327
 deuteron–triton reaction, 1327
 deviation angle, 1005
 diamagnetic material, 957
 diamagnetism, 957–958, 958
 diamond:
 as insulator, 1255, 1262
 unit cell, 1253, 1253
 diamond lattice, 1253
 diatomic molecules, 566
 degrees of freedom, 568–570, 569, 569
 molar specific heats at constant volume, 565t
 potential energy, 205
 dielectrics:
 atomic view, 733–734, 734
 capacitors with, 731–733
 and Gauss' law, 735, 735–737
 polarization of light by reflection, 998
 dielectric constant, 731–732, 732t
 dielectric strength, 731–733, 732t
 differential equations, 907
 diffraction, 1081–1107. *See also* interference; single-slit diffraction
 circular aperture, 1090–1094, 1091
 double-slit, 1094–1097, 1095, 1096
 Fresnel bright spot, 1083
 intensity in double-slit, 1095, 1096–1097
 intensity in single-slit, 1086–1090, 1089
 interference vs., 1097
 neutron, 1168
- pinhole, 1082
 and wave theory of light, 1081–1083
 x-ray, 1104–1106, 1105
 and Young's interference experiment, 1053–1054, 1054
- diffraction factor, 1096
 diffraction gratings, 1098, 1098–1101
 dispersion, 1101–1104
 resolving power, 1102–1104, 1103
 spacing, 1099–1100
 x rays, 1105
- diffraction patterns:
 defined, 1082
 double-slit, 1095–1096, 1096
 single-slit, 1095–1096, 1096
- diffusion current, *p-n* junctions, 1266
- dimensional analysis, 452
- dip angle, 141
- dip meter, 951
- dip north pole, 951
- dipole antenna, 974, 974
- dipole axis, 636, 950
- dip-slip, 60
- direct current (dc), 772, 913
- direction:
 of acceleration in one-dimensional motion, 20
 of acceleration in two- and three-dimensional motion, 68
 of angular momentum, 305
 of displacement in one-dimensional motion, 14–15
 of vector components, 43
 of vectors, 41–42, 42
 of velocity in one-dimensional motion, 16
 of velocity in two- and three-dimensional motion, 66
- discharging, 611
 capacitors, 719, 789, 790–792
 charged objects, 612
- disintegration, 1280
- disintegration constant, 1286, 1288
- disintegration energy, 1290
- disks:
 diffraction by circular aperture, 1090–1094, 1091
 electric field due to charged, 643–644
 electric potential due to charged, 700, 700
- dispersion:
 chromatic, 993, 993–994
 by diffraction gratings, 1101–1104
- displacement:
 damped harmonic oscillator, 430–431, 431
 electric, 736
 one-dimensional motion, 14–15
 simple harmonic motion, 416, 417, 418
 traveling waves, 449–450
- two- and three-dimensional motion, 63–64, 64
 as vector quantity, 15, 41, 41
 waves on vibrating string, 446–448, 447
- displacement amplitude:
 forced oscillations, 433, 433
 sound waves, 483, 483–484
- displacement current, 946–950, 947
- displacement ton, 11
- displacement vector, 15, 41, 41
- dissipated energy, in resistors, 761, 774
- distortion parameter, 1314
- distribution of molecular speeds, 560–563, 561
- diverging lens, 1023, 1024, 1025
- dominoes, 328, 328
- donor atoms, 1263–1264
- doped semiconductors, 762, 1263, 1263–1265
- Doppler effect, 498–502, 1120
 detector moving, source stationary, 500, 500
 for light, 1134–1137, 1136, 1357
 source moving, detector stationary, 501, 501
- dose equivalent, radiation, 1297
- dot product, 51, 51, 54, 661
- double-slit diffraction, 1094–1097, 1095, 1096
- double-slit interference:
 intensity, 1060–1062, 1061, 1096
 from matter waves, 1167, 1167–1168
 single-photon, wide-angle version, 1163–1164, 1164
 single-photon version, 1162–1164
 Young's experiment, 1053–1058, 1055
- doubly magic nuclides, 1299
- down quark, 1349, 1350t, 1351
- drag coefficient, 130–131
- drag force, 130–132
 damped simple harmonic motion, 430
 mechanical energy not conserved in presence of, 186
 as nonconservative force, 179
- drain, FETs, 1270, 1270
- drift current, *p-n* junctions, 1267
- drift speed:
 and current density, 749, 749–750, 752
 Hall effect for determining, 810–813, 811
- driven oscillations, 433, 914, 914
- driving angular frequency, 914
- driving frequency, of emf, 914
- d* subshells, 1235, 1236
- E**
- E (exponent of 10), 2
- Earth, 354–355, 1362. *See also* gravitational force

- atmospheric electric field, 717
 average density, 387t
 density of, as function of
 distance from center, 360
 eccentricity of orbit, 369
 effective magnetic dipole
 moment, 1225
 ellipsoidal shape of, 360
 escape speed, 367–368, 367t
 gravitation near surface,
 359–362
 interior of, 380, 380
 Kepler's law of periods, 370t
 level of compensation, 408
 magnetic dipole moment, 826t
 magnetism, 950–951
 nonuniform distribution of
 mass, 360, 360
 rotation, 360–361, 361
 satellite orbits and energy,
 371–373, 372
 variation in length of day over
 4-year period, 6
- earthquakes:
 building oscillations during, 414
 buildings submerged during, 7
 and liquefaction, 7–8
 natural angular frequency of
 buildings, 433, 433
 S and P waves, 506
- Earth's magnetic field, 807, 950,
 950–951
 polarity reversal, 950, 951
 at surface, 806t
- eccentricity, of orbits, 369, 369
 and orbital energy, 371–372
 planets of Solar System, 370t
- eddy currents, 874
- edges, diffraction of light at, 1082
- edge effect, 674
- effective cross-sectional area, 131
- effective magnetic dipole
 moment, 1225
- effective phase difference, optical
 interference, 1051
- efficiency:
 Carnot engines, 592–593
 real engines, 593, 597–598
 Stirling engines, 594
- eightfold way, 1347, 1347–1348,
 1347t
- Einstein, Albert, 95, 977, 1117,
 1117, 1120, 1166. *See also*
 relativity
- Bose-Einstein condensate,
 1337, 1337
- and bosons, 1337
- and lasers, 1242
- view of gravitation, 374,
 374–376
- work on photoelectric effect,
 1156–1158
- work on photons, 1153–1155
- Einstein-de Haas experiment,
 1221, 1222
- Einstein ring, 376, 376
- elastic bodies, 339
- elastic collisions:
 defined, 233
 elasticity, 327, 339–342, 340
 in one dimension, with moving
 target, 238–239
 in one dimension, with
 stationary target, 237,
 237–238
 in two dimensions, 240, 240–241
 and wave speed on stretched
 string, 452
- elasticity, 338–342
 of atoms and rigid bodies, 339,
 339–340
 and dimensions of solids, 340,
 340
 and equilibrium of indetermi-
 nate structures, 338–339, 339
 hydraulic stress, 341–342, 341t
 sample problem involving, 342
 shearing, 341
 tension and compression,
 340–341, 341
- elastic potential energy, 178
 determining, 182–183
 traveling wave on stretched
 string, 454, 454
- electrical breakdown, 646, 646
- electrically isolated object, 611
- electrically neutral objects, 611
- electrical-mechanical analogy,
 906–907, 906t
- electric charge, 610–611. *See also*
 circuits
- conservation of, 621–622
 and current, 747–748
 enclosed, 667, 670
 excess, 611
 free, 735
 hypercharge, 1364
 induced, 612–613
 LC oscillations, 904, 908
 lines of, 638–643, 639, 699,
 699–700
 measures of, 639t
 negative, 611, 611
 net, 611
 neutralization of, 611
 positive, 611, 734
 quantization of, 619–621
 in RLC circuits, 911, 912
 sharing of, 619
 in single-loop circuits, 772
- electric circuits, *see* circuits
- electric current, 745–752, 746, 747
 in alternating current, 913–914
 for capacitive load, 918
 current density, 748–752, 749
 decay, 885
 direction in circuits, 747,
 747–748
 induced, 864–865, 870–874
 for inductive load, 920
 LC oscillations, 904, 908–910
 magnetic field due to, 837,
 837–842, 838
 in multiloop circuits, 781–782
- power in, 760–761
 for resistive load, 916
 in single-loop circuits, 774,
 774–775
 time-varying, in RC circuits, 790
- electric dipole, 825
 in electric field, 647–650
 electric field due to, 635–638,
 636
 electric potential due to,
 697–698, 698
 induced, 698
 potential energy of, 648
 electric dipole antenna, 974,
 974–975
- electric dipole moment, 637, 648
- dielectrics, 733–734
 induced, 698
 permanent, 698
- electric displacement, 736
- electric field, 630–651, 804
 calculating from potential,
 701, 701–702
 calculating potential from,
 691, 691–693
 capacitors, 720
 crossed fields, 810–813, 811
 as displacement current,
 948–949
 due to charged disk, 643–644,
 700, 700
 due to charged particle, 633,
 633–635
 due to electric dipole, 635–638,
 636
 due to line of charge, 638–643,
 639
 electric dipole in, 647–650
 energy stored in capacitor,
 728–730
- equipotential surfaces, 690,
 690–691, 691
- external, 669–670, 707, 707
- field lines in, 631–632
 and Gauss' law, 666–667, 844,
 942, 949t
- Hall effect, 810–813, 811, 820
- induced, 874–879, 875, 977,
 977–978
- net, 634–635
- nonuniform, 632, 663–664
- point charge in, 645–647
- polarized light, 907, 988
- potential energy in, 687–689,
 730
- rms of, 982–983
- in spherical metal shell, 670
- system of charged particles in,
 703–705, 704
- traveling electromagnetic
 waves in, 974–977, 975, 976
- uniform, 632, 660–662, 692
- as vector field, 631
- work done by, 686–689
- electric field lines, 631, 631–632,
 632
- electric fish, 786–787
- electric flux, 659–664
 in closed surface, 661–664
 and Gauss' law, 659–664
 and induction, 872
 net, 661–662
 through Gaussian surfaces, 660,
 660–664, 661
 in uniform electric fields,
 660–662
- electric force, 803
- electric generator, 772
- electric motor, 822–824, 823, 950
- electric potential, 685–708
 calculating field from, 701,
 701–702
- charged isolated conductor,
 706, 706–707
- defined, 686
- due to charged particles, 694,
 694–696, 695
- due to continuous charge
 distribution, 698–700, 699,
 700
- due to electric dipole, 697–698,
 698
- from electric fields, 691–693
- and electric potential energy,
 686, 686–689, 689
- equipotential surfaces, 690–691,
 691
- and induced electric field,
 877–878
- in LC oscillator, 909–910
- potential energy of charged
 particle system, 703–705, 704
 and power/emf, 779
 and self-induction, 882
- electric potential energy:
 and electric potential, 686,
 686–689, 689
- for system of charged particles,
 703–705, 704
- electric quadrupole, 654
- electric spark, 646, 646
 airborne dust explosions set off
 by, 729–730
- dangers of, 707, 707
- and pit stop fuel dispenser fire,
 792, 792
- electric wave component, of
 electromagnetic waves,
 975–976, 976
- electromagnets, 804, 804, 806t
- electromagnetic energy, 909.
 See also electromagnetic
 waves
- electromagnetic force, 1338,
 1352–1353
- electromagnetic oscillations, 904
 damped, in RLC circuits,
 910–912
- defined, 904
- forced, 912–920, 914
- LC oscillations, 903–910
- electromagnetic radiation, 974
- electromagnetic spectrum, 973,
 973–974

- electromagnetic waves, 445, 972–999. *See also* reflection; refraction
 energy transport and Poynting vector, 980–983, 982
 Maxwell's rainbow, 973–974
 polarization, 907, 985–990, 986, 988, 997–998
 radiation pressure, 983–985
 reflection of, 990–998, 998
 refraction of, 990–996
 traveling, 974–980, 976, 977
 electromagnetism, 836, 950, 1334
 electromotive force (emf), 772–774. *See also* emf devices
 in alternating current, 913–914
 defined, 772, 876–877
 and energy and work, 773, 773–774
 induced, 865, 867–868, 870–871
 potential and power in circuits, 779
 self-induced, 881
 electrons, 612, 1335
 accelerator studies, 818
 in alternating current, 913
 barrier tunneling, 1176–1179, 1177
 in Bohr model, 1203, 1203–1204
 bubble chamber tracks, 622, 622, 806
 charge, 620, 620t
 Compton scattering, 1159–1162, 1160
 conduction, 1255–1261
 discovery by Thomson, 808–810, 809, 1276
 energy of, 1142, 1186–1191
 excitation of, 1189, 1189, 1255
 as fermions, 1336
 in hydrogen atom, 1212
 kinetic energy of, 1118, 1118
 as leptons, 1338, 1344, 1344t
 magnetic dipole moment, 826, 826t
 and magnetism, 952–957
 majority carrier in *n*-type semiconductors, 1264, 1264t
 matter waves, 1166–1170, 1167, 1168
 matter waves of, 1166–1170, 1167, 1168, 1173, 1186
 momentum, 954
 momentum of, 953–955, 955, 1142
 orbits of, 955, 955–956, 956
 from proton–antiproton annihilation, 1340t
 in *p*-type semiconductors, 1264, 1264t
 radial probability density of, 1211–1212
 radiation dosage, 1296–1297
 speed of, 1118, 1118
 spin, 1336–1337, 1337
 spin-flip, 966
- in superconductors, 763
 valence, 1187, 1235, 1256
 wave functions of trapped, 1191–1195
 electron capture, 1292n
 electron diffraction, 1168
 electron microscope, 1183
 electron neutrinos, 1343–1344, 1344t
 electron–positron annihilation, 622, 622, 1338
 electron spin, 1336–1337, 1337
 electron traps:
 finite well, 1195, 1195–1197
 hydrogen atoms as, 1202
 multiple electrons in rectangular, 1230–1234
 nanocrystallites, 1197–1198, 1198
 one-dimensional, 1187–1199
 quantum corrals, 1199, 1199
 quantum dots, 1187, 1198, 1198–1199
 two- and three-dimensional, 1200, 1200–1201
 wave functions, 1191–1195, 1192
 electron-volt, 689, 1258
 electroplaques, 786, 786–787
 electrostatic equilibrium, 668
 electrostatic force, 611, 631
 and Coulomb's law, 613, 613–619
 electric field due to point charge, 633, 633–635
 point charge in electric field, 645–647
 work done by, 686, 688–689
 electrostatic stress, 744
 electroweak force, 1353
 elementary charge, 620, 645–646
 elementary particles, 1334–1354
 bosons, 1337, 1337
 conservation of strangeness, 1346–1347
 eightfold way patterns, 1347–1348
 fermions, 1336, 1337
 general properties, 1334–1343
 hadrons, 1338, 1345–1346
 leptons, 1338, 1343–1345
 messenger particles, 1352–1354
 quarks, 1349–1352
 elevator cab, velocity and acceleration of, 18–19
 elliptical orbits, 373–374
 emf, *see* electromotive force
 emf devices, 772, 773. *See also* batteries
 internal dissipation rate, 779
 real and ideal, 773, 773
 emf rule, 775
 emission. *See also* photon emission
 from hydrogen atom, 1212
 spontaneous, 1242, 1242–1243
 stimulated, 1242–1243
- emission lines, 1098, 1098–1099, 1206
 emissivity, 536, 1166
 enclosed charge, 667, 670
 endothermic reactions, 1343
 energy. *See also* kinetic energy; potential energy; work
 for capacitor with dielectric, 733
 conservation of, 149, 195–199, 197, 705
 in current-carrying wire, 761
 damped, 431
 defined, 149
 of electric dipole in electric field, 650
 in electric field, 728–730
 and induction, 873
 and magnetic dipole moment, 825, 954
 in magnetic field, 887–888
 and relativity, 1138–1143
 in *RLC* circuits, 911
 scalar nature of, 41
 in simple harmonic motion, 421–423, 422
 as state property, 585
 in transformers, 932
 transport, by electromagnetic waves, 980–983, 982
 of trapped electrons, 1186–1191
 traveling wave on stretched string, 454, 454–455
 energy bands, 1254, 1254
 energy density, 730, 889–890
 energy density, kinetic, 402
 energy gap, 1254, 1254
 energy levels:
 excitation and de-excitation, 1189–1190
 full, empty, and partially occupied, 1231
 hydrogen, 1204, 1206, 1207
 in infinite potential well, 1190–1191, 1201, 1232–1234
 multiple electron traps, 1231–1233
 nuclear, 1284
 in single electron traps, 1188, 1189
 of trapped electrons, 1187–1191
 energy-level diagrams, 1189, 1189, 1232, 1232
 energy method, of calculating current in single-loop circuits, 774
 engines:
 Carnot, 590–593, 591, 597–598
 efficiency, 591, 592–593, 596, 597, 597–598
 ideal, 591–592
 perfect, 593, 593
 Stirling, 594, 594
 Englert, François, 1354
 entoptic halos, 1108, 1110
 entropy, 583–603
 change in, 584–588
- engines, 590–595
 force due to, 589–590
 and irreversible processes, 584
 and probability, 601–602
 refrigerators, 595–598, 596
 sample problems involving, 587–588, 594–595, 600–602
 and second law of thermodynamics, 588–590
 as state function, 585, 586–587
 statistical mechanics view of, 598–602
 entropy changes, 584–588
 Carnot engines, 592–593
 Stirling engines, 594
 entropy postulate, 584
 envelope, in diffraction intensity, 1095
 equation of continuity, 398–401, 400
 equations of motion:
 constant acceleration, 24, 24t
 constant linear vs. angular acceleration, 266t
 free-fall, 27–28
 equilibrium, 99, 327–342, 1308
 and center of gravity, 330–332, 331
 electrostatic, 668
 of forces on particles, 618
 and Hall effect, 811
 of indeterminate structures, 338–339, 339
 protons, 618
 requirements of, 329–330
 sample problems involving, 332–337, 526–527
 secular, 1304
 static, 327–329, 328, 329
 thermal, 515
 equilibrium charge, capacitors in *RC* circuits, 789
 equilibrium points, in potential energy curves, 189–190
 equilibrium position, simple pendulum, 425
 equilibrium separation, atoms in diatomic molecules, 205
 equipartition of energy, 569
 equipotential surfaces, 690, 690–691
 equivalence, principle of, 374–375
 equivalent capacitance:
 in parallel capacitors, 724, 724, 726–727, 783t
 in series capacitors, 724–727, 783t
 equivalent resistance:
 in parallel resistors, 782, 782–787, 783t
 in series resistors, 777, 783t
 escape speed, 367–368, 367t, 704, 713
 evaporative cooling, 545
 events, 1117
 Lorentz factor, 1122–1123, 1123, 1138

- Lorentz transformation, 1129–1133
measuring, 1118–1119, 1119
relativity of length, 1125–1128, 1126, 1132–1133
relativity of simultaneity, 1120, 1120–1121, 1131
relativity of time, 1121, 1121–1125, 1131
relativity of velocity, 1133, 1133–1134
event horizon, 362
excess charge, 611
exchange coupling, 962
excitation, of electrons, 1189, 1189, 1255
excitation energy, 1217
excited states, 1189, 1189
expansion, of universe, 1356–1357
exploding bodies, Newton's second law and motion of, 221
explosions:
 one-dimensional, 231, 231
 two-dimensional, 232, 232
extended objects, 108
 drawing rays to locate, 1026, 1026
 in plane mirrors, 1012, 1012–1013
external agents, applied force from, 688
external electric field:
 Gaussian surfaces, 669–670
 isolated conductor in, 707, 707
external forces, 99
 collisions and internal energy transfers, 196–197
 system of particles, 220–223
 work done with friction, 192–194
 work done without friction, 192
external magnetic field:
 and diamagnetism, 958
 and ferromagnetism, 957
 and paramagnetism, 957, 959, 960
external torque, 310–311, 313, 314
eye, *see* human eye
eyepiece:
 compound microscope, 1032, 1032
 refracting telescope, 1033
- F**
face-centered cubic, 1253
Fahrenheit temperature scale, 518, 518–519
falling body, terminal speed of, 130–132, 131
farad, 718
Faraday, Michael, 610, 631, 731–732, 865, 880
Faraday's experiments, 865–866
 and Lenz's law, 868, 868–871, 869
Maxwell's equation form, 949t
mutual induction, 891
- reformulation, 876–877
self-induction, 881, 881–882
Faraday's law of induction, 865–866, 943, 978
faults, rock, 60
femtometer, 1282
fermi (unit), 1282
Fermi, Enrico, 1310, 1320, 1336
Fermi–Dirac statistics, 1258
Fermi energy, 1255, 1257–1259, 1261
Fermilab accelerator, 1335, 1352
Fermi level, 1255
fermions, 1336, 1337
Fermi speed, 1255–1256
ferromagnetic materials, 957, 996
ferromagnetism, 957, 961–964, 962. *See also* iron
FET (field-effect-transistor), 1270, 1270–1271
field declination, 951
field-effect-transistor (FET), 1270, 1270–1271
field inclination, 951
field of view:
 refracting telescope, 1033
 spherical mirror, 1015
final state, 528, 529, 565
finite well electron traps, 1195, 1195–1197
fires, pit stop fuel dispenser, 792, 792
first law of thermodynamics, 528–533
 equation and rules, 531
 heat, work, and energy of a system, 528–530, 533
 sample problem involving, 533
 special cases of, 532–533, 532t
first-order line, 1099
first reflection point, 1006
fish, electric, 786–787
fission, nuclear, 1309–1316
fission rate, nuclear reactor, 1319–1320
fixed axis, 259, 311, 311–312
floaters, 1082
floating, 395, 395
flow, 398–400, 399, 400, 402
flow calorimeter, 547
fluids, 130, 386–405
 apparent weight in, 396–397
 Archimedes' principle, 394–397, 395
 Bernoulli's equation, 401–404
 defined, 386–387
 density, 387
 equation of continuity, 398–401, 400
 motion of ideal, 398, 398–399
 Pascal's principle, 393, 393–394
 pressure, 387–388
 pressure measurement, 392, 392–393
 at rest, 388–391, 389
 sample problems involving, 388, 391, 397, 401, 403–404
- fluid streamlines, 399–400, 400
flux. *See also* electric flux
 magnetic, 866–867, 880, 942
 volume, 660
focal length:
 compound microscope, 1032, 1032
 refracting telescope, 1033, 1033
 simple magnifying lens, 1031, 1031–1032
 spherical mirrors, 1015, 1015–1016
 thin lenses, 1024, 1024–1025
focal plane, 1057
focal point:
 compound microscope, 1032, 1032
 objects outside, 1017
 real, 1016, 1016
 refracting telescope, 1033, 1033
 simple magnifying lens, 1031, 1031–1032
 spherical mirrors, 1015, 1015–1016
 thin lenses, 1024, 1024–1025
two-lens system, 1027, 1027–1028
virtual, 1016, 1016
- force(s), 312t. *See also specific forces, e.g.: gravitational force*
 attractive, 356
 buoyant, 394–397, 395
 centripetal, 133–138, 134
 conservative, 179–181, 180
 in crossed magnetic fields, 809–810
 defined, 94
 and diamagnetism, 958
 due to entropy, 589–590
 electric field vs., 631
 equilibrium, 99
 equilibrium of, on particles, 618
 external vs. internal, 99
 and linear momentum, 224–225
 lines of, 631
 and motion, 14
 net, 99, 616–618
 and Newton's first law, 96–98
 Newton's laws applied to, 108–113
 and Newton's second law, 98–101
 and Newton's third law, 106–107
 nonconservative, 179
 normal, 104, 104–105
 path independence of
 conservative, 179–181, 180
 principle of superposition for, 96
 and radiation pressure, 984
 resultant, 99
 of rolling, 299, 299–301
 superposition principle for, 615
 tension, 105, 105–106
 unit of, 96, 96–97
 as vector quantities, 96
 and weight, 103–104
- force constant, 159
forced oscillations, 432–433, 433, 912–920, 914
forced oscillators, 432–433, 433
force law, for simple harmonic motion, 419
forward-bias connection, junction rectifiers, 1267–1268, 1268
fractional efficiency, 1182
Franklin, Benjamin, 611, 619, 621
Fraunhofer lines, 1250–1251
free-body diagrams, 99–101, 100, 108–113
free charge, 735
free electrons, 746
free-electron model, 758, 1255
free expansion:
 first law of thermodynamics for, 532, 532t
 ideal gases, 573–575, 585, 585–588, 586
free-fall acceleration (g), 27, 27–28, 427
free-fall flight, 28
free oscillations, 432–433, 914
free particle:
 Heisenberg's uncertainty principle for, 1172, 1172–1174
 matter waves for, 1187
free space, 974
freeze-frames, 414, 415, 416
freezing point, 518t, 525
freight ton, 11
frequency. *See also* angular frequency
 of circulating charged particles, 814–817
 cutoff, 1156–1157
 of cyclotrons, 818–819
 driving, 914
 and index of refraction, 1050
 of photons, 1154
 proper, 1135
 simple harmonic motion, 414–417, 417
 sound waves, 483
 waves, 448
 and wavelength, 446–449
 wave on stretched string, 453
Fresnel bright spot, 1082–1083, 1083
friction, 105, 105, 124–130, 125–126
 cold-weld, 126–127, 127
 as nonconservative force (kinetic friction), 179
 properties of, 127
 and rolling, 299, 299
sample problems involving, 128–130, 132
types of, 125, 126
work done by external force with, 192, 192–194, 193
frictionless surface, 95, 105
fringing, 674
f subshells, 1235
fuel charge, nuclear reactor, 1320–1321

fuel rods, 1317, 1320–1321
 fulcrum, 345
 full electron levels, 1231
 fully charged capacitor, 719
 fully constructive interference, 460, 460, 461t, 465, 486
 fully destructive interference, 460, 460, 461t, 465, 486–487
 fundamental mode, 468, 494
 fused quartz:
 coefficient of linear expansion for, 521t
 index of refraction, 992t
 index of refraction as function of wavelength, 993
 resistivity, 754t
 fusion, 1140, 1284, 1322–1329
 controlled, 1326–1329
 laser, 1328–1329
 most probable speed in, 1322, 1333
 process of, 1322–1323
 in Sun and stars, 1322, 1324, 1324–1326

G

g (free-fall acceleration), 27, 27–28
 measuring, with physical pendulum, 427
G (gravitational constant), 355
g units (acceleration), 21
 galaxies, 354
 Doppler shift, 1135–1136, 1148, 1148
 formation in early universe, 1360
 gravitational lensing caused by, 375, 376
 matter and antimatter in, 1338–1339
 recession of, and expansion of universe, 1356
 superluminal jets, 1149
 Galilean transformation equations, 1129
Galileo, 382
 gamma rays, 622, 806, 974
 bubble chamber track, 1169, 1169
 radiation dosage, 1297
 ultimate speed, 1118
 gamma-ray photons, 1324, 1338
 gas constant, 551
 gases, 549. *See also* ideal gases;
 kinetic theory of gases
 compressibility, 387
 confined to cylinder with movable piston, 528–530, 529
 density of selected, 387t
 as fluids, 387
 polyatomic, 565
 specific heats of selected, 525t
 speed of sound in, 481t
 thermal conductivity of selected, 535t
 gas state, 526
 gauge pressure, 390

gauss (unit), 806
 Gauss, Carl Friedrich, 660
 Gaussian form, of thin-lens formula, 1043
 Gaussian surfaces:
 capacitors, 719–723
 defined, 660
 electric field flux through, 660, 660–664, 661
 external electric field, 669, 669–670
 and Gauss' law for magnetic fields, 942
 Gauss' law, 659–677
 charged isolated conductor, 668–670
 and Coulomb's law, 666–667
 cylindrical symmetry, 671, 671–672
 dielectrics, 735, 735–737
 for electric fields, 942, 949t
 and electric flux, 659–664
 formulas, 664–665
 for magnetic fields, 941–943, 942, 949t
 and Maxwell's equation, 949t
 planar symmetry, 673, 673–675, 674
 spherical symmetry, 675–677, 676
 Geiger counter, 1276
 general theory of relativity, 374–376, 1117, 1123–1124
 generator. *See also* alternating current generator
 electric, 772
 homopolar, 835
 geomagnetic pole, 807, 950
 geometric addition of vectors, 41, 41–42, 42, 44
 geometrical optics, 991, 1054, 1082
 geosynchronous orbit, 382
 glass:
 coefficient of linear expansion, 521t
 index of refraction, 992t
 as insulator, 612
 polarization of light by reflection, 998
 rubbing rod with silk, 610, 610, 621
 shattering by sound waves, 490
 Global Positioning System (GPS), 1, 1117
g-LOC (*g*-induced loss of consciousness), 77, 408
 gluons, 818, 1350, 1354
 gold, 1239
 alpha particle scattering, 1277–1279
 impact with alpha particle, 705
 isotopes, 1280
 GPS (Global Positioning System), 1, 1117
 grand jeté, 221–222, 222
 grand unification theories (GUTs), 1355

graphs, average velocity on, 15, 16, 16
 graphical integration:
 of force in collision, 227, 227
 for one-dimensional motion, 29, 29–30
 work calculated by, 164–166
 grating spectroscope, 1100, 1100–1101
 gravitation, 354–377
 and Big Bang, 1360
 defined, 355
 Einstein's view of, 374–376, 376
 gravitational acceleration (a_g), 360
 inside Earth, 362–364
 near Earth's surface, 359–362, 360
 Newton's law of, 355–356, 369
 potential energy of, 364–368
 sample problems involving, 358, 362, 368, 373–374
 variation with altitude, 360t
 gravitational constant (*G*), 355
 gravitational force, 102–103, 621, 1338
 center of gravity, 330–332, 331
 and Newton's law of gravitation, 355–356, 356
 pendulums, 425, 425
 and potential energy, 366–367
 and principle of superposition, 357–359
 work done by, 155–158, 156
 gravitational lensing, 376, 376
 gravitational potential energy, 178, 364–368, 365
 determining, 182
 and escape speed, 367–368
 and gravitational force, 366–367
 graviton, 376
 gray (unit), 1296
 grounding, 612
 ground speed, 90
 ground state, 1189, 1189–1190
 wave function of hydrogen, 1208–1210, 1209
 zero-point energy, 1193–1194
 gry (unit), 8
g subshells, 1235
 gyroscope precession, 317, 317–318

H

hadrons, 1338, 1345–1346
 half-life, 1281, 1287, 1295, 1335
 half-width of diffraction grating lines, 1098, 1099–1100
 Hall effect, 810–813, 811, 820
 Hall potential difference, 811
 halogens, 1236
 halo nuclides, 1282
 hang, in basketball, 86–87
 hanging blocks, 108, 108–109
 hard reflection, of traveling waves at boundary, 467

- human body:
as conductor, 612
physiological emf devices, 772
- human eye, 1031
floaters, 1082
image production, 1012
and resolvability in vision,
1092, 1093
sensitivity to different
wavelengths, 973, 974
- human wave, 472
- Huygens, Christian, 1048
- Huygens' principle, 1048, 1048–1049
- Huygens' wavelets, 1083
- hydraulic compression, 341
- hydraulic engineering, 386
- hydraulic jack, 394
- hydraulic lever, 393, 393–394
- hydraulic stress, 341–342, 341t
- hydrogen, 1201–1212
Bohr model, 1203, 1203–1204
as electron trap, 1202
emission lines, 1100, 1100–1101
formation in early universe,
1360
in fusion, 1140, 1322–1329
heats of transformation, 526t
quantum numbers, 1206–1208,
1208t
RMS speed at room
temperature, 556t
and Schrödinger's equation,
1205–1212
spectrum of, 1206
speed of sound in, 481t
thermal conductivity, 535t
wave function of ground state,
1208–1210, 1209
- hydrogen bomb (thermonuclear
bomb), 1326–1327
- hydrostatic pressures, 388–391
- hypercharge, 1364
- hysteresis, 963, 963–964
- I**
- icicles, 546
- ideal emf devices, 773
- ideal engines, 591–592
- ideal fluids, 398, 398–399
- ideal gases, 550–554
adiabatic expansion, 571–575,
572
average speed of molecules,
561–563
free expansion, 585, 585–588,
586
- ideal gas law, 551–552
- internal energy, 564–568
- mean free path, 558, 558–560
- molar specific heats, 564–568
- most probable speed of
molecules, 562
- RMS speed, 554–556, 555, 556t
- sample problems involving,
553–554, 556, 560, 563,
567–570, 574–575
- translational kinetic energy, 557
work done by, 552–554
- ideal gas law, 551–552, 552
- ideal gas temperature, 517
- ideal inductor, 882
- ideal refrigerators, 596
- ideal solenoid, 849–850
- ideal spring, 160
- ideal toroids, 850
- ideal transformers, 931, 931–932
- ignition, in magnetic confinement,
1328
- images, 1010–1036
extended objects, 1026, 1026
locating by drawing rays, 1026,
1026
from plane mirrors, 1010–1014,
1012
from spherical mirrors,
1014–1020, 1015, 1016, 1033,
1033–1034
from spherical refracting surfaces,
1020–1022, 1021, 1034,
1034
from thin lenses, 1023–1030,
1025, 1026, 1034–1036, 1035
types of, 1010–1011
- image distances, 1012
- impedance, 923, 926, 932
- impedance matching, in
transformers, 932
- impulse, 227
series of collisions, 227–228, 228
single collision, 226, 226–227
- incident ray, 991, 991
- incoherent light, 1059
- incompressible flow, 398
- indefinite integral, 26
- independent particle model, of
nucleus, 1298–1299
- indeterminate structures,
equilibrium of, 338–339, 339
- index of refraction:
and chromatic dispersion,
993–994
common materials, 992t
defined, 992, 1049
and wavelength, 1050–1052
- induced charge, 612–613
- induced current, 864–865
- induced electric dipole moment,
698
- induced electric fields, 874–879,
875, 977, 977–978
- induced emf, 865, 867–868, 870–873
- induced magnetic fields, 943–946,
944
- displacement current, 947, 948
- finding, 948
- from traveling electromagnetic
waves, 979, 979–980
- inductance, 879–880
LC oscillations, 903–910
RLC circuits, 910–912
RL circuits, 882–886
series *RLC* circuits, 921–926
- solenoids, 880, 881
- induction:
of electric fields, 874–879
and energy density of magnetic
fields, 889–890
and energy stored in magnetic
fields, 887–888
and energy transfers, 871–874,
872
- Faraday's and Lenz's laws,
864–871, 978
- in inductors, 879–880
- Maxwell's law, 944, 979
- mutual, 890–892, 891
- and *RL* circuits, 882–886
self-, 881, 881–882, 890
- inductive reactance, 919
- inductive time constant, 884–885
- inductors, 879–880
with ac generator, 918, 918–919,
919
- phase and amplitude relation-
ships for ac circuits, 920t
- RL* circuits, 882–886
- series *RLC* circuits, 922
- inelastic collisions:
defined, 233
in one dimension, 234,
234–236, 235
in two dimensions, 240–241
- inertial confinement, 1328
- inertial reference frames,
86–87, 1117
- inexact differentials, 531
- infinitely deep potential energy
well, 1188, 1189
- infinite potential well, 1189
detection probability in,
1192–1194
energy levels in, 1190–1191,
1201, 1232–1234
wave function normalization in,
1194–1195
- inflation, of early universe, 1359
- initial conditions, 420
- initial state, 528, 529, 565
- in phase:
ac circuits, 920t
resistive load, 915
sound waves, 486
thin-film interference, 1064
traveling electromagnetic
waves, 974
waves, 459, 461
- instantaneous acceleration:
one-dimensional motion,
20–22, 21
two- and three-dimensional
motion, 67–69
- instantaneous angular
acceleration, 261
- instantaneous angular
velocity, 260
- instantaneous power, 167, 198
- instantaneous velocity:
one-dimensional motion, 18–19
two- and three-dimensional
motion, 65
- insulators, 612–613, 762
electrical properties, 1254,
1254–1255
resistivities of selected, 754t
unit cell, 1253
- integrated circuits, 1271
- intensity:
defined, 981
diffraction gratings, 1098–1099
double-slit diffraction, 1095,
1096–1097
double-slit interference,
1060–1062, 1061, 1096
electromagnetic waves, 982,
982–983
single-slit diffraction,
1086–1090, 1087, 1089
of sound waves, 488–492, 489
of transmitted polarized light,
987–990, 988
- interference, 459, 459–461, 460,
1047–1072. *See also*
diffraction
combining more than two
waves, 1062
- diffraction vs., 1095–1097
- double-slit from matter waves,
1167, 1167–1168
- double-slit from single photons,
1162, 1162–1164
- fully constructive, 460, 460,
461t, 465, 486
- fully destructive, 460, 460, 461t,
465, 486–487
- intensity in double-slit,
1059–1063, 1061
- intermediate, 460, 460, 461t, 487
and rainbows, 1051–1052, 1052
- sound waves, 485–488, 486
- thin films, 1064, 1064–1071
- and wave theory of light,
1047–1052
- Young's double-slit experiment,
1053–1058, 1055
- interference factor, 1096
- interference fringes, 1055,
1055–1056
- interference pattern, 1055,
1055, 1057
- interfering waves, 459
- interferometer, 1070–1071
- intermediate interference, 460,
460, 461t, 487
- internal energy, 514
and conservation of total
energy, 195
and external forces, 196–197
- and first law of
thermodynamics, 531
of ideal gas by kinetic theory,
564–568
- internal forces, 99, 220–223
- internal resistance:
ammeters, 788
circuits, 776, 776
emf devices, 779–780
- internal torque, 310

International Bureau of Weights and Standards, 3, 6–7
 International System of Units, 2–3, 2t
 interplanar spacing, 1106
 intrinsic angular momentum, 953, 954
 inverse cosine, 45, 45
 inverse sine, 45, 45
 inverse tangent, 45, 45
 inverse trigonometric functions, 45, 45
 inverted images, 1016, 1017
 ionization energy, 1220, 1221
 ionized atoms, 1206
 ion tail, 1002
 iron, 1236
 Curie temperature, 962
 ferromagnetic material, 957, 962
 quantum corral, 1199, 1199
 radius of nucleus, 620–621
 resistivity, 754t
 iron filings:
 bar magnet's effect on, 942, 942
 current-carrying wire's effect on, 838
 irreversible processes, 584, 588–590
 irrotational flow, 398, 402
 island of stability, 1281
 isobars, 1281
 isobaric processes summarized, 575, 575t
 isochoric processes summarized, 575, 575t
 isolated spherical capacitors, 722, 730
 isolated system, 184–185
 conservation of total energy, 196
 linear momentum conservation, 230–231
 isospin, 1364
 isotherm, 552, 552
 isothermal compression, 552, 591, 591
 isothermal expansion, 552
 Carnot engine, 591, 591
 entropy change, 585–586, 586
 isothermal processes, 575, 575t
 isotopes, 1280
 isotopic abundance, 1280n.a
 isotropic materials, 754
 isotropic point source, 982
 isotropic sound source, 489

J
 joint, in rock layers, 141
 Josephson junction, 1178
 joule (J), 150, 524
 jump seat, 443
 junctions, circuits, 781. *See also p-n junctions*
 junction diodes, 762
 junction lasers, 1269, 1269
 junction plane, 1266, 1266

junction rectifiers, 1267–1268, 1268
 junction rule, Kirchoff's, 781
 Jupiter, escape speed for, 367t

K
 kaons, 1124–1125, 1335
 and eightfold way, 1347t
 and strangeness, 1346
 kelvins, 515, 516, 518, 521
 Kelvin temperature scale, 515, 516–517, 518
 Kepler, Johannes, 369
 Kepler's first law (law of orbits), 369, 369
 Kepler's second law (law of areas), 369, 369–370
 Kepler's third law (law of periods), 370, 370–371, 370t
 kilogram, 6, 6–7
 kilowatt-hour, 167
 kinematics, 14
 kinetic energy, 283t
 in collisions, 233
 and conservation of mechanical energy, 184–187
 and conservation of total energy, 195–199
 defined, 150
 and momentum, 1141, 1142
 in pion decay, 1342
 and relativity, 1140–1141, 1141
 of rolling, 297, 298–301
 of rotation, 271–273, 272
 sample problems involving, 150, 161–162, 277
 satellites in orbit, 371–372, 372
 simple harmonic motion, 422, 422
 traveling wave on stretched string, 454, 454–455
 and work, 152, 152–155
 yo-yo, 302
 kinetic energy density, of fluids, 402
 kinetic energy function, 188
 kinetic frictional force, 126–127, 127
 as nonconservative force, 179
 rolling wheel, 299
 kinetic theory of gases, 549–576
 adiabatic expansion of ideal gases, 571–575, 572
 average speed of molecules, 561–563
 and Avogadro's number, 550
 distribution of molecular speeds, 560–563, 561
 ideal gases, 550–554
 mean free path, 558, 558–560
 molar specific heat, 564–571
 most probable speed of molecules, 562
 pressure, temperature, and RMS speed, 554–556
 and quantum theory, 569, 570–571
 RMS speed, 554–556, 556t
 translational kinetic energy, 557

Kirchoff's current law, 781
 Kirchoff's junction rule, 781
 Kirchoff's loop rule, 775
 Kirchoff's voltage law, 775
 K shell, 1238, 1238
 Kundt's method, 513

L
 lagging, in ac circuits, 920, 920t
 lagging waves, 461
 lambda particles, eightfold way and, 1347t
 lambda-zero particle, 1348
 laminar flow, 398
 Large Magellanic Cloud, 1293
 lasers, 1240–1245
 coherence, 1060
 helium–neon gas, 1243, 1243–1245
 junction, 1269, 1269
 operation, 1242, 1242–1245
 radiation pressure, 985
 surgery applications, 1241, 1241
 laser fusion, 1328–1329
 lasing, 1244
 lateral magnification:
 compound microscope, 1032
 spherical mirrors, 1017
 two-lens system, 1027–1030
 lateral manipulation, using STM, 1178
 lattice, 339, 339, 1253, 1253
 law of areas (Kepler's second law), 369, 369–370
 law of Biot and Savart, 837–838, 844, 852
 law of conservation of angular momentum, 312, 312–316
 law of conservation of electric charge, 621–622
 law of conservation of energy, 195–199, 197
 law of conservation of linear momentum, 230
 law of orbits (Kepler's first law), 369, 369
 law of periods (Kepler's third law), 370, 370, 370t
 laws of physics, 47
 law of reflection, 991
 law of refraction, 992, 1048, 1048–1052
 Lawson's criteria, 1327, 1328–1329
 LC oscillations, 903–910
 and electrical–mechanical analogy, 906–907, 906t
 qualitative aspects, 904, 904–906
 quantitative aspects, 907–910
 LC oscillators, 906–910, 906t
 electrical–mechanical analogy, 906–907
 quantitative treatment of, 907–910
 radio wave creation, 974, 974–977

lead:
 coefficient of linear expansion, 521t
 heats of transformation, 526t
 specific heats, 525t
 thermal conductivity, 535t
 leading, in ac circuits, 920, 920t
 leading waves, 461
 LEDs (light-emitting diodes), 1268–1270, 1269
 Leidenfrost effect, 545
 length:
 coherence, 1241
 consequences of Lorentz transformation equations, 1131–1132
 length contraction, 1126–1128
 proper, 1126
 relativity of, 1125–1128, 1126, 1131–1132
 rest, 1126
 of selected objects, 4t
 units of, 3–4
 in wavelengths of light, 1071
 lens, 1023. *See also thin lenses*
 bi-concave, 1044
 bi-convex, 1044
 converging, 1023, 1024, 1025
 diffraction by, 1091
 diverging, 1023, 1024, 1025
 magnifying, 1031, 1031–1032
 meniscus concave, 1044
 meniscus convex, 1044
 plane-concave, 1044
 plane-convex, 1044
 simple magnifying, 1031, 1031–1032
 symmetric, 1025–1026
 thin-film interference of coating on, 1068
 lens maker's equation, 1024
 Lenz's law, 868, 868–871, 869, 881
 leptons, 1338, 1343–1345, 1344t
 conservation of lepton number, 1344–1345
 formation in early universe, 1359
 lepton number, 1344–1345
 lifetime:
 compound nucleus, 1300
 radionuclide, 1287–1288
 subatomic particles, 1123
 lifting capacity, balloons, 581
 light, 445, 977. *See also diffraction; interference; photons; reflection; refraction*
 absorption and emission by atoms, 1221
 coherent, 1059, 1241
 components of, 993–994
 Doppler effect, 499
 in early universe, 1359–1360
 Huygens' principle, 1048, 1048–1049
 incoherent, 1059

law of reflection, 991
 law of refraction, 992, 1048,
 1048–1052
 monochromatic, 993, 995–996,
 1241
 polarized light, 907, 986,
 986–989, 988
 as probability wave, 1162–1164
 speed of, 445
 travel through media of
 different indices of
 refraction, 1050, 1050
 unpolarized light, 986, 986
 visible, 974, 1118
 as wave, 1047–1052, 1048
 wave theory of, 1047–1052,
 1081–1083
 white, 993, 993–994, 994, 1085
 light-emitting diodes (LEDs),
 1268–1270, 1269
 light-gathering power refracting
 telescope, 1033
 lightning, 610, 717
 in creation of lodestones, 964
 upward streamers, 672, 672
 light quantum, 1154–1155
 light wave, 977, 982–983
 light-year, 12
 line(s):
 diffraction gratings, 1099–1100
 spectral, 1206
 as unit, 8
 linear charge density, 638–639, 639t
 linear density, of stretched string,
 452, 453
 linear expansion, 521, 521
 linear momentum, 224–225, 312t
 completely inelastic collisions
 in one dimension, 234–236
 conservation of, 230–232, 242
 elastic collisions in one
 dimension, with moving
 target, 238–239
 elastic collisions in one
 dimension, with stationary
 target, 237–238
 elastic collisions in two
 dimensions, 240–241
 at equilibrium, 328
 and impulse of series of
 collisions, 227–228
 and impulse of single collision,
 226–227
 inelastic collisions in one
 dimension, 234, 234–236, 235
 inelastic collisions in two
 dimensions, 240–241
 of photons, 1159, 1159–1162,
 1160
 sample problems involving, 229,
 231–232, 236, 239–240, 243
 system of particles, 225
 linear momentum-impulse
 theorem, 227
 linear motion, 259
 linear oscillator, 419, 419–421

linear simple harmonic oscillators,
 419, 419–421
 line integral, 692
 line of action, of torque, 278, 278
 lines of charge:
 electric field due to, 638–643,
 639
 electric potential due to, 699,
 699–700
 lines of force, 631
 line of symmetry, center of mass
 of solid bodies with, 217
 line shapes, diffraction grating,
 1103
 liquefaction, of ground during
 earthquakes, 7–8
 liquids:
 compressibility, 341, 387
 density of selected, 387t
 as fluids, 386–387
 heat absorption, 524–527
 speed of sound in, 481t
 thermal expansion, 520–522
 liquid state, 525–526
 Local Group, 354
 Local Supercluster, 354
 lodestones, 950, 964
 longitudinal magnification, 1045
 longitudinal motion, 446
 longitudinal waves, 446, 446
 long jump, conservation of
 angular momentum in,
 314, 314
 loop model, for electron orbits,
 955, 955–956, 956
 loop rule, 775, 781, 883, 883–884
 Lorentz factor, 1122–1123, 1123,
 1138
 Lorentz transformation,
 1129–1133
 consequences of, 1131–1133
 pairs of events, 1130t
 Loschmidt number, 581
 loudness, 489
 L shell, 1238, 1238
 Lyman series, 1206, 1207, 1212

M

Mach cone, 503, 503
 Mach cone angle, 503, 503
 Mach number, 503
 magic electron numbers, 1299
 magnets, 610, 803–808, 804, 807,
 950–952
 applications, 803–804
 bar, 806–807, 807, 826, 826t,
 942, 942, 950, 950
 electromagnets, 804, 804, 806t
 north pole, 807, 807, 942
 permanent, 804
 magnetically hard material,
 966, 996
 magnetically soft material,
 966, 996
 magnetic confinement, 1327
 magnetic dipoles, 807, 824–826,
 825, 942, 942

magnetic dipole moment,
 824–826, 825, 1221, 1222,
 1222. *See also* orbital mag-
 netic dipole moment; spin
 magnetic dipole moment
 of compass needle, 964
 diamagnetic materials, 957–958
 effective, 1225
 ferromagnetic materials,
 957, 962
 paramagnetic materials,
 957, 959
 magnetic domains, 962–964, 963
 magnetic energy, 887–888
 magnetic energy density, 889–890
 magnetic field, 803–827, 836–854.
See also Earth's magnetic
 field
 Ampere's law, 844, 844–848
 circulating charged particle,
 814–817, 815, 816
 crossed fields and electrons,
 808–810, 811
 current-carrying coils as
 magnetic dipoles, 851–854
 cyclotrons and synchrotrons,
 818, 818–819
 defined, 804–808, 805
 dipole moment, 824–826
 displacement current,
 946–950, 947
 due to current, 836–842
 Earth, 950, 950–951
 energy density of, 889–890
 energy stored in, 887–888
 external, 957–960
 and Faraday's law of induction,
 865–866
 force on current-carrying wires,
 820–822
 Gauss' law for, 941–943, 949t
 Hall effect, 810, 810–813
 induced, 943–946, 944
 induced electric field from,
 878–879
 induced emf in, 870–871
 and Lenz' law, 868, 868–871, 869
 parallel currents, 842–843, 843
 producing, 804
 rms of, 982–983
 selected objects and situations,
 806t
 solenoids and toroids, 848–851
 torque on current loops,
 822–824, 823
 traveling electromagnetic
 waves, 974–977, 975, 976
 magnetic field lines, 806–807, 807,
 838–839
 magnetic flux, 866–867, 880, 942
 magnetic force, 610, 805
 circulating charged particle,
 814–817, 815, 816
 current-carrying wire, 820,
 820–822, 842–843, 843
 particle in magnetic field, 805,
 805–806

magnetic materials, 941, 956–957
 magnetic monopole, 804, 942
 magnetic potential energy,
 887–888
 magnetic resonance, 1229–1230,
 1230
 magnetic resonance imaging
 (MRI), 941, 941
 magnetic wave component, of
 electromagnetic waves,
 975–976, 976
 magnetism, 941–965. *See also*
 Earth's magnetic field
 of atoms, 1221, 1221
 diamagnetism, 957–958, 958
 and displacement current,
 946–950
 of electrons, 952–957
 ferromagnetism, 957, 961–964,
 962
 Gauss' law for magnetic fields,
 941–943
 induced magnetic fields,
 943–946
 magnets, 950–952
 Mid-Atlantic Ridge, 951, 951
 paramagnetism, 957, 959,
 959–961
 magnetization:
 ferromagnetic materials, 962
 paramagnetic materials,
 959, 960
 magnetization curves:
 ferromagnetic materials, 962
 hysteresis, 963, 963
 paramagnetic materials, 960
 magnetizing current, transformers,
 931
 magnetometers, 951
 magnification:
 angular, 1031–1033
 lateral, 1017, 1027–1030, 1032
 longitudinal, 1045
 magnifying lens, simple, 1031,
 1031–1032
 magnitude:
 of acceleration, in one-
 dimensional motion, 20
 of acceleration, in two- and
 three-dimensional motion, 68
 of angular momentum, 305–306
 of displacement in one-dimen-
 sional motion, 14–15
 estimating order of, 4–5
 of free-fall acceleration, 27
 of vectors, 41–42, 42
 of velocity, in one-dimensional
 motion, 15
 of velocity, in two- and three-
 dimensional motion, 68
 magnitude-angle notation (vec-
 tors), 43
 magnitude ratio, traveling electro-
 magnetic waves, 976
 majority carriers, 1264, 1266,
 1266–1267
 mantle (Earth), 360, 380, 380

- mass, 283t
 defined, 97–98
 sample problems involving, 243
 scalar nature of, 41, 98
 of selected objects, 7t
 units of, 6–8
 and wave speed on stretched string, 452
 weight vs., 104
 mass dampers, 422
 mass energy, 1138–1139, 1139t
 mass excess, 1283
 mass flow rate, 400
 massless cord, 105, 105
 massless-frictionless pulleys, 105, 106, 108, 108–109
 massless spring, 160
 mass number, 621–622, 1280, 1280t
 mass spectrometer, 817, 817
 matter:
 antimatter, 1310t, 1338–1339
 baryonic, 1358, 1361
 dark, 1358, 1361, 1361
 energy released by 1 kg, 1310t
 magnetism of, *see* magnetism
 nonbaryonic, 1361, 1361
 nuclear, 1285
 particle nature of, 1168, 1168–1169, 1169
 wave nature of, 1166–1170
 matter waves, 445, 1166–1179, 1186–1213
 barrier tunneling by, 1176–1179
 of electrons, 1166–1170, 1167, 1169, 1173, 1186
 of electrons in finite wells, 1195–1197, 1196
 energies of trapped electrons, 1186–1191
 and Heisenberg uncertainty principle, 1172–1174
 hydrogen atom models, 1201–1212
 reflection from a potential step, 1174–1176
 Schrödinger's equation for, 1170–1172
 two- and three-dimensional electron traps, 1197–1201
 wave functions of trapped electrons, 1191–1195
 matter wave interference, 1168
 maxima:
 diffraction patterns, 1082, 1082
 double-slit interference, 1055, 1055–1057, 1060–1061
 single-slit diffraction, 1083–1085, 1088, 1090
 thin-film interference, 1066
 Maxwell, James Clerk, 561, 569, 610, 844, 944, 973–974, 984, 1048, 1353
 Maxwellian electromagnetism, 1334
 Maxwell's equations, 941, 949t, 1171
 Maxwell's law of induction, 944, 979
 Maxwell's rainbow, 973–974
 Maxwell's speed distribution law, 561, 561–563
 mean free distance, 759
 mean free path, of gases, 558, 558–560
 mean free time, 759
 mean life, radioactive decay, 1287, 1335
 measurement, 1–8
 of angles, 45
 conversion factors, 3
 International System of Units, 2–3
 of length, 3–4
 of mass, 6–8
 of pressure, 392, 392–393
 sample problems involving, 4–5, 7–8
 significant figures and decimal places, 4
 standards for, 1–2
 of time, 5–6
 mechanical energy:
 conservation of, 184–187
 and conservation of total energy, 195
 damped harmonic oscillator, 430–431
 and electric potential energy, 705
 satellites in orbit, 371–372, 372
 simple harmonic motion, 421–422, 422
 mechanical waves, 445. *See also* wave(s)
 medium, 977
 megaphones, 1082
 melting point, 525, 526t
 meniscus concave lens, 1044
 meniscus convex lens, 1044
 mercury barometer, 388, 392, 392
 mercury thermometer, 520
 mesons, 1338, 1345–1346
 and eightfold way, 1347–1348, 1347t
 and quark model, 1349–1351, 1355
 underlying structure suggested, 1348
 messenger particles, 1352–1354
 metals:
 coefficients of linear expansion, 521t
 density of occupied states, 1259–1260, 1260
 density of states, 1257, 1257–1258
 elastic properties of selected, 341t
 electrical properties, 1252–1261
 lattice, 339, 339
 occupancy probability, 1258, 1258–1259
 resistivities of selected, 754t
 speed of sound in, 481t
 thermal conductivity of selected, 535t
 unit cell, 1253
 metallic conductors, 746, 762
 metal-oxide-semiconductor-field effect-transistor (MOSFET), 1270, 1270–1271
 metastable states, 1242
 meter (m), 1–4
 metric system, 2
 Michelson's interferometer, 1070–1071, 1071
 microfarad, 718
 micron, 8
 microscopes, 1030, 1032, 1032
 microscopic clocks, time dilation tests, 1123
 microstates, in statistical mechanics, 599–600
 microwaves, 445, 499, 649
 Mid-Atlantic Ridge, magnetism, 951, 951
 Milky Way galaxy, 354, 355
 Millikan oil-drop experiment, 645, 645–646
 millimeter of mercury (mm Hg), 388
 miniature black holes, 379
 minima:
 circular aperture diffraction, 1091, 1091
 diffraction patterns, 1082, 1082
 double-slit interference, 1055, 1055, 1056, 1060–1061
 single-slit diffraction, 1083–1088, 1087
 thin-film interference, 1067
 minority carriers, 1264, 1267
 mirage, 1011, 1011
 mirrors, 1012
 in Michelson's interferometer, 1071
 plane, 1010–1014, 1012
 spherical, 1015, 1015–1021, 1016, 1033, 1033–1034
 moderators, for nuclear reactors, 1317
 modulus of elasticity, 340
 Mohole, 380
 molar mass, 550
 molar specific heat, 525, 564–571
 at constant pressure, 566–567, 566–567
 at constant volume, 565, 565–566, 565t, 567
 and degrees of freedom, 568–570, 569t
 of ideal gas, 564–568
 and rotational/oscillatory motion, 570, 570–571
 of selected materials, 525t
 molecular mass, 550
 molecular speeds, Maxwell's distribution of, 560–563, 561
 molecules, 1220
 moment arm, 278, 278
 moment of inertia, 272
 momentum, 224–225. *See also* angular momentum; linear momentum
 center of momentum frame, 1151
 and kinetic energy, 1141, 1142
 in pion decay, 1342
 in proton decay, 1348
 and relativity, 1138
 and uncertainty principle, 1173–1174
 monatomic molecules, 564, 568–570, 569, 569t
 monochromatic light, 993
 lasers, 1241
 reflection and refraction of, 995–996
 monovalent atom, 1256
 Moon, 354, 355
 escape speed, 367t
 potential effect on humans, 378–379
 radioactive dating of rocks, 1296
 more capacitive than inductive circuit, 924
 more inductive than capacitive circuit, 924
 Moseley plot, 1238, 1239–1240
 MOSFET (metal-oxide-semiconductor-field-effect transistor), 1270, 1270–1271
 most probable configuration, 600
 most probable speed in fusion, 562, 1322, 1333
 motion:
 graphical integration, 29, 29–30
 one-dimensional, *see* one-dimensional motion
 oscillatory and rotational, 570, 570–571
 projectile, 70, 70–75
 properties of, 14
 relative in one dimension, 78, 78–79
 relative in two dimensions, 80, 80–81
 of system's center of mass, 220–221
 three-dimensional, *see* three-dimensional motion
 two-dimensional, *see* two-dimensional motion
 motorcycle, acceleration of, 25–26
 mountain pull, 380
 MRI (magnetic resonance imaging), 941, 941
 M shell, 1238, 1238
 multiloop circuits, 781, 781–787, 782
 current in, 781–782
 resistances in parallel, 782, 782–787
 multimeter, 788
 multiplication factor, nuclear reactors, 1318

multiplication of vectors, 50–55
multiplying a vector by a scalar, 50
multiplying two vectors, 50–55
scalar product of, 51, 51–52
vector product of, 50, 52–55, 53
multiplicity, of configurations in statistical mechanics, 599
muons, 1123–1124, 1335, 1343, 1344t
decay, 1341–1342
from proton-antiproton annihilation, 1340, 1340t
muon neutrinos, 1343, 1344t
musical sounds, 492–496, 493, 495
mutual induction, 890–892, 891
mysterious sliding stones, 140

N

nanotechnology, 1187
National Institute of Standards and Technology (NIST), 6
natural angular frequency, 433, 914
nautical mile, 11
NAVSTAR satellites, 1117
n channel, in MOSFET, 1270
near point, 1031, 1031
negative charge, 611, 611
negative charge carriers, 747, 750
negative direction, 14, 14
negative lift, in race cars, 136, 136–137
negative terminal, batteries, 718, 718–719, 773
negative work, 530
net current, 845, 850
net electric charge, 611
net electric field, 634–635
net electric flux, 661–662
net electric potential, 692
net force, 99, 616–618
net torque, 278, 310–311, 823
net wave, 458, 495
net work, 153, 592
neutral equilibrium (potential energy curves), 190
neutralization, of charge, 611
neutral pion, 1118
neutrinos, 1292
and beta decay, 1292, 1293
and conservation of lepton number, 1344–1345
in fusion, 1325
as leptons, 1338
as nonbaryonic dark matter, 1358
from proton-antiproton annihilation, 1340t
neutrons, 612, 1335
accelerator studies, 818
balance in nuclear reactors, 1317, 1317–1318
charge, 620, 620t
control in nuclear reactors, 1317, 1317–1320
discovery of, 1353

and eightfold way, 1347
as fermions, 1336
formation in early universe, 1359
as hadrons, 1338
magnetic dipole moment, 826
and mass number, 621–622
as matter wave, 1168
spin angular momentum, 953
thermal, 1311–1315, 1317
neutron capture, 1300
neutron diffraction, 1168
neutron excess, 1281
neutron number, 1280, 1280t
neutron rich fragments, 1312
neutron stars, 88, 380
density of core, 387t
escape speed, 367t
magnetic field at surface of, 806t
newton (N), 96
Newton, Isaac, 95, 355, 369, 1082
Newtonian form, of thin-lens formula, 1043
Newtonian mechanics, 95, 1171, 1334
Newtonian physics, 1187
newton per coulomb, 631
Newton's first law, 95–98
Newton's law of gravitation, 355–356, 369
Newton's laws, 95, 108–113
Newton's second law, 98–101
angular form, 307–308
and Bohr model of hydrogen, 1203–1204
for rotation, 279–281
sample problems involving, 100–101, 108–113, 223, 280–281
system of particles, 220–223, 221
in terms of momentum, 224–225
translational vs. rotational forms, 283t, 312t
units in, 99t
Newton's third law, 106–107
NIST (National Institute of Standards and Technology), 6
NMR (nuclear magnetic resonance), 1229–1230
NMR spectrum, 1229–1230, 1230
noble gases, 1235, 1299
nodes, 465, 466, 467–468
noise, background, 508
nonbaryonic dark matter, 1358
nonbaryonic matter, 1361, 1361
nonconductors, 612
electric field near parallel, 674–675
Gauss' law for, 673, 673
nonconservative forces, 179
noninertial frame, 97
nonlaminar flow, 398
nonpolar dielectrics, 734
nonpolar molecules, 698

nonquantized portion, of energy level diagram, 1196, 1196
nonsteady flow, 398
nonuniform electric field, 632, 663–664
nonuniform magnetic field, 955, 956, 956
nonviscous flow, 398
normal (optics), 991, 991
normal force, 104, 104–105
normalizing, wave function, 1193–1195
normal vector, for a coil of current loop, 824
north magnetic pole, 950
north pole, magnets, 807, 807, 942, 942
n-type semiconductors, 1263, 1263–1264. *See also p-n* junctions
nuclear angular momentum, 1284
nuclear binding energy, 1217, 1283, 1283–1284, 1312, 1313
per nucleon, 1283, 1283, 1285, 1312
selected nuclides, 1280t
nuclear energy, 1284, 1309–1329
fission, 1309–1316
in nuclear reactors, 1316–1321
thermonuclear fusion, 1322–1329
nuclear fission, 1284, 1309–1316, 1313
nuclear force, 1284
nuclear fusion, *see* thermonuclear fusion
nuclear magnetic moment, 1284
nuclear magnetic resonance (NMR), 1229–1230
nuclear physics, 1276–1301
alpha decay, 1289–1291
beta decay, 1292–1295
discovery of nucleus, 1276–1279
nuclear models, 1297–1300
nuclear properties, 1279–1287
radiation dosage, 1296–1297
radioactive dating, 1295–1296
radioactive decay, 1286–1289
nuclear power plant, 1318
nuclear radii, 1282
nuclear reactions, 1139
nuclear reactors, 1316–1321
nuclear spin, 1284
nuclear weapons, 1284
nucleons, 1280, 1338
binding energy per, 1283, 1283, 1285, 1312
magic nucleon numbers, 1299
nucleus, 612
discovery of, 1276–1279
models, 1297–1300, 1298
mutual electric repulsion in, 620–621
properties of, 1279–1287
radioactive decay, 621–622, 1335–1336

nuclides, 1279, 1280t. *See also radioactive decay*
halo, 1282
magic nucleon numbers, 1299
organizing, 1280–1281, 1281
transuranic, 1319
valley of, 1294, 1294
nuclidic chart, 1280–1281, 1281, 1293–1294, 1294
number density:
of charge carriers, 811–812, 1253t, 1262
of conduction electrons, 1256

O

objects:
charged objects, 631
electrically isolated, 611
electrically neutral, 611
extended, 1012, 1012–1013, 1026, 1026
object distance, 1012
objective:
compound microscope, 1032, 1032
refracting telescope, 1033, 1033
occupancy probability, 1258, 1258–1259
occupied levels, 1231
occupied state density, 1259–1260, 1260
ohm (unit), 753, 754
ohmic losses, 930
ohmmeter, 754
ohm-meter, 754
Ohm's law, 756–759, 757, 758
oil slick, interference patterns from, 1064
one-dimensional elastic collisions, 237, 237–240
one-dimensional electron traps:
infinite potential well, 1188
multiple electrons in, 1231
single electron, 1187–1199
one-dimensional explosions, 231, 231
one-dimensional inelastic collisions, 234, 234–236, 235
one-dimensional motion, 13–32
acceleration, 20–30
average velocity and speed, 15–17
constant acceleration, 23–27
defined, 13
free-fall acceleration, 27–28
graphical integration for, 29–30
instantaneous acceleration, 20–22
instantaneous velocity and speed, 18–19
position and displacement, 14–15
properties of, 14
relative, 78, 78–79
sample problems involving, 17–19, 22, 25–26, 28, 30, 79

- Schrödinger's equation for, 1170–1172
 one-dimensional variable force, 162–163, 163
 one-half rule, for intensity of transmitted polarized light, 987
 one-way processes, 584
 open ends (sound waves), 493–495
 open-tube manometer, 392, 392–393
 optics, 973
 optical fibers, 997, 1241, 1269
 optical instruments, 1030–1036
 optical interference, 1047. *See also* interference
 orbit(s):
 circular vs. elliptical, 373–374
 eccentricity of, 369, 370t, 371–372
 geosynchronous, 382
 law of, 369, 369
 sample problems involving, 373–374
 of satellites, 371–373, 372
 semimajor axis of, 369, 369
 of stars, 382
 orbital angular momentum, 954, 955, 1222–1224, 1223, 1223t
 orbital energy, 1204–1205
 orbital magnetic dipole moment, 954, 1223–1224
 diamagnetic materials, 957–958
 ferromagnetic materials, 957
 paramagnetic materials, 959
 orbital magnetic quantum number, 954–955, 1208, 1208t, 1223t
 orbital quantum number, 1208, 1208t, 1223t, 1254
 orbital radius, 1203–1204
 order numbers, diffraction gratings, 1099
 order of magnitude, 4–5
 organizing tables, for images in mirrors, 1018, 1018t
 orienteering, 44
 origin, 14
 oscillation(s), 413–434. *See also* electromagnetic oscillations; simple harmonic motion (SHM)
 of angular simple harmonic oscillator, 423, 423–424
 damped, 430–431, 431
 damped simple harmonic motion, 430–432
 energy in simple harmonic motion, 421–423
 forced, 432–433, 433
 free, 432–433
 and molar specific heat, 570, 570–571
 of pendulums, 424–428
 simple harmonic motion, 413–421
 simple harmonic motion and uniform circular motion, 428–429
 oscillation mode, 467–468
 out of phase:
 ac circuits, 920t
 capacitive load, 917–918
 inductive load, 919
 sound waves, 486
 thin-film interference, 1066
 waves, 459
 overpressure, 393
 oxygen, 569
 distribution of molecular speeds at 300 K, 561
 heats of transformation, 526t
 molar specific heat and degrees of freedom, 569t
 molar specific heat at constant volume, 565t
 paramagnetism of liquid, 959
 RMS speed at room temperature, 556t
- P**
- pair production, 622
 pancake collapse, of tall building, 253
 parallel-axis theorem, for calculating rotational inertia, 273–275, 274
 parallel circuits:
 capacitors, 724, 724, 726–727, 783t
 resistors, 782, 782–787, 783t
 summary of relations, 783t
 parallel components, of unpolarized light, 998
 parallel currents, magnetic field between two, 842–843, 843
 parallel-plate capacitors, 718, 718 capacitance, 720–721
 with dielectrics, 733–734, 734, 735
 displacement current, 947, 947–949
 energy density, 730
 induced magnetic field, 943–946
 paramagnetic material, 957
 paramagnetism, 957, 959, 959–961
 parent nucleus, 622
 partial derivatives, 484, 978
 partially occupied levels, 1231
 partially polarized light, 907, 986
 particles, 14, 620. *See also specific types, e.g.: alpha particles*
 particle accelerators, 818–819, 1334–1335, 1336
 particle-antiparticle annihilation, 1338
 particle detectors, 1335, 1336
 particle nature of matter, 1168, 1168–1169, 1169
 particle systems. *See also* collisions
 angular momentum, 310–311
 center of mass, 214–219, 215, 219
 electric potential energy of, 703–705, 704
 linear momentum, 225
 Newton's second law for, 220–223, 221
 pascal (Pa), 388, 480, 985
 Pascal's principle, 393, 393–394
 Paschen series, 1206, 1207
 patch elements, 661
 path-dependent quantities, 530
 path-independent quantities, 688
 conservative forces, 179–181, 180
 gravitational potential energy, 366
 path length difference:
 double-slit interference, 1055, 1055–1056, 1061–1063
 and index of refraction, 1051
 single-slit diffraction, 1083, 1083–1084, 1084, 1086
 sound waves, 486
 thin-film interference, 1065–1066
 Pauli exclusion principle, 1230
 and bosons, 1337
 and energy levels in crystalline solids, 1254
 and fermions, 1337
 and Fermi speed, 1255–1256
 nucleons, 1298–1299
 and periodic table, 1235
 pendulum(s), 424–428
 as angular simple harmonic oscillator, 423, 423–424
 ballistic, 236, 236
 bob of, 425
 conical, 146
 conservation of mechanical energy, 185, 185–186
 physical, 426, 426–428, 427
 simple, 425, 425–426
 torsion, 423, 423
 underwater swinging (damped), 430
 perfect engines, 593, 593
 perfect refrigerators, 596, 596
 perihelion distance, 371
 period(s):
 law of, 370, 370, 370t
 of revolution, 76
 simple harmonic motion, 414, 417, 418
 sound waves, 483
 waves, 448, 448
 periodic motion, 414
 periodic table, 1154, 1221
 building, 1234–1236
 x rays and ordering of elements, 1236–1240
 permanent electric dipole moment, 698
 permanent magnets, 804
 permeability constant, 837
 permittivity constant, 614–615
 perpendicular components, of unpolarized light, 998
 phase:
 simple harmonic motion, 416, 417
 waves, 447, 447
 phase angle:
 alternating current, 920t
- simple harmonic motion, 416, 417
 phase change, 525–526
 phase constant:
 alternating current, 920t, 924, 924, 926
 simple harmonic motion, 416, 417
 waves, 448, 448–449
 phase difference:
 double-slit interference, 1055, 1060, 1061–1063
 Michelson's interferometer, 1071
 optical interference, 1050–1052
 and resulting interference type, 461t
 single-slit diffraction, 1086
 sound waves, 486
 thin-film interference, 1066
 waves, 459–460
 phase shifts, reflection, 1065, 1065
 phase-shifted sound waves, 487
 phase-shifted waves, 459–460
 phasors, 462–464, 463
 capacitive load, 917, 917–918
 double-slit interference, 1061–1063
 inductive load, 919
 resistive load, 915–916
 series RLC circuits, 924
 single-slit diffraction, 1086–1090, 1087, 1089
 phasor diagram, 462–463
 phosphorus, doping silicon with, 1265
 photodiode, 1269
 photoelectric current, 1156
 photoelectric effect, 1057, 1155–1158
 photoelectric equation, 1157–1158
 photoelectrons, 1156
 photomultiplier tube, 1164
 photons, 1153–1155
 as bosons, 1337
 in early universe, 1359
 gamma-ray, 1324, 1338
 and light as probability wave, 1162–1164
 momentum, 1159, 1159–1162, 1160
 and photoelectric effect, 1155–1158
 as quantum of light, 1153–1155
 in quantum physics, 1164–1166
 virtual, 1353
 photon absorption, 1154, 1155, 1221
 absorption lines, 1206, 1207
 energy changes in hydrogen atom, 1205
 energy for electrons from, 1189–1190
 lasers, 1242
 photon emission, 1154, 1221
 emission lines, 1206, 1207

- energy changes in hydrogen atom, 1205
 energy from electrons for, 1190
 lasers, 1242, 1242–1243
 stimulated emission, 1242, 1243
physics, laws of, 47
 physical pendulum, 426–428, 427
 picofarad, 718
 piezoelectricity, 1178
 pinhole diffraction, 1082
 pions, 1118, 1335
 decay, 1341, 1342
 and eightfold way, 1347t
 as hadrons, 1338
 as mesons, 1338
 from proton-antiproton annihilation, 1339–1343, 1340t
 reaction with protons, 1342–1343
 pipes, resonance between, 495–496
 pitch, 387
 pitot tube, 410–411
 planar symmetry, Gauss' law, 673, 673–675, 674
 planar waves, 480
 Planck, Max, 1165–1166
 Planck constant, 1154
 plane-concave lens, 1044
 plane-convex lens, 1044
 plane mirrors, 1010–1014, 1012
 plane of incidence, 991
 plane of oscillation, polarized light, 986, 986
 plane of symmetry, center of mass of solid bodies with, 217
 plane-polarized waves, 985–986
 plane waves, 974
 plastics:
 electric field of plastic rod, 641–642
 as insulators, 612
 plates, capacitor, 718, 718–719
 plate tectonics, 13
 plum pudding model, of atom, 1277
p-n junctions, 1266, 1266–1270
 junction lasers, 1269, 1269
 junction rectifiers, 1267–1268, 1268
 light-emitting diodes (LEDs), 1268–1270, 1269
pn junction diode, 757, 762
 point (unit), 8
 point charges. *See also* charged particles
 Coulomb's law, 613, 613–619
 in electric field, 633–635, 645–647
 electric potential due to, 694, 694–695, 695
 pointillism, 1092–1093
 point image, 1012–1013
 point of symmetry, center of mass of solid bodies with, 217
 point source, 480
 isotropic, 489, 982
 light, 982, 1012
 polar dielectrics, 733–734
 polarity:
 of applied potential difference, 756–757
 of Earth's magnetic field, reversals in, 950, 951
 polarization, 907, 985–990, 986, 988
 intensity of transmitted polarized light, 987–990
 and polarized light, 986, 986–987
 by reflection, 997–998, 998
 polarized light, 907, 986, 986–989, 988
 polarized waves, 907, 985–990, 986
 polarizer, 988
 polarizing direction, 986–987, 987
 polarizing sheets, 907, 988, 988–990
 polarizing sunglasses, 998
 polar molecules, 698
 Polaroid filters, 986
 pole faces, horseshoe magnet, 807
 polyatomic gases, 565
 polyatomic molecules, 566
 degrees of freedom, 568–570, 569, 569t
 molar specific heats at constant volume, 565t
 polycrystalline solids, 963
 population inversion, in lasers, 1243–1245, 1269
 porcelain, dielectric properties, 733
 position, 283t
 one-dimensional motion, 14, 14–15, 15
 reference particle, 429
 relating linear to angular, 269
 simple harmonic motion, 417
 two- and three-dimensional motion, 63, 63–64, 64
 uncertainty of particle, 1173–1174
 position vector, 63, 63
 positive charge, 611, 734
 positive charge carriers, 747
 drift speed, 750
 emf devices, 773
 positive direction, 14, 14
 positive ions, 612
 positive kaons, 1124–1125
 positive terminal, batteries, 718, 718–719, 773
 positrons:
 antihydrogen, 1338
 bubble chamber tracks, 622, 806
 electron–positron annihilation, 622, 622, 1338
 in fusion, 1322–1323
 potassium, radioactivity of, 1289
 potential, *see* electric potential
 potential barrier, 1176–1179, 1177, 1290–1291, 1314
 potential difference, 779
 across moving conductors, 812–813
 across real battery, 778–780
 for capacitive load, 918
 capacitors, 719–723, 720
 capacitors in parallel, 724, 724, 726–727
 capacitors in series, 724–727, 725
 Hall, 811
 for inductive load, 920
LC oscillations, 904
 and Ohm's law, 756–757
 for resistive load, 916
 resistors in parallel, 782–787
 resistors in series, 776, 776–777, 784–787
RL circuits, 882–886, 883
 single-loop circuits, 774, 774–775
 between two points in circuit, 777, 777–780, 779
 potential energy, 177–183
 and conservation of
 mechanical energy, 184, 184–187, 185
 and conservation of total energy, 195–196
 defined, 177
 determining, 181–183
 electric, 686, 686–689, 689, 703–705, 704
 of electric dipoles, 648
 in electric field, 689, 730
 magnetic, 887–888
 sample problems involving, 181, 183, 190–191, 194
 satellites in orbit, 371–372, 372
 simple harmonic motion, 421–422, 422
 and work, 178, 178–181, 179
 yo-yo, 301–302
 potential energy barrier, 1176–1179, 1177
 potential energy curves, 187–191, 189
 potential energy function, 188–190, 189
 potential energy step, reflection from, 1174–1176, 1175
 potential method, of calculating current in single-loop circuits, 774–775
 potential well, 190
 potentiometer, 732
 pounds per square inch (psi), 388
 power, 166–168, 167, 197–198, 283t
 in alternating current circuits, 927–929
 average, 166
 defined, 166
 in direct current circuits, 760–761
 of electric current, 760–761
 and emf in circuits, 779
 radiated, 1166
 resolving, 1033, 1033, 1102–1104, 1103, 1183
 in *RLC* circuit, 929, 933
 in rotation, 283
 sample problem involving, 168
 traveling wave on stretched string, 454, 454–455
 power factor, 927, 929
 power lines, transformers for, 930
 power transmission systems, 745, 930–931
 Poynting vector, 980–983, 982
 precession, of gyroscope, 317, 317–318
 precession rate, of gyroscope, 318
 prefixes, for SI units, 2t
 pressure:
 fluids, 387–388
 and ideal gas law, 550–554
 measuring, 392, 392–393
 radiation, 983–985
 and RMS speed of ideal gas, 554–556
 scalar nature of, 41
 as state property, 585
 triple point of water, 516
 work done by ideal gas at constant, 553
 pressure amplitude (sound waves), 483, 484
 pressure field, 631
 pressure sensor, 387
 pressurized-water nuclear reactor, 1318, 1318
 primary coil, transformer, 931
 primary loop, pressurized-water reactor, 1318, 1318–1319
 primary rainbows, 994, 1007, 1052, 1052
 primary winding, transformer, 931
 principal quantum number, 1208, 1208t, 1223t, 1254
 principle of conservation of mechanical energy, 185
 principle of energy conservation, 149
 principle of equivalence, 374–375
 principle of superposition, 96, 615
 for gravitation, 357–359
 for waves, 458, 458
 prisms, 994, 994, 1005
 probability, entropy and, 601–602
 probability density, 1171–1172
 barrier tunneling, 1177
 finding, 1172
 trapped electrons, 1192, 1192–1194
 probability distribution function, 561
 probability of detection:
 hydrogen electron, 1209, 1212
 trapped electrons, 1192–1194
 probability wave:
 light as, 1162–1164
 matter wave as, 1167
 projectile(s):
 defined, 70
 dropped from airplane, 74

- elastic collisions in one dimension, with moving target, 238–239
- elastic collisions in one dimension, with stationary target, 237–238
- inelastic collisions in one dimension, 234
- launched from water slide, 75
- series of collisions, 228
- single collision, 226–227
- projectile motion, 70, 70–75
- effects of air on, 73, 73
- trajectory of, 73, 73
- vertical and horizontal components of, 70–73, 71–73
- proper frequency, 1135
- proper length, 1126
- proper period, 1137
- proper time, 1122
- proper wavelength, 1135
- protons, 612, 1335
- accelerator studies, 818
 - and atomic number, 621
 - as baryons, 1338
 - charge, 620, 620t
 - decay of, 1348
 - in equilibrium, 618
 - as fermions, 1336
 - formation in early universe, 1359
 - in fusion, 1322–1329
 - as hadrons, 1338
 - magnetic dipole moment, 826, 826t
 - mass energy, 1139t
 - and mass number, 621–622
 - as matter wave, 1168, 1187
 - reaction with pions, 1342–1343
 - spin angular momentum, 953
 - ultrarelativistic, 1142–1143
- proton number, 1280, 1280t
- proton-proton (p-p) cycle, 1324, 1324–1326
- proton synchrotrons, 819
- p* subshells, 1235
- p*-type semiconductors, 1264, 1264
- pulleys, massless-frictionless, 105, 106, 108, 108–109
- pulsars, secondary time standard based on, 9
- pulse, wave, 445, 446
- P waves, 506
- Q**
- QCD (quantum chromodynamics), 1354
- QED (quantum electrodynamics), 954, 1352
- quadrupole moment, 654
- quanta, 1154
- quantization, 629, 1154, 1187
- electric charge, 619–621
 - energy of trapped electrons, 1187–1191
- orbital angular momentum, 954
- of orbital energy, 1204–1205
- spin angular momentum, 953
- quantum, 1154
- quantum chromodynamics (QCD), 1354
- quantum corrals, 1199, 1199
- quantum dots, 1187, 1198, 1198–1199
- quantum electrodynamics (QED), 954, 1352
- quantum jump, 1189
- quantum mechanics, 95, 1154
- quantum numbers, 1188, 1223t
- charge, 1341
 - conservation of, 1348–1349
 - for hydrogen, 1206–1208
 - orbital, 1208, 1208t, 1223t, 1254
 - orbital magnetic, 954–955, 1208, 1208t, 1223t
 - and Pauli exclusion principle, 1230
 - and periodic table, 1234–1236
 - principal, 1208, 1208t, 1223t, 1254
 - spin, 1223t, 1225, 1335–1336
 - spin magnetic, 953, 1223t, 1224, 1335–1336
- quantum physics. *See also* electron traps; Pauli exclusion principle; photons; Schrödinger's equation
- barrier tunneling, 1176–1179, 1177
 - and basic properties of atoms, 1220–1222
 - confinement principle, 1187
 - correspondence principle, 1193
 - defined, 1154
 - Heisenberg's uncertainty principle, 1172, 1172–1174
 - hydrogen wave function, 1208–1210
 - matter waves, 1187
 - nucleus, 1276
 - occupancy probability, 1258, 1258–1259
 - particles, 1335
 - photons in, 1164–1166
 - and solid-state electronic devices, 1253
 - quantum states, 1187, 1221
 - degenerate, 1200
 - density of, 1257, 1257–1258
 - density of occupied, 1259–1260, 1260
 - hydrogen with $n = 2$, 1210, 1210–1211
- quantum theory, 569, 570–571, 1154, 1187
- quantum transition, 1189
- quantum tunneling, 1176–1179, 1177
- quarks, 818, 1349–1352, 1350, 1350t
- charge, 620
 - formation in early universe, 1359
- quark family, 1350t
- quark flavors, 1350, 1353–1354
- quasars, 376, 1356
- quicksand, 412
- Q value, 1140, 1291, 1294–1295, 1316, 1324–1325
- R**
- R*-value, 534–535
- race cars:
- collision with wall, 229, 229
 - fuel dispenser fires, 792, 792
 - negative lift in Grand Prix cars, 136, 136–137
- rad (unit), 1296–1297
- radar waves, 445
- radial component:
- of linear acceleration, 270
 - of torque, 278
- radial probability density, 1209, 1211–1212
- radians, 45, 260
- radiated power, 1166
- radiated waves, 974
- radiation:
- in cancer therapy, 1276
 - cosmic background, 1357–1358, 1360, 1361
 - dose equivalent, 1297
 - electromagnetic, 974
 - reflected, 984
 - short wave, 974
 - ultraviolet, 950
- radiation dosage, 1296–1297
- radiation heat transfer, 536–538
- radiation pressure, 983–985
- radioactive dating, 1295, 1295–1296
- radioactive decay, 621–622, 1286–1289, 1335–1336
- alpha decay, 1289–1291, 1290
 - beta decay, 1292–1295, 1293, 1351
 - muons, 1123
 - and nuclidic chart, 1293–1294, 1294
 - process, 1286–1288
- radioactive elements, 1277
- radioactive wastes, 1318, 1319
- radioactivity, of potassium, 1289
- radionuclides, 1280
- radio waves, 445, 499, 974
- radius of curvature:
- spherical mirrors, 1015, 1015–1016, 1016
 - spherical refracting surfaces, 1020–1021, 1021
- radon, 1276
- rail gun, 843, 843
- rainbows, 994, 994–995
- Maxwell's, 973–974
 - and optical interference, 1051–1052, 1052
 - primary, 994, 1007, 1052, 1052
 - secondary, 994, 994, 1007, 1052
 - tertiary, 1007
- ramp, rolling down, 299, 299–300
- randomly polarized light, 986, 986
- range, in projectile motion, 73, 73
- rare earth elements, 957, 1239
- rattlesnake, thermal radiation sensors, 537
- rays, 480, 480
- incident, 991, 991
 - locating direct images with, 1018, 1018–1019
 - locating indirect object images with, 1026, 1026
 - reflected, 991, 991
 - refracted, 991, 991
- ray diagrams, 1018, 1018–1019
- Rayleigh's criterion, 1091, 1091–1094
- RBE (relative biology effectiveness factor), 1297
- RC circuits, 788–792, 789
- capacitor charging, 789, 789–790
 - capacitor discharging, 789, 790–792
- real batteries, 773, 773, 777, 777–778
- real emf devices, 773, 773
- real engines, efficiency of, 593, 597–598
- real fluids, 398
- real focal point, 1016, 1016
- real images, 1011
- spherical mirrors, 1017
 - spherical refracting surfaces, 1020–1021, 1021
 - thin lenses, 1025, 1025
- real solenoids, 849
- recessional speed, of universe, 1357
- rechargeable batteries, 773–774
- recharging batteries, 779
- red giant, 1325
- red shift, 1135, 1367–1368
- reference circle, 429
- reference configuration, for potential energy, 182
- reference frames, 78–79
- inertial, 86–87
 - noninertial, 97
- reference line, 259, 259
- reference particle, 429
- reference point, for potential energy, 182
- reflected light, 991
- reflected radiation, 984
- reflected ray, 991, 991
- reflecting planes, 1105, 1105–1106
- reflection, 990–998, 991
- first and second reflection points, 1006
 - law of, 991
 - polarization by, 997–998, 998
 - from potential energy step, 1174–1176, 1175
 - from a potential step, 1174–1176
- of standing waves at boundary, 466–467, 467
- total internal, 996–997, 997

reflection coefficient, 1176
 reflection phase shifts, 1065, 1065
 reflectors, corner, 1046
 refracted light, 991
 refracted ray, 991, 991
 refracting telescope, 1032–1033, 1033
 refraction, 990–996, 991. *See also* index of refraction
 angle of, 991, 991
 and chromatic dispersion, 993, 993–994
 law of, 992, 1048, 1048–1052
 refrigerators, 595–598, 596
 relative biology effectiveness (RBE) factor, 1297
 relative motion:
 in one dimension, 78, 78–79
 in two dimensions, 80, 80–81
 relative speed, 242
 relativistic particles, 1124–1125
 relativity, 1116–1144, 1153, 1334
 Doppler effect for light, 1134–1137, 1136
 and energy, 1138–1143
 general theory of, 374–376, 1117, 1123–1124
 of length, 1125–1128, 1126, 1131–1132
 Lorentz transformation, 1129–1133
 measuring events, 1118–1119, 1119
 and momentum, 1138
 postulates, 1117–1118
 simultaneity of, 1120, 1120–1121, 1131
 special theory of, 95, 977, 1117 of time, 1121, 1121–1125, 1131 of velocities, 1133, 1133–1134
 relaxed state of spring, 159, 159–160
 released energy, from fusion reaction, 1140
 rem (unit), 1297
 repulsion, in nucleus, 620–621
 repulsive force, 610
 resistance, 752–763
 alternating current, 920t
 Ohm's law, 756–759, 757
 parallel circuits, 782, 782–787 and power in electric current, 760–761
 RC circuits, 788–792 and resistivity, 752–756, 754
 RLC circuits, 910–912, 921–926
 RL circuits, 882–886
 in semiconductors, 762–763 series circuits, 776, 776–777, 921–926
 superconductors, 763
 resistance rule, 775
 resistivity, 754, 1253 calculating resistance from, 754, 754–755
 Ohm's law, 756–759

selected materials at room temperature, 754t
 semiconductors, 1262
 silicon vs. copper, 762–763, 762t, 1253t
 resistors, 753, 753–754
 with ac generator, 914, 914–916
 in multiloop circuits, 781–787, 782, 785
 Ohm's law, 756–759, 757
 in parallel, 782, 782–787
 phase and amplitude in ac circuits, 920t
 power dissipation in ac circuits, 927
 and power in circuits, 760–761
 RC circuits, 788–792, 789
 RLC circuits, 922
 RL circuits, 882–886, 883
 in series, 776, 776–777, 922
 single-loop circuits, 774, 774–775
 work, energy, and emf, 773, 773–774
 resolvability, 1091, 1091–1093
 resolving power:
 diffraction grating, 1102–1104, 1103
 microscope, 1183
 refracting telescope, 1033, 1033
 resolving vectors, 43
 resonance:
 forced oscillations, 433
 magnetic, 1229–1230, 1230
 magnetic resonance imaging, 941, 941
 nuclear magnetic, 1229–1230
 between pipes, 495–496
 series RLC circuits, 924–926, 925
 and standing waves, 467, 467–470, 468
 resonance capture, of neutrons in nuclear reactors, 1317
 resonance condition cyclotrons, 818
 resonance curves, series RLC circuits, 925, 925–926
 resonance peak, 433, 1230
 resonant frequencies, 467, 467–468, 493, 494
 response time, nuclear reactor control rods, 1318
 rest, fluids at, 388–391, 389
 rest energy, 1139
 rest frame, 1123
 rest length, 1126
 restoring torque, 425–426
 resultant, of vector addition, 41
 resultant force, 99
 resultant torque, 278
 resultant wave, 458, 458
 reverse saturation current, junction rectifiers, 1274
 reversible processes, 585–588
 right-handed coordinate system, 46, 46

right-hand rule, 264–265, 265
 Ampere's law, 843, 845
 angular quantities, 264–265, 265
 displacement current, 947
 induced current, 868, 869
 Lenz's law, 868, 868
 magnetic dipole moment, 825, 825
 magnetic field due to current, 838, 838
 magnetic force, 805, 805–806
 magnetism, 843
 vector products, 52, 53, 54, 842
 rigid bodies:
 angular momentum of rotation about fixed axis, 311, 311–312
 defined, 259
 elasticity of real, 339–340
 ring charge distributions, 638–640, 639, 642
 Ritz combination principle, 1218
 RLC circuits, 910–912, 911
 resonance curves, 925, 925–926
 series, 921–926, 922
 transient current series, 923
 RL circuits, 882–886, 883, 884
 RMS, *see* root-mean-square
 RMS current:
 in ac circuits, 927–928
 in transformers, 933
 rock climbing:
 crimp hold, 348, 348
 energy conservation in descent using rings, 196, 196
 energy expended against gravitational force climbing Mount Everest, 211
 friction coefficients between shoes and rock, 127
 lie-back climb along fissure, 347, 347
 rockets, 241–243, 242
 roller coasters, maximum acceleration of, 21
 rolling, 295–302
 down ramp, 299, 299–301
 forces of, 299, 299–301
 friction during, 299, 299
 kinetic energy of, 297, 298–301
 as pure rotation, 296, 296–297
 sample problem involving, 301
 as translation and rotation combined, 295–297, 297
 yo-yo, 301–302, 302
 room temperature, 515
 root-mean-square (RMS):
 and distribution of molecular speeds, 562
 of electric/magnetic fields, 982–983
 for selected substances, 556t
 speed, of ideal gas, 554–556, 555
 rotation, 257–287
 angular momentum of rigid body rotating about fixed axis, 311, 311–312
 conservation of angular momentum, 313, 313–315, 314, 315
 constant angular acceleration, 266–268
 kinetic energy of, 271–273, 272
 and molar specific heat, 570, 570–571
 Newton's second law for, 279–281
 relating linear and angular variables, 268–271, 269
 in rolling, 295–297, 296
 sample problems involving, 262–264, 267–268, 270–271, 275–277, 280–281, 284
 rotational equilibrium, 329
 rotational inertia, 272, 273–277, 283t
 rotational kinetic energy, 271–272 of rolling, 299
 and work, 282–284
 yo-yo, 301–302
 rotational symmetry, 632, 633
 rotational variables, 259–265, 312t
 rotation axis, 259, 259
 Rotor (amusement park ride), 267–268
 Rowland ring, 962, 962
 rubber band, entropy change on stretching, 589–590
 rulers, 2
 rulings, diffraction grating, 1098
 Rutherford, Ernest, 1276–1277
 Rutherford scattering, 1278–1279
 Rydberg constant, 1205

S

Sagittarius A*, 355
 satellites:
 energy of, in orbit, 371–373
 geosynchronous orbit, 382
 gravitational potential energy, 365
 Kepler's laws, 368–371
 orbits and energy, 372
 scalars:
 multiplying vectors by, 50
 vectors vs., 40–41
 scalar components, 46
 scalar fields, 631
 scalar product, 51, 51–52
 scanning tunneling microscope (STM), 1178, 1178, 1199, 1199
 scattering:
 Compton, 1159, 1159–1162, 1160
 of polarized light, 988
 Rutherford, 1278–1279
 x rays, 1105, 1105
 schematic diagrams, 718
 Schrödinger's equation, 1170–1172
 for electron in finite well, 1195
 for electron in infinite well, 1192

- for electron in rectangular box, 1200
 for electron in rectangular corral, 1200
 and hydrogen, 1205–1212
 for hydrogen ground state, 1208–1210, 1209
 for multicomponent atoms, 1234
 probability density from, 1172
 scientific notation, 2–3
 Scoville heat unit, 12
 screen, in Young's experiment, 1057
 seat of emf, 772
 secondary coil, transformer, 931
 secondary loop, pressurized water reactor, 1318, 1319
 secondary maxima, diffraction patterns, 1082, 1082
 secondary rainbows, 994, 994, 1007, 1052
 secondary standards, 3
 secondary winding, transformer, 931
 second law of thermodynamics, 588–590
 second minima:
 and interference patterns, 1057
 for single-slit diffraction, 1084, 1087–1088
 second-order bright fringes, 1056–1057
 second-order dark fringes, 1057
 second-order line, 1099
 second reflection point, 1006
 second side maxima, interference patterns of, 1056–1057
 secular equilibrium, 1304
 seismic waves, 445, 512
 self-induced emf, 881, 881
 self-induction, 881, 881–882, 890
 semi-classical angle, 1223
 semiconducting devices, 762
 semiconductors, 612, 1261–1265.
See also p-n junctions; transistors
 doped, 1263, 1263–1265
 electrical properties, 1262, 1262
 LEDs, 1268–1270, 1269
 nanocrystallites, 1198, 1198
 n-type, 1263, 1263–1264. *See also p-n junctions*
 p-type, 1264, 1264
 resistance in, 762–763
 resistivities of, 754t
 unit cell, 1253
 semimajor axis, of orbits, 369, 369, 370t
 series, of spectral lines, 1206
 series circuits:
 capacitors, 724–727, 725, 783t
 RC, 788–792, 789
 resistors, 776, 776–777, 783t
 RLC, 911, 921–926, 922
 summary of relations, 783t
 series limit, 1206, 1207
 shake (unit), 11
 shearing stress, 340, 340
 shear modulus, 341
 shells, 1211, 1225
 and characteristic x-ray spectrum, 1237–1238
 and electrostatic force, 615
 and energy levels in crystalline solids, 1254
 and periodic table, 1234–1236
 shell theorem, 356
 SHM, *see simple harmonic motion*
 shock waves, 33, 503, 503
 short wave radiation, 974
 side maxima:
 diffraction patterns, 1082, 1082
 interference patterns, 1056–1057
 sievert (unit), 1297
 sigma particles, 1335, 1346, 1347t
 sign:
 acceleration, 21–22
 displacement, 14–15
 heat, 523
 velocity, 21–22, 29
 work, 153
 significant figures, 4
 silicon:
 doping of, 1265
 electric properties of copper vs., 762–763, 762t, 1253t, 1262
 in MOSFETs, 1270
 properties of *n*- vs. *p*-doped, 1264t
 resistivity of, 754t
 as semiconductor, 612, 762–763, 1262
 unit cell, 1253, 1253
 silk, rubbing glass rod with, 610, 610, 621
 simple harmonic motion (SHM), 413–434, 415, 417
 acceleration, 418, 418, 420
 angular, 423, 423–424
 damped, 430, 430–432, 431
 energy in, 421–423, 422
 force law for, 419
 freeze-frames of, 414–416, 415
 pendulums, 424–428, 425, 426
 quantities for, 416, 416–417
 sample problems involving, 420–424, 427–428, 432
 and uniform circular motion, 428–429, 428–429
 velocity, 417, 417–418, 418, 421
 waves produced by, 445–446
 simple harmonic oscillators:
 angular, 423, 423–424
 linear, 419, 419–421
 simple magnifying lens, 1031, 1031–1032
 simple pendulum, 425, 425–426
 simultaneity:
 and Lorentz transformation equations, 1131
 relativity of, 1120, 1120–1121
 sine, 45, 45
 single-component forces, 96
 single-loop circuits, 771–780, 914
 charges in, 772
 current in, 774, 774–775
 internal resistance, 776, 776
 potential difference between two points, 777, 777–780, 779
 with resistances in series, 776, 776–777
 work, energy, and emf, 773, 773–774
 single-slit diffraction, 1081–1090
 intensity in, 1086–1090, 1087, 1089
 minima for, 1083, 1083–1085, 1084
 and wave theory of light, 1081–1083
 Young's interference experiment, 1053–1054, 1055
 sinusoidal waves, 446–448, 447, 448
 siphons, 412
 Sirius B, escape speed for, 367t
 SI units, 2–3
 skateboarding, motion analyzed, 73
 slab (rotational inertia), 274t
 sliding block, 108, 108–109
 sliding friction, 126, 127
 slope, of line, 15–16, 16
 Snell's law, 992, 1048–1049
 snorkeling, 407
 soap bubbles, interference patterns from, 1064, 1067, 1067
 sodium, 1235
 sodium chloride, 1236
 index of refraction, 992t
 x-ray diffraction, 1105, 1105
 sodium doublet, 1250
 sodium vapor lamp, 1155
 soft reflection, of traveling waves at boundary, 467
 solar system, 1361
 solar wind, 1002
 solenoids, 848–851, 849
 induced emf, 867–868
 inductance, 880
 magnetic energy density, 889
 magnetic field, 848–851, 849
 real, 849
 solids:
 compressibility, 342
 crystalline, 1252–1261, 1253, 1254
 elasticity and dimensions of, 340, 340
 heat absorption, 524–527
 polycrystalline, 963
 specific heats of selected, 525t
 speed of sound in, 481t
 thermal conductivity of selected, 535t
 thermal expansion, 520–522, 521
 solid bodies:
 center of mass, 216–219
 Newton's second law, 221
 solid state, 525
 solid-state electronic devices, 1253
 sonar, 480
 sonic boom, 503
 sound intensity, 488–492, 489
 sound levels, 488–492, 490t
 sound waves, 445–446, 479–504
 beats, 496–498, 497
 defined, 479–480
 Doppler effect, 498–502
 intensity and sound level, 488–492, 489, 490t
 interference, 485–488, 486
 sample problems involving, 485, 487–488, 491–492, 495–496, 498, 502
 sources of musical, 492–496, 493, 495
 speed of, 480–482, 481t
 supersonic speed, 503, 503–504
 traveling waves, 482–485, 483
 south pole, magnet's, 807, 807, 942, 942
 space charge, 1266
 space curvature, 375, 375–376
 space time, 375, 1153, 1359
 spacetime coordinates, 1118–1119
 spark, *see electric spark*
 special theory of relativity, 95, 977, 1117
 specific heat, 524–525, 525t. *See also molar specific heat*
 speckle, 1059
 spectral radiancy, 1165–1166
 spectroscope, grating, 1100, 1100–1101
 spectrum, 1206
 speed:
 average in one-dimensional motion, 16
 drift, 749, 749–750, 752, 810–813, 811
 escape, 704, 713
 Fermi, 1255–1256
 most probable, 1322, 1333
 one-dimensional motion, 18
 recessional, of universe, 1357
 relating linear to angular, 269
 relative, 242
 in rolling, 296–297, 297
 waves, *see wave speed*
 speed amplifier, 254
 speed deamplifier, 254
 speed of light, 445, 977, 1117–1118
 speed of light postulate, 1117–1118
 speed of sound, 480–482
 and RMS speed in gas, 556
 in various media, 481t
 speed parameter, in time dilation, 1122–1123, 1123
 spherical aberrations, 1033
 spherical capacitors, 722, 730
 spherical conductors, Coulomb's law for, 615–619
 spherically symmetric charge distribution, 675–677, 676, 695

spherical mirrors, 1015, 1016
focal points, 1015–1016, 1016
images from, 1014–1020, 1015, 1016, 1033, 1033–1034
spherical refracting surfaces, 1020–1022, 1021, 1034, 1034
spherical shell:
Coulomb's law for, 615–619
electric field and enclosed charge, 670
rotational inertia of, 274
spherical symmetry, Gauss' law, 675–677, 676
spherical waves, 480
spin, 1223t, 1336–1337
electron, 1336–1337, 1337
isospin, 1364
nuclear, 1284
nuclides, 1280t, 1284
spin angular momentum, 953–954, 1223t, 1224, 1225
spin-down electron state, 953, 1224, 1229, 1229
spin-flipping, 966, 1229, 1230
spin magnetic dipole moment, 953–954, 954, 1225, 1225
diamagnetic materials, 957
ferromagnetic materials, 957
paramagnetic materials, 957, 959
spin magnetic quantum number, 953, 1223t, 1224, 1335–1336
spin quantum number, 1223t, 1225, 1335–1336
spin-up electron state, 953, 1224, 1229, 1229
spontaneous emission, 1242, 1242–1243
spontaneous otoacoustic emission, 508
spring constant, 159
spring force, 159–161
as conservative force, 179, 179
work done by, 159, 159–162
spring scale, 103, 103–104
sprites, 637, 637–638
s subshells, 1235
stable equilibrium potential energy curves, 190
stable static equilibrium, 328, 328–329, 329
stainless steel, thermal conductivity of, 535t
standards, 1–2
standard kilogram, 6, 6–7
standard meter bar, 3
Standard Model, of elementary particles, 1336
standing waves, 465–470, 466, 467, 1187
reflections at boundary, 466–467, 467
and resonance, 467, 467–470, 468
transverse and longitudinal waves on, 445, 446, 446
wave equation, 456–457
wave speed on, 452–453, 453

stars, 1153
Doppler shift, 1135–1136
formation in early universe, 1360
fusion in, 1284, 1322, 1324, 1324–1326
matter and antimatter in, 1338–1339
neutron, 806t
orbiting, 382
rotational speed as function of distance from galactic center, 1358, 1358
state, 525
state function, entropy as, 586–587
state properties, 585–586
static equilibrium, 327–329, 328, 329
fluids, 389, 390
indeterminate structures, 338–339, 339
requirements of, 329–330
sample problems involving, 332–337
static frictional force, 125–126, 125–127, 299
statistical mechanics, 598–602
steady flow, 398
steady-state current, 746, 923
Stefan–Boltzmann constant, 536, 1166
step-down transformer, 931
step-up transformer, 931
Stern–Gerlach experiment, 1226, 1226–1228
stick-and-slip, 127
stimulated emission, 1242–1243
Stirling engines, 594, 594
Stirling's approximation, 601
STM, *see* scanning tunneling microscope
stopping potential, photoelectric effect, 1057, 1156, 1157
straight line charge distributions, 642–643
strain, 339–342, 340
strain gage, 341, 341
strangeness, conservation of, 1346–1357
strange particles, 1346
strange quark, 1349, 1350, 1350t
streamlines:
in electric fields, 749
in fluid flow, 399, 400
strength:
ultimate, 340, 340, 341t
yield, 340, 340, 341t
stress, 340, 340
compressive, 340–341
electrostatic, 744
hydraulic, 341–342, 341t
shearing, 340, 340
tensile, 340, 340
stress-strain curves, 340, 340
stress-strain test specimen, 340
stretched strings, 480
energy and power of traveling wave on, 454, 454–455
harmonics, 469–470
resonance, 467, 467–470
strike-slip, 60
string theory, 1354
string waves, 451–455
strokes, 591
strong force, 123, 1284, 1338
conservation of strangeness, 1346
messenger particle, 1353–1354
strong interaction, 1340–1341
strong nuclear force, 621
subcritical state, nuclear reactors, 1318
submarines:
rescue from, 578
sonar, 480
subshells, 1211, 1223t, 1225
and energy levels in crystalline solids, 1254
and periodic table, 1234–1236
substrate, MOSFET, 1270
subtraction:
of vectors by components, 49
of vectors geometrically, 42, 42
Sun, 1361
convection cells in, 536
density at center of, 387t
escape speed, 367t
fusion in, 1284, 1322, 1324, 1324–1326
monitoring charged particles from, 745
neutrinos from, 1293
period of revolution about galactic center, 382
pressure at center of, 388t
randomly polarized light, 986
speed distribution of photons in core, 562
sunglasses, polarizing, 998
sunjamming, 118
sunlight, coherence of, 1059
superconductivity, 763
superconductors, 612, 763
supercooling, 605
supercritical state, nuclear reactors, 1318
supermassive black holes, 355
supernovas, 88, 367t, 1325, 1325–1326, 1361
supernova SN1987a, 1325
supernumeraries, 1052, 1052
superposition, principle of, *see* principle of superposition
supersonic speed, 503, 503–504
surface charge density, 629, 639t
surface wave, 512
S waves, 506
symmetric lenses, 1025–1026
symmetry:
axis of, 632
center of mass of bodies with, 217
cylindrical, Gauss' law, 671, 671–672
importance in physics, 659
of messenger particles, 1354
planar, Gauss' law, 673, 673–675, 676
rotational, 632, 633
spherical, Gauss' law, 675–677, 676
system, 99, 523. *See also* particle systems
systolic blood pressure, normal, 387t

T

tangent, 45, 45
tangential component:
of linear acceleration, 269–270
of torque, 278
target:
collisions in two dimensions, 240, 240–241
elastic collisions in one dimension, with moving, 238–239
elastic collisions in one dimension, with stationary, 237, 237–238
inelastic collisions in one dimension, 234
series of collisions, 228, 228
single collision, 226–227
tattoo inks, magnetic particles in, 941, 941
tau neutrinos, 1344, 1344t
tau particles, 1344, 1344t
teapot effect, 406
telescopes, 1030, 1032–1033, 1033
television, 803–804, 950
television waves, 445
temperature, 514–519
defined, 515
for fusion, 1323
and heat, 523, 523–524, 526–527
and ideal gas law, 550–554
measuring, 516–517
and RMS speed of ideal gas, 554–556
sample problems involving, 519, 522
scalar nature of, 41
selected values, 518t
as state property, 585
work done by ideal gas at constant, 552, 552–553
and zeroth law of thermodynamics, 515–516, 516
temperature coefficient of resistivity, 755, 1253
selected materials, 754t
semiconductors, 1262
silicon vs. copper, 762t, 1253t
temperature field, 631
temperature scales:
Celsius, 518–519
compared, 518
Fahrenheit, 518–519
Kelvin, 515, 516–517
temporal separation, of events, 1121

- 10-hour day, 5
 tensile stress, 340, 340
 tension force, 105, 105–106
 and elasticity, 340–341
 and wave speed on stretched string, 453
 terminals, battery, 718–719, 773
 terminal speed, 130–132, 131
 tertiary rainbows, 1007
 tesla (unit), 806
 test charge, 631, 631, 632
 Tevatron, 1352
 theories of everything (TOE), 1354
 thermal agitation:
 of ferromagnetic materials, 962
 of paramagnetic materials, 959–960
 thermal capture, of neutrons, 1317
 thermal conduction, 535, 535
 thermal conductivity, 535, 535t
 thermal conductor, 535
 thermal efficiency:
 Carnot engines, 592–593
 Stirling engines, 594
 thermal energy, 179, 195, 514, 873
 thermal equilibrium, 515
 thermal expansion, 520, 520–522
 thermal insulator, 535
 thermal neutrons, 1311–1315, 1317
 thermal radiation, 536–538
 thermal reservoir, 528, 529
 thermal resistance to conduction, 535
 thermodynamics:
 defined, 514
 first law, 528–533
 second law, 588–590
 zeroth law, 515–516, 516
 thermodynamic cycles, 529, 530, 532
 thermodynamic processes, 528–531, 529, 575
 thermometers, 515
 constant-volume gas, 516, 516–517
 liquid-in-glass, 520
 thermonuclear bomb, 1326–1327
 thermonuclear fusion, 1140, 1284, 1322–1329
 controlled, 1326–1329
 process of, 1322–1323
 in Sun and stars, 1322, 1324, 1324–1326
 thermopiles, 772
 thermoscope, 515, 515
 thin films, interference, 1064, 1064–1071
 thin lenses, 1023–1030
 formulas, 1024
 images from, 1023–1030, 1025, 1026, 1034–1036, 1035
 two-lens systems, 1027, 1027–1029
 thin-lens approximation, 1035–1036
 third-law force pair, 106, 356
 three-dimensional electron traps, 1200, 1200–1201
- three-dimensional motion:
 acceleration, 66, 66
 position and displacement, 63, 63
 velocity, 64–66, 65, 66
 three-dimensional space, center of mass in, 216
 thrust, 242
 thunderstorm sprites, 637, 637–638
 time:
 directional nature of, 584
 for free-fall flight, 28
 intervals of selected events, 5t
 proper, 1122
 between relativistic events, 1121, 1121–1125
 relativity of, 1121, 1121–1125, 1131
 sample problems involving, 7–8
 scalar nature of, 41
 space, 1153, 1359
 units of, 5–6
 time constants:
 inductive, 884–885
 for *LC* oscillations, 904
 for *RC* circuits, 789, 790
 for *RL* circuits, 884–885
 time dilation, 1122
 and length contraction, 1127–1128
 and Lorentz transformation, 1131
 tests of, 1123–1125
 time intervals, 5, 5t
 time signals, 6
 TOE (theories of everything), 1354
 tokamak, 1327
 ton, 11
 top gun pilots, turns by, 77–78
 top quark, 1350t, 1351, 1352
 toroids, 850, 850
 torque, 277–281, 302–304, 312t
 and angular momentum of system of particles, 310–311
 and conservation of angular momentum, 313
 for current loop, 822–824, 823
 of electric dipole in electric field, 650
 and gyroscope precession, 317, 317
 internal and external, 310–311
 and magnetic dipole moment, 825
 net, 278, 310–311
 Newton's second law in angular form, 307
 particle about fixed point, 303, 303–304
 restoring, 425–426
 rolling down ramp, 299–300
 sample problems involving, 304, 308–309
 and time derivative of angular momentum, 308–309
 torr, 388
- torsion constant, 423
 torsion pendulum, 423, 423
 total energy, relativity of, 1139–1140
 total internal reflection, 996–997, 997
 tour jeté, 314, 314–315
 Tower of Pisa, 337
 tracer, for following fluid flow, 398–399, 399
 trajectory, in projectile motion, 73
 transfer:
 collisions and internal energy transfers, 196–197
 heat, 534–538
 transformers, 930–933
 energy transmission requirements, 930–931
 ideal, 931, 931–932
 impedance matching, 932
 in *LC* oscillators, 974
 transient current series *RLC* circuits, 923
 transistors, 762, 1270–1271
 FET, 1270, 1270–1271
 MOSFET, 1270, 1270–1271
 transition elements, paramagnetism of, 957
 translation, 258, 295–297, 296
 translational equilibrium, 329
 translational kinetic energy:
 ideal gases, 557
 of rolling, 298
 yo-yo, 301–302
 translational variables, 312t
 transmission coefficient, 1176, 1177
 transparent materials, 991
 in Michelson's interferometer, 1071
 thin-film interference in, 1068–1070, 1069
 transuranic nuclides, 1319
 transverse Doppler effect, 1136, 1136–1137
 transverse motion, 446
 transverse waves, 445, 445–446, 450–451, 975
 travel distance, for relativistic particle, 1124–1125
 traveling waves, 446, 1187
 electromagnetic, 974–980, 976, 977
 energy and power, 454, 454–455
 hard vs. soft reflection of, at boundary, 467
 sound, 482–485, 483
 speed, 449, 449–451
 wave function, 1170–1172
 travel time, 1119, 1142–1143
 triangular prisms, 994, 994
 trigonometric functions, 45, 45
 triple point cell, 516, 516
 triple point of water, 516–517
 tritium, 1294, 1327, 1328
 triton, 1327
- tube length, compound microscope, 1032
 tunneling, barrier, 1176–1179, 1177, 1290–1291
 turbulent flow, 398
 turns:
 in coils, 823–824
 in solenoids, 848–849
 turning points, in potential energy curves, 188–189, 189
 turns ratio, transformer, 932, 933
 two-dimensional collisions, 240, 240–241
 two-dimensional electron traps, 1200, 1200–1201
 two-dimensional explosions, 232, 232
 two-dimensional motion:
 acceleration, 67–69, 68
 position and displacement, 63–64, 64
 projectile motion, 70–75
 relative, 80, 80–81
 sample problems involving, 63–64, 67, 69, 74–78, 80–81, 229
 uniform circular motion, 76–78
 velocity, 64–67
- U**
- ultimate strength, 340, 340, 341t
 ultrarelativistic proton, 1142–1143
 ultrasound (ultrasound imaging), 480, 480
 bat navigation using, 502
 blood flow speed measurement using, 511
 ultraviolet light, 445
 ultraviolet radiation, 950
 uncertainty principle, 1172, 1172–1174
 underwater illusion, 506
 uniform charge distributions:
 electric field lines, 631, 631–632, 632
 types of, 642–643
 uniform circular motion, 76–78
 centripetal force in, 133–138, 134
 sample problems involving, 135–138
 and simple harmonic motion, 428–429, 428–429
 velocity and acceleration for, 76, 77
 uniform electric fields, 632
 electric potential of, 692
 flux in, 660–662
 units, 1–2
 changing, 3
 heat, 524
 length, 3–4
 mass, 6–8
 time, 5–6
 unit cell, 1105
 determining, with x-ray diffraction, 1106

metals, insulators, and semiconductors, 1253, 1253
 United States Naval Observatory time signals, 6
 unit vectors, 46, 46, 49, 54–55
 universe:
 Big Bang, 1358–1361, 1359
 color-coded image of universe at 379 000 yrs old, 1360, 1360
 cosmic background radiation, 1357–1358, 1361
 dark energy, 1361
 dark matter, 1358
 estimated age, 1356
 expansion of, 1356–1357
 temperature of early, 515
 unoccupied levels, 1231, 1255, 1299
 unpolarized light, 986, 986
 unstable equilibrium, 190
 unstable static equilibrium, 328–329
 up quark, 1349, 1350t, 1351
 uranium, 387t
 enrichment of, 1317
 mass energy of, 1139t
 uranium²²⁸:
 alpha decay, 1289–1290
 half-life, 1290, 1291t
 uranium²³⁵:
 enriching fuel, 1317
 fission, 1311–1315, 1313
 fissionability, 1314–1316, 1314t, 1321
 in natural nuclear reactor, 1320–1321
 uranium²³⁶, 1312, 1314t
 uranium²³⁸, 621–622, 1286
 alpha decay, 1289–1291, 1290
 binding energy per nucleon, 1283
 fissionability, 1314–1315, 1314t, 1321
 half-life, 1291, 1291t
 uranium²³⁹, 1314t
 UTC (Coordinated Universal Time), 6

V

vacant levels, 1255
 valence band, 1262, 1262, 1263
 valence electrons, 1187, 1235, 1256
 valence number, 1263
 valley of nuclides, 1294, 1294
 vaporization, 526
 vapor state, 526
 variable capacitor, 742
 variable force:
 work done by general variable, 162–166, 163
 work done by spring force, 159, 160–162
 variable-mass systems, rockets, 241–243, 242
 vector(s), 40–55, 631
 adding, by components, 46–47, 49
 adding, geometrically, 41, 41–42, 42, 44
 area, 661
 for a coil of current loop, 824
 coupled, 1221
 and laws of physics, 47
 multiplying, 50–55, 51, 53
 Poynting, 980–983, 982
 problem-solving with, 45
 resolving, 43
 sample problems involving, 44–45, 48–49, 54–55
 scalars vs., 40–41
 unit, 46, 46, 49, 54–55
 velocity, 41
 vector angles, 43, 43, 45
 vector-capable calculator, 46
 vector components, 42–44, 43
 addition, 46–49
 rotating axes of vectors and, 47
 vector equation, 41
 vector fields, 631
 vector product, 50, 52–55, 53
 vector quantities, 15, 41, 96
 vector sum (resultant), 41, 41–42
 velocity, 283t
 angular, 260–265, 265, 283t
 average, 15–17, 16, 24, 65
 graphical integration in motion analysis, 29, 29
 instantaneous, 18–19
 line of sight, 382
 and Newton's first law, 95–98
 and Newton's second law, 98–101
 one-dimensional motion, 15–19
 projectile motion, 70–75
 reference particle, 429
 relative motion in one dimension, 78–79
 relative motion in two dimensions, 80–81
 relativity of, 1133, 1133–1134
 rockets, 241–243
 sign of, 21–22
 simple harmonic motion, 417, 417–418, 418, 421
 two- and three-dimensional motion, 64–67, 65–67
 uniform circular motion, 76, 76–78, 77
 as vector quantity, 41
 velocity amplitude:
 forced oscillations, 433, 433
 simple harmonic motion, 418
 velocity vectors, 41
 venturi meter, 411
 vertical circular loop, 135
 vertical motion, in projectile motion, 72–73, 73
 virtual focal point, 1016, 1016
 virtual images:
 defined, 1011
 spherical mirrors, 1017
 spherical refracting surfaces, 1020–1021, 1021
 thin lenses, 1025, 1025
 virtual photons, 1353
 viscous drag force, 398

visible light, 445, 974, 1118
 vision, resolvability in, 1092–1093
 volcanic bombs, 90
 volt, 687, 689
 voltage. *See also* potential difference
 ac circuits, 920t
 transformers, 931–932
 voltage law, Kirchoff's, 775
 volt-ampere, 761
 voltmeters, 788, 788
 volume:
 and ideal gas law, 550–554
 as state property, 585
 work done by ideal gas at constant, 553
 volume charge density, 626, 628, 639t
 volume expansion, 521–522
 volume flow rate, 400, 660–661
 volume flux, 660
 volume probability density, 1209, 1210, 1211

W

water:
 boiling/freezing points of, in Celsius and Fahrenheit, 518t
 bulk modulus, 341, 481
 as conductor, 612
 density, 387t
 dielectric properties, 732t, 733–734
 diffraction of waves, 1053
 as electric dipole, 648, 648
 heats of transformation, 525–526, 526t
 index of refraction, 992t
 as insulator, 612
 in microwave cooking, 649
 as moderator for nuclear reactors, 1317
 polarization of light by reflection in, 998
 RMS speed at room temperature, 556t
 specific heats, 525t
 speed of sound in, 481, 481t
 thermal properties, 521
 thin-film interference of, 1067
 triple point, 516
 water waves, 445
 watt (W), 2, 167
 Watt, James, 167
 wave(s), 444–470. *See also* electromagnetic waves; matter waves
 amplitude, 447, 447, 448
 lagging vs. leading, 461
 light as, 1047–1052
 net, 458, 495
 phasors, 462–464, 463
 principle of superposition for, 458, 458
 probability, 1162–1164, 1167
 resultant, 458, 458

sample problems involving, 450–452, 455, 461, 464, 469–470
 seismic, 512
 shock, 33, 503, 503
 sinusoidal, 446–448, 447
 sound, *see* sound waves
 speed of traveling waves, 449–451
 standing, *see* standing waves
 on stretched string, 452
 string, 451–455
 transverse and longitudinal, 445, 445–446, 446, 450–451
 traveling, *see* traveling waves
 types of, 445
 wavelength and frequency of, 446–449
 wave equation, 456–457
 wave forms, 445, 446
 wavefronts, 480, 480, 966
 wave function, 1170–1172. *See also* Schrödinger's equation
 hydrogen ground state, 1208–1210, 1209
 normalizing, 1193–1195
 of trapped electrons, 1191–1195, 1192
 wave interference, 459, 459–461, 460, 485–488, 486
 wavelength, 447, 447
 Compton, 1161
 cutoff, 1156–1157, 1237
 de Broglie, 1167, 1171, 1189
 determining, with diffraction grating, 1099
 and frequency, 446–449
 of hydrogen atom, 1203
 and index of refraction, 1050–1052
 proper, 1135
 sound waves, 483
 wavelength Doppler shift, 1136
 wave shape, 446
 wave speed, 449, 449–453
 sound waves, 483
 on stretched string, 452–453, 453
 traveling waves, 449, 449–451
 wave theory of light, 1047–1052, 1081–1083
 wave trains, 1241
 weak force, 1338, 1353
 weak interaction, 1341
 weber (unit), 866
 weight, 103–104
 apparent, 104, 396–397
 mass vs., 104
 weightlessness, 134
 whiplash injury, 30
 white dwarfs, 367t, 387t
 white light:
 chromatic dispersion, 993, 993–994, 994
 single-slit diffraction pattern, 1085

- Wien's law, 1166
 Wilkinson Microwave Anisotropy Probe (WMAP), 1360
 windings, solenoid, 848–849
 window glass, thermal conductivity of, 535t
 Wintergreen LifeSaver, blue flashes from, 613
 WMAP (Wilkinson Microwave Anisotropy Probe), 1360
 W messenger particle, 1353
 work, 283t
 and applied force, 688
 for capacitor with dielectric, 733
 Carnot engines, 592
 and conservation of mechanical energy, 184–187
 and conservation of total energy, 195–199, 197
 defined, 151
 done by electric field, 688–689
 done by electrostatic force, 688–689
 done by external force with friction, 192–194
 done by external force without friction, 192
 done by gravitational force, 155–158, 156
 done by ideal gas, 552–554
 done by spring force, 159, 159–162
 done by variable force, 162–166, 163
 done in lifting and lowering objects, 156, 156–158
 done on system by external force, 191–194, 193
 and energy/emf, 773–774
 first law of thermodynamics, 531–533
 and heat, 524, 528–530
 and induction, 872, 873
 and kinetic energy, 152, 152–155, 1141
 and magnetic dipole moment, 825–826
 negative, 530
 net, 153, 592
 path-dependent quantity, 530
 path independence of conservative forces, 179–181, 180
 and photoelectric effect, 1158
 and potential energy, 178, 178–181, 179
 and power, 166–168, 167
 and rotational kinetic energy, 282–284
 sample problems involving, 154–155, 157–158, 161–162, 164–166, 533
 signs for, 153
 work function, 1157
 working substance, 590–591
 work-kinetic energy theorem, 153–155, 164–166, 283t
- X**
 x component, of vectors, 42–43, 43
 xenon, decay chain, 1311
 xi-minus particle, 1347t, 1348–1349, 1352
 x rays, 445, 974
 characteristic x-ray spectrum, 1237–1238, 1238
- Y**
 y component, of vectors, 42–43, 43
 yield strength, 340, 340, 341t
 Young's double-slit interference experiment, 1054–1058, 1055
 single-photon version, 1162, 1162–1164
 wide-angle version, 1163–1164, 1164
 Young's modulus, 341, 341t
 yo-yo, 301–302, 302
- Z**
 zero angular position, 259
 zero-point energy, 1193–1194
 zeroth law of thermodynamics, 515–516, 516
 zeroth-order line, 1099
 Z messenger particle, 1353

This page intentionally left blank

SOME PHYSICAL CONSTANTS*

Speed of light	c	$2.998 \times 10^8 \text{ m/s}$
Gravitational constant	G	$6.673 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2$
Avogadro constant	N_A	$6.022 \times 10^{23} \text{ mol}^{-1}$
Universal gas constant	R	$8.314 \text{ J/mol} \cdot \text{K}$
Mass–energy relation	c^2	$8.988 \times 10^{16} \text{ J/kg}$ 931.49 MeV/u
Permittivity constant	ϵ_0	$8.854 \times 10^{-12} \text{ F/m}$
Permeability constant	μ_0	$1.257 \times 10^{-6} \text{ H/m}$
Planck constant	h	$6.626 \times 10^{-34} \text{ J} \cdot \text{s}$ $4.136 \times 10^{-15} \text{ eV} \cdot \text{s}$
Boltzmann constant	k	$1.381 \times 10^{-23} \text{ J/K}$ $8.617 \times 10^{-5} \text{ eV/K}$
Elementary charge	e	$1.602 \times 10^{-19} \text{ C}$
Electron mass	m_e	$9.109 \times 10^{-31} \text{ kg}$
Proton mass	m_p	$1.673 \times 10^{-27} \text{ kg}$
Neutron mass	m_n	$1.675 \times 10^{-27} \text{ kg}$
Deuteron mass	m_d	$3.344 \times 10^{-27} \text{ kg}$
Bohr radius	a	$5.292 \times 10^{-11} \text{ m}$
Bohr magneton	μ_B	$9.274 \times 10^{-24} \text{ J/T}$ $5.788 \times 10^{-5} \text{ eV/T}$
Rydberg constant	R	$1.097\,373 \times 10^7 \text{ m}^{-1}$

*For a more complete list, showing also the best experimental values, see Appendix B.

THE GREEK ALPHABET

Alpha	A	α	Iota	I	ι	Rho	P	ρ
Beta	B	β	Kappa	K	κ	Sigma	Σ	σ
Gamma	Γ	γ	Lambda	Λ	λ	Tau	T	τ
Delta	Δ	δ	Mu	M	μ	Upsilon	Y	ν
Epsilon	E	ϵ	Nu	N	ν	Phi	Φ	ϕ, φ
Zeta	Z	ζ	Xi	Ξ	ξ	Chi	X	χ
Eta	H	η	Omicron	O	\o	Psi	Ψ	ψ
Theta	Θ	θ	Pi	Π	π	Omega	Ω	ω

SOME CONVERSION FACTORS*

Mass and Density

$$\begin{aligned}1 \text{ kg} &= 1000 \text{ g} = 6.02 \times 10^{26} \text{ u} \\1 \text{ slug} &= 14.59 \text{ kg} \\1 \text{ u} &= 1.661 \times 10^{-27} \text{ kg} \\1 \text{ kg/m}^3 &= 10^{-3} \text{ g/cm}^3\end{aligned}$$

Length and Volume

$$\begin{aligned}1 \text{ m} &= 100 \text{ cm} = 39.4 \text{ in.} = 3.28 \text{ ft} \\1 \text{ mi} &= 1.61 \text{ km} = 5280 \text{ ft} \\1 \text{ in.} &= 2.54 \text{ cm} \\1 \text{ nm} &= 10^{-9} \text{ m} = 10 \text{ \AA} \\1 \text{ pm} &= 10^{-12} \text{ m} = 1000 \text{ fm} \\1 \text{ light-year} &= 9.461 \times 10^{15} \text{ m} \\1 \text{ m}^3 &= 1000 \text{ L} = 35.3 \text{ ft}^3 = 264 \text{ gal}\end{aligned}$$

Time

$$\begin{aligned}1 \text{ d} &= 86400 \text{ s} \\1 \text{ y} &= 365 \frac{1}{4} \text{ d} = 3.16 \times 10^7 \text{ s}\end{aligned}$$

Angular Measure

$$\begin{aligned}1 \text{ rad} &= 57.3^\circ = 0.159 \text{ rev} \\\pi \text{ rad} &= 180^\circ = \frac{1}{2} \text{ rev}\end{aligned}$$

Speed

$$\begin{aligned}1 \text{ m/s} &= 3.28 \text{ ft/s} = 2.24 \text{ mi/h} \\1 \text{ km/h} &= 0.621 \text{ mi/h} = 0.278 \text{ m/s}\end{aligned}$$

Force and Pressure

$$\begin{aligned}1 \text{ N} &= 10^5 \text{ dyne} = 0.225 \text{ lb} \\1 \text{ lb} &= 4.45 \text{ N} \\1 \text{ ton} &= 2000 \text{ lb} \\1 \text{ Pa} &= 1 \text{ N/m}^2 = 10 \text{ dyne/cm}^2 \\&\quad = 1.45 \times 10^{-4} \text{ lb/in.}^2 \\1 \text{ atm} &= 1.01 \times 10^5 \text{ Pa} = 14.7 \text{ lb/in.}^2 \\&\quad = 76.0 \text{ cm Hg}\end{aligned}$$

Energy and Power

$$\begin{aligned}1 \text{ J} &= 10^7 \text{ erg} = 0.2389 \text{ cal} = 0.738 \text{ ft \cdot lb} \\1 \text{ kW} \cdot \text{h} &= 3.6 \times 10^6 \text{ J} \\1 \text{ cal} &= 4.1868 \text{ J} \\1 \text{ eV} &= 1.602 \times 10^{-19} \text{ J} \\1 \text{ horsepower} &= 746 \text{ W} = 550 \text{ ft \cdot lb/s}\end{aligned}$$

Magnetism

$$1 \text{ T} = 1 \text{ Wb/m}^2 = 10^4 \text{ gauss}$$

*See Appendix D for a more complete list.