

Appendix A

UNITS AND NUMBERS

THE INTERNATIONAL SYSTEM OF UNITS

Within SI, units are based on multiples of 10. Thus the centimeter is one-hundredth the length of a meter, the millimeter one-thousandth, and so on. In the same way, a kilometer is 1000 meters, a kilogram is 1000 grams, and so on. This organization differs from that of the English system, in which a foot equals 12 inches and a yard is 3 feet. A list of metric prefixes follows.

Metric Prefixes

If the prefix is:	Multiply the basic unit by:	If the prefix is:	Divide the basic unit by:
giga- (G)	1 billion (thousand million)	deci- (d)	10
mega- (M)	1 million	centi- (c)	100
kilo- (k)	1000	milli- (m)	1000
hecto- (h)	100	micro- (μ)	1 million
deka- (da)	10	nano- (n)	1 billion

UNITS OF LENGTH, MASS, AND TEMPERATURE

Next we give the conversion factors between SI and English units of length and mass.

Length and Mass Conversion from SI to English Units

To get:	Multiply:	By:
inches	meters	39.4
feet	meters	3.281
miles	kilometers	0.621

Length and Mass Conversion from English to SI Units

To get:	Multiply:	By:
meters	inches	0.0254
meters	feet	0.3048
kilometers	miles	1.609

For example, a distance of 5 miles can be converted to kilometers by multiplying by the factor 1.609:

$$5 \text{ miles} \times 1.609 = 8.05 \text{ kilometers}$$

To convert between Celsius and Fahrenheit degrees, use the following formulas:

$$^{\circ}\text{F} = 1.8(^{\circ}\text{C}) + 32 \quad ^{\circ}\text{C} = 0.55(^{\circ}\text{F} - 32)$$

where $^{\circ}\text{F}$ and $^{\circ}\text{C}$ stand for degrees Fahrenheit and Celsius, respectively. To find temperatures in the Kelvin scale, simply add 273.15 to the temperature on the Celsius scale.

UNITS OF FORCE, ENERGY, AND POWER

Once the basic units of mass, length, time, and temperature have been defined, the units of other quantities such as force and energy follow. Recall the energy units that we have defined in the text:

joule	a force of 1 newton acting through 1 meter
foot-pound	a force of 1 pound acting through 1 foot
calorie	energy required to raise the temperature of 1 gram of water by 1°C
British Thermal Unit (BTU)	energy required to raise the temperature of 1 pound of water by 1°F
kilowatt-hour	1000 joules per second for 1 hour
newton	a force required to accelerate a mass of 1 kilogram at a rate of 1 meter per second per second

Power units are:

watt	1 joule per second
horsepower	550 foot-pounds per second

Conversion factors between SI and English units for energy and power follow.

Energy and Power Conversion from SI to English Units

To get:	Multiply:	By:
BTUs	joules	0.00095
calories	joules	0.2390
kilowatt-hours	joules	2.78×10^{-7}
foot-pounds	joules	0.7375
horsepower	watts	0.00134
pounds	newtons	0.2248 ^a

^aRecall that the weight of a 1-kilogram mass is 9.806 newtons.

Energy and Power Conversion from English to SI Units

To get:	Multiply:	By:
joules	BTUs	1055
joules	calories	4.184
joules	kilowatt-hours	3.6×10^6
joules	foot-pounds	1.356
watts	horsepower	745.7
newtons	pounds	4.448

POWERS OF 10

Powers of ten notation allows us to write very large or very small numbers conveniently, in a compact way. Any number can be written by following three rules:

1. Every number is written as a number between 1 and 10 followed by 10 raised to a power, or an exponent.
2. If the power of 10 is positive, it means “move the decimal point this many places to the right.”
3. If the power of 10 is negative, it means “move the decimal point this many places to the left.”

Thus, using this notation, five trillion is written 5×10^{12} , instead of 5,000,000,000,000. Similarly, five-trillionths is written 5×10^{-12} , instead of 0.000000000005.

Multiplying or dividing numbers in powers of 10 notation requires special care. If you are multiplying two numbers, such as 2.5×10^3 and 4.3×10^5 , you multiply 2.5 and 4.3, but you add the two exponents:

$$\begin{aligned}(2.5 \times 10^3) \times (4.3 \times 10^5) &= (2.5 \times 4.3) \times 10^{3+5} \\ &= 10.75 \times 10^8 \\ &= 1.075 \times 10^9\end{aligned}$$

When dividing two numbers, such as 4.3×10^5 divided by 2.5×10^3 , you divide 4.3 by 2.5, but you subtract the denominator exponent from the numerator exponent:

$$\begin{aligned}\frac{4.3 \times 10^5}{2.5 \times 10^3} &= \frac{4.3}{2.5} \times 10^{5-3} \\ &= 1.72 \times 10^2 \\ &= 172\end{aligned}$$

SELECTED MATHEMATICAL FORMULAS

Circumference of a circle, radius R :

$$C = 2\pi R$$

Area of a circle, radius R :

$$A = \pi R^2$$

Volume of a sphere, radius R :

$$V = \frac{4}{3}\pi R^3$$

Surface area of a sphere, radius R :

$$A = 4\pi R^2$$

Volume of a cylinder, radius R , height h :

$$V = \pi R^2 h$$

Appendix B

SELECTED PHYSICAL CONSTANTS

Average acceleration due to gravity at Earth's surface:

$$g = 9.8 \text{ m/s}^2$$

Gravitational constant:

$$G = 6.67 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$$

Coulomb's law constant:

$$k = 9 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$$

Charge on electron:

$$e = 1.6 \times 10^{-19} \text{ C}$$

Proton mass:

$$m_p = 1.66 \times 10^{-27} \text{ kg}$$

Electron mass:

$$m_e = 9.11 \times 10^{-31} \text{ kg}$$

Speed of light in a vacuum:

$$c = 3.00 \times 10^8 \text{ m/s}$$

Planck's constant:

$$h = 6.63 \times 10^{-34} \text{ J}\cdot\text{s}$$

Boltzmann's constant:

$$k = 1.38 \times 10^{-23} \text{ J/K}$$

Astronomical unit (mean distance from Earth to the Sun):

$$\text{AU} = 1.46 \times 10^{11} \text{ m}$$

Light-year:

$$\begin{aligned} 1 \text{ ly} &= 9.46 \times 10^{12} \text{ km} \\ &= 6.3 \times 10^4 \text{ AU} \end{aligned}$$

Parsec:

$$1 \text{ pc} = 3.3 \text{ light-years}$$

Power output of the Sun:

$$P = 4.24 \times 10^{23} \text{ kW}$$

Mass of the Sun:

$$M_{\text{sun}} = 1.989 \times 10^{30} \text{ kg}$$

Mass of Earth:

$$M_E = 5.974 \times 10^{24} \text{ kg}$$

Mass of the Moon:

$$M_{\text{moon}} = 7.348 \times 10^{22} \text{ kg}$$

Radius of the Sun:

$$R_{\text{sun}} = 6.96 \times 10^5 \text{ km}$$

Radius of Earth:

$$R_E = 6.378 \times 10^3 \text{ km}$$

Radius of the Moon:

$$R_{\text{moon}} = 1.738 \times 10^3 \text{ km}$$

PERIODIC TABLE AND ATOMIC WEIGHTS

PERIODIC TABLE OF THE ELEMENTS

		Atomic number																metal			metalloid	nonmetal				
		1 H 1.00794																							VIIIA (18)	
		Atomic mass																								

Names of elements 110–114 are temporary. Official names and symbols must be approved by the International Union of Pure and Applied Chemistry.

TABLE OF ATOMIC WEIGHTS

Atomic				Atomic			
Name	Symbol	Number	Weight	Name	Symbol	Number	Weight
Actinium	Ac	89	227.0	Indium	In	49	114.8
Aluminum	Al	13	26.98	Iodine	I	53	126.9
Americium	Am	95	243.1	Iridium	Ir	77	192.2
Antimony	Sb	51	121.8	Iron	Fe	26	55.85
Argon	Ar	18	39.95	Krypton	Kr	36	83.80
Arsenic	As	33	74.92	Lanthanum	La	57	138.9
Astatine	At	85	210.0	Lawrencium	Lr	103	260.1
Barium	Ba	56	137.3	Lead	Pb	82	207.2
Berkelium	Bk	97	247.1	Lithium	Li	3	6.941
Beryllium	Be	4	9.012	Lutetium	Lu	71	175.0
Bismuth	Bi	83	209.0	Magnesium	Mg	12	24.31
Bohrium	Bh	107	(264)	Manganese	Mn	25	54.94
Boron	B	5	10.81	Meitnerium	Mt	109	(268)
Bromine	Br	35	79.90	Mendelevium	Md	101	258.1
Cadmium	Cd	48	112.4	Mercury	Hg	80	200.6
Calcium	Ca	20	40.08	Molybdenum	Mo	42	95.94
Californium	Cf	98	242.06	Neodymium	Nd	60	144.2
Carbon	C	6	12.01	Neon	Ne	10	20.18
Cerium	Ce	58	140.1	Neptunium	Np	93	237.05
Cesium	Cs	55	132.9	Nickel	Ni	28	58.69
Chlorine	Cl	17	35.45	Niobium	Nb	41	92.91
Chromium	Cr	24	52.00	Nitrogen	N	7	14.01
Cobalt	Co	27	58.93	Nobelium	No	102	259.1
Copper	Cu	29	63.55	Osmium	Os	76	190.2
Curium	Cm	96	247.1	Oxygen	O	8	16.00
Darmstadtium	Ds	110	(271)	Palladium	Pd	46	106.4
Dubnium	Db	105	(262)	Phosphorus	P	15	30.97
Dysprosium	Dy	66	162.5	Platinum	Pt	78	195.1
Einsteinium	Es	99	252.1	Plutonium	Pu	94	244.1
Erbium	Er	68	167.3	Polonium	Po	84	209.0
Europium	Eu	63	152.0	Potassium	K	19	39.10
Fermium	Fm	100	257.1	Praseodymium	Pr	59	140.9
Fluorine	F	9	19.00	Promethium	Pm	61	144.9
Francium	Fr	87	223.0	Protactinium	Pa	91	231.0
Gadolinium	Gd	64	157.25	Radium	Ra	88	226.0
Gallium	Ga	31	69.72	Radon	Rn	86	222.0
Germanium	Ge	32	72.61	Rhenium	Re	75	186.2
Gold	Au	79	197.0	Rhodium	Rh	45	102.9
Hafnium	Hf	72	178.5	Rubidium	Rb	37	85.47
Hassium	Hs	108	(269)	Ruthenium	Ru	44	101.1
Helium	He	2	4.003	Rutherfordium	Rf	104	(261)
Holmium	Ho	67	164.9	Samarium	Sm	62	150.4
Hydrogen	H	1	1.008	Scandium	Sc	21	44.96

TABLE OF ATOMIC WEIGHTS (continued)

Atomic				Atomic			
Name	Symbol	Number	Weight	Name	Symbol	Number	Weight
Seaborgium	Sg	106	(266)	Tin	Sn	50	118.7
Selenium	Se	34	78.96	Titanium	Ti	22	47.88
Silicon	Si	14	28.09	Tungsten	W	74	183.85
Silver	Ag	47	107.9	Ununbium	Uub	112	(285)
Sodium	Na	11	22.99	Ununquadium	Uuq	114	(289)
Strontium	Sr	38	87.62	Unununium	Uuu	111	(272)
Sulfur	S	16	32.07	Uranium	U	92	238.0
Tantalum	Ta	73	180.95	Vanadium	V	23	50.94
Technetium	Tc	43	98.91	Xenon	Xe	54	131.3
Tellurium	Te	52	127.6	Ytterbium	Yb	70	173.0
Terbium	Tb	65	158.9	Yttrium	Y	39	88.91
Thallium	Tl	81	204.4	Zinc	Zn	30	65.39
Thorium	Th	90	232.0	Zirconium	Zr	40	91.22
Thulium	Tm	69	168.9				

Elements by Name, Symbol, Atomic Number, and Atomic Weight.

(Atomic weights are given to four significant figures for elements below atomic number 104.)

Names of elements 110–114 are temporary. Official names and symbols must be approved by the International Union of Pure and Applied Chemistry.

Glossary

Note: Numbers in parentheses refer to the page on which the term is found. **Bolded** page numbers refer to key terms.

absolute zero The lowest possible temperature, at which no energy can be extracted from atoms. (p. 228)

absorption The conversion of electromagnetic wave energy into heat, resulting in a reduction (partial or complete) of the wave strength. (p. 426)

absorption lines The frequencies missing from white light after it passes through a material. (p. 458)

acceleration The change in velocity divided by the time it takes for that change to occur. Acceleration can involve changes of speed, changes in direction, or both. (p. 60, 81)

acceleration due to gravity (*g*) The velocity change of a freely falling body at the Earth's surface. (p. 66)

active optics Optical devices (such as the mirrors in a reflecting telescope) that are able to move in order to focus and make corrections. (p. 424)

additive primary colors See **primary additive colors**.

air resistance The resultant force that occurs in the opposite direction of an object's movement, when the object moves through air; this force increases in proportion to the object's speed; also known as *drag*. (p. 82)

alkali metals The highly reactive elements in the left-hand column of the periodic table. (p. 463)

alkaline earths Elements in the second column of the periodic table; they combine with oxygen to form colorless compounds with high melting temperatures. (p. 463)

alpha decay The spontaneous release of an alpha particle (two protons and two neutrons) from an atomic nucleus. (p. 559)

alpha particle A helium-4 nucleus; frequently emitted during radioactive decay. (p. 450)

alternating current (AC) Electric current that changes direction periodically in a circuit. (p. 366)

ampere (amp) The physical unit used to define a quantity of electric current. (p. 375)

amplitude The maximum displacement from equilibrium of a wave medium or a vibrating body. (p. 293)

amplitude modulation (AM) The process of encoding a radio wave with information by varying its strength or amplitude. (p. 404)

angle of incidence The angle that the direction of incoming radiation makes with a line drawn perpendicular to the surface. (p. 421)

angle of reflection The angle that the direction of reflected radiation makes with a line drawn perpendicular to the surface. (p. 421)

angular frequency The number of radians traversed in 1 second. (p. 143)

angular momentum The moment of inertia of a body, times its angular velocity. (p. 147)

angular speed The angle through which an object has moved about the axis of rotation, divided by the time it takes it to go through that angle. (p. 141)

annihilation Process by which matter and antimatter come together and have all their mass converted into energy. (p. 590)

antimatter Any substance that annihilates with an equal amount of ordinary matter, resulting in a complete conversion to electromagnetic energy. (p. 590)

antinodes The points of a standing wave where the amplitude of the oscillations of the medium is a maximum. (p. 299)

applied research The type of research performed by scientists with specific and practical goals in mind. This research is often translated into practical systems by large-scale research and development projects. (p. 14)

Archimedes' principle The statement that the upward force exerted on an object immersed in a fluid (the buoyant force) is equal to the weight of the fluid that the object displaces. (p. 213)

artificial intelligence The concept of creating a machine or computer that performs functions normally associated with human intelligence. (p. 546)

astronomy The study of stars, planets, and other objects in space. (p. 13)

atom The tiniest particle of matter that retains the chemical properties of an element. (p. 187)

atomic number The number of protons in the nucleus of an atom. (p. 463, 554)

aurora borealis and **aurora australis** The light displays (northern lights and southern lights) produced when the charged particles in the Van Allen belt enter the Earth's atmosphere. (p. 347)

average velocity The total distance traveled divided by the total time it takes to travel that distance. (p. 61)

Avogadro's principle The statement that equal volumes of any gas at the same temperature and pressure contain the same number of gas molecules. (p. 188)

axis of rotation The line through the center of an object, around which everything else rotates. (p. 139)

base One of the three semiconductor regions of a transistor. (p. 536)

base load The electric power that needs to be supplied around the clock. (p. 535)

basic research The type of research performed by scientists who are interested simply in finding out how the world works, in knowledge for its own sake. (p. 14)

battery A device that uses stored chemical energy as an electric power source. (p. 354)

beats The slow, pulsing sound heard when two sound waves of slightly different frequencies interfere. (p. 322)

Bernoulli effect The effect by which the pressure exerted by a fluid decreases as the fluid velocity increases. (p. 215)

beta decay The spontaneous transformation of a neutron into a proton in an atomic nucleus, accompanied by the release of an electron and a neutrino. (p. 560)

big bang theory The theory that the universe was, at one time, a very small, dense collection of matter and energy that has been expanding ever since. (p. 636)

binary Presenting information as a string of 0s and 1s, representing off or on. (p. 540)

binary digit See bit.

binding energy The energy required to separate a nucleus into its constituent parts. (p. 557)

biology The study of living systems. (p. 13)

biosphere The part of the Earth's surface and atmosphere that is capable of supporting life. (p. 282)

bit The smallest unit of information storage. (p. 540)

Bohr atom A model of the atom proposed in 1913 by Danish physicist Niels Bohr; the Bohr atom revolutionized our understanding of physics. (p. 451)

buoyant force The upward force on an object due to the pressure of a fluid. (p. 213)

byte Eight bits of information. (p. 540)

calorie The amount of heat required to raise the temperature of 1 gram of water by 1 degree Celsius. (p. 235)

capacitance The ratio of stored charge to voltage across a capacitor. (p. 381)

capacitor A charge configuration that consists of equal amounts of opposite charge separated by some distance; usually used as a device in an electric circuit. (p. 380)

center of mass (center of gravity) The point of support on which an object can be balanced. (p. 152)

central processing unit (CPU) The main part of a computer that stores and manipulates relatively small amounts of information. (p. 542)

centripetal acceleration Acceleration directed inward toward the center of a circle, perpendicular to the velocity. (p. 69)

centripetal force The force in circular motion, directed toward the center of the circle, that keeps an object following a curved or circular path. (p. 103)

Cepheid variable A star that shows a regular pattern of brightening and dimming over a period of weeks or months; used in astronomy as a standard candle. (p. 628)

chain reaction A self-sustaining sequence of nuclear fission in which each fissioning nucleus produces the neutrons that cause more splitting. (p. 570)

change of phase A process by which a material, without changing its constituent atoms or molecules, changes their arrangement. (p. 196)

chaos theory The field of study devoted to systems in nature that can be described in simple Newtonian terms but whose futures are extremely sensitive to initial conditions, and which are, for all intents and purposes, unpredictable. (p. 111)

charge See electric charge.

chemical bonds The forces that hold atoms together in stable configurations to form molecules. (p. 187, 494)

chemical reaction The formation or breaking apart of chemical bonds. (p. 506)

chemistry The study of atoms in combination. (p. 13)

chromatic aberration The effect that results when different colors are focused at different locations by a lens. (p. 434)

circuit breaker A device that prevents too much current from flowing through it by creating an open circuit. (p. 382)

classical mechanics The field of study that focuses on how any object is affected by any force. (p. 80)

classical physics The study of classical mechanics, thermodynamics, electricity, and magnetism. (p. 367)

coefficient of linear expansion A quantity that relates the temperature change with the corresponding length change of a material. (p. 232)

collector One of the three semiconductor regions of a transistor. (p. 536)

composite materials Materials that combine the properties of several materials in order to improve their working characteristics. (p. 505)

compound A material that is made up of two or more elements. (p. 187)

compression The condition in which the atoms of a material are squeezed closer together, due to an external force. (p. 219)

compressive strength The ability of a solid to withstand crushing. (p. 503)

computer A machine that stores and manipulates information. (p. 542)

concave mirror A curved mirror that bows inward, away from the incoming light. (p. 423)

conduction The transfer of heat due to atomic or molecular collisions. (p. 240)

conduction electrons The electrons in a conductor or semiconductor that are free to move from place to place. (p. 518)

conservation law Statement that a quantity is constant in nature. (p. 124)

conservation of angular momentum The physical law that states that in the absence of external torques, the angular momentum of any system must stay constant over time. (p. 149)

conservation of electric charge The physical law that states that the total amount of charge in the universe does not change. (p. 338)

constant An unchanging value, often determined by measurements, that defines a quantitative mathematical relationship. (p. 4)

constellations Closely spaced groups of stars. (p. 51)

convection Heat transfer due to the motion of a liquid or a gas. (p. 242)

convection cell A region of a fluid that is either rising or sinking due to the heat convection process. (p. 242)

converging lens A lens that bends light towards its axis. (p. 432)

conversion factor Established mathematical quantity used to shift from one system of units to another. (p. 37)

convex mirror A curved mirror that bows outward, toward the incoming light. (p. 423)

cosmic microwave background radiation The electromagnetic radiation from space that is thought to be a remnant of the big bang. (p. 638)

cosmic rays High-speed particles (mostly protons) that originate in space and travel throughout the universe. (p. 346, 585)

cosmology The branch of science devoted to the study of the history and structure of the universe. (p. 630)

coulomb The physical unit used for quantifying amounts of electric charge. (p. 338)

Coulomb's law The law of physics that defines the force between electrically charged objects. (p. 339)

covalent bond Chemical bond formed when two or more atoms in a molecule share electrons. (p. 497)

crest The highest point of a wave; commonly associated with water waves. (p. 293)

critical mass The minimal amount of fissionable material that makes a chain reaction possible. (p. 574)

crystal A material whose atoms are arranged in an ordered, repeating pattern. (p. 191)

cubed A term describing a number multiplied twice by itself. (p. 33)

Curie point The temperature below which neighboring atoms in a material begin to align themselves into ferromagnetic domains. (p. 525)

Curie's law The law that states that the magnetic field produced by a paramagnet is proportional to the applied magnetic field. (p. 526)

cycle One complete back-and-forth vibration or oscillation. (p. 290)

cyclotron A type of particle accelerator in which the particles spiral outward between two magnets, gaining energy through the repeated application of a high-frequency voltage. (p. 586)

dark energy Newly discovered energy that pushes galaxies away from one another, causing the universe to expand more rapidly as time goes by. (p. 647)

dark matter The unseen matter in the universe that has been postulated to account for the observed structure of the universe. (p. 645)

daughter nucleus The nucleus that is a product of radioactive decay. (p. 560)

de Broglie relation The mathematical formula that relates the wavelength to the momentum of a quantum object. (p. 481)

deceleration The process of slowing down; because the process involves a change in velocity, it is actually a form of acceleration. (p. 61)

decibel (dB) A unit of the intensity of sound. (p. 319)

density The mass per unit volume of a substance; it is a measure of how much material is packed into a given volume. (p. 204)

diamagnetism The magnetic properties of a material associated with the alignment of atoms in the presence of an applied magnetic field; in diamagnetism the induced field opposes the applied field. (p. 525)

diffuse scattering The scattering of light in many different directions. (p. 421)

digital Presenting information in a numerical system that can have a finite number of states. Binary is one form of digital information. (p. 540)

dimensional analysis The process of ensuring that the units in a problem come out correctly. (p. 60)

diode A semiconductor device formed from one *p*-type (positive) and one *n*-type (negative) region; typically used as a rectifier. (p. 533)

dipole field The field created by an electric or magnetic dipole. (p. 344)

direct current (DC) Electric current that is always in the same direction in a circuit. (p. 366)

direct relationship The simplest relationship between two variables, in which the two variables change together. (p. 31)

dispersion The phenomenon that different wavelengths of light refract different amounts when entering a medium. (p. 434)

diverging lens A lens that bends light away from its axis. (p. 432)

Divine Calculator Proposed by French mathematician Pierre Simon Laplace (1749–1827), the idea that with a known position and velocity of every atom in the universe, and with infinite computational power, the position and velocity of every atom in the universe for all times could be predicted. (p. 111)

doping The addition of small amounts of an impurity to an element or compound to enhance its conduction properties. (p. 532)

Doppler effect A shift in the observed frequency of a wave due to the motion of the source of the wave, the observer, or both. (p. 299)

double bond A covalent bond in which two electrons from each atom are shared. (p. 498)

drag See **air resistance**.

drift velocity The speed with which the electrons in a circuit move from one place in the circuit to another. (p. 375)

echolocation The process of determining the distance to objects by bouncing sound waves off those objects. (p. 317)

efficiency A measure of how much useful work you can get from an engine compared to the amount of energy put into it; it is equal to the work done by an engine divided by the heat input to the engine. (p. 273)

elastic limit The point at which Hooke's law no longer describes the elastic properties of a material because too much force is applied; the maximum force or torque that can be applied to a solid without bending or breaking it. (p. 218, 503)

elasticity A term used to describe the way materials respond to forces. (p. 218)

electric charge The property of an object or particle that quantifies its response to electric and magnetic phenomena; charges are either *positive* or *negative*. (p. 334)

electric circuit An unbroken path of material that carries electricity. (p. 374)

electric current A flow of charged particles. (p. 354)

electric field A measure of how much electric force a positive electric charge would experience at a particular location in space; it is defined as the force per unit charge. (p. 342)

electric force The force exerted on charged objects by other charged objects. (p. 339)

electric generator A device that uses electromagnetic induction to produce electricity. (p. 365)

electric motor A device that does work by running electric current through coils of wire in the presence of permanent magnets. (p. 358)

electric potential The quantity in electric circuits that is analogous to pressure in water flowing through pipes; it is the potential energy per unit charge across a region in a circuit; also called voltage. (p. 375)

electrical conductor A material in which charges are free to move from place to place. (p. 515)

electrical insulator A material in which charges are not free to move from place to place. (p. 517)

electrical resistance (measured in **ohms**) The quantity that defines how hard it is to run electric current through an object; the tendency of a material to resist the flow of electric charges through it. (p. 375, 515)

electricity A general term used to define the presence and or motion of electric charges. (p. 334)

electromagnet A device that creates a magnetic field by running electric current through coils of wire. (p. 357)

electromagnetic force *See* **electromagnetism**.

electromagnetic induction The effect in which a changing magnetic field causes electric current in a loop of wire. (p. 361)

electromagnetic radiation *See* **electromagnetic wave**.

electromagnetic spectrum The entire collection of electromagnetic waves, from the shortest wavelength (gamma rays) to the longest wavelength (radio waves) and everything in between. (p. 403)

electromagnetic wave or **electromagnetic radiation** A wave that incorporates electric and magnetic fields that oscillate together. (p. 399)

electromagnetism One of the four fundamental forces in nature; associated with electric charges and electromagnetic radiation. (p. 354, 595)

electron A negatively charged fundamental particle; it is one of the primary building blocks of the atom. (p. 449)

electron shells *See* **shells**.

electroweak force The force that results from the unification of the weak force and the electromagnetic force. (p. 598)

element A substance that cannot be broken down into other substances by chemical means. (p. 187)

elementary particles The particles that constitute the basic building blocks of all matter. (p. 584)

elementary-particle physics *See* **high-energy physics**.

ellipse A curve drawn so that the sum of the distances from any point on the curve to two fixed points is always the same. (p. 53)

emitter One of the three semiconductor regions of a transistor. (p. 536)

endothermic reaction A chemical reaction that takes place only if energy is supplied. (p. 508)

energy The ability to do work. (p. 166)

English system The traditional system of units that has roots going back into the Middle Ages, still predominantly used today in the United States. (p. 35)

entropy A measure of the disorder in a system. (p. 278)

equation The definition of a precise mathematical relationship between two or more measurements. (p. 29)

excited state In a system with quantized energy levels, any energy level with more energy than the ground state. (p. 453)

exothermic reaction A chemical reaction that gives off energy. (p. 507)

experiment The manipulation of some aspect of nature to observe the outcome. (p. 3)

experimentalist A scientist who manipulates nature with controlled experiments. (p. 11)

ferromagnetic domain A region of a material, typically about a thousand atoms on a side, in which the angular momentum vectors of the atoms are lined up. (p. 525)

ferromagnetism The magnetic properties of a material associated with the spontaneous alignment of domains of magnetic fields of its atoms. (p. 525)

fiber optics A technology that uses long and thin glass fibers to carry light great distances using the principle of total internal reflection. (p. 425)

field researcher A scientist who goes into natural settings to observe nature at work. (p. 11)

first law of thermodynamics The law of physics that states the relationship between heat, work, and changes in the internal energy of a closed system. (p. 261)

fission The splitting of a nucleus into two or more smaller pieces; usually associated with the splitting of uranium to get energy. (p. 569)

fluid A term used to refer collectively to both liquids and gases. (p. 194)

focal length The distance from a mirror or a lens to the focal point. (p. 423)

focal point The point at which parallel rays will converge in a mirror or lens system. (p. 423)

focus A fixed point used as the basis for drawing an ellipse. (p. 54)

foot The basic unit of length in the English system. (p. 35)

foot-pound The unit of work in the English system, corresponding to the work done in lifting a weight of 1 pound 1 foot upward against the force of gravity. (p. 165)

force (measured in newtons) A physical effect that can produce a change in an object's state of motion. (p. 81)

Fourier analysis or **Fourier synthesis** The technique of taking a complex wave and breaking it down into a sum of simple, single-frequency waves. (p. 326)

frame of reference A set of physical surroundings from which events are observed and measured. (p. 604)

freezings or **phase transitions** Moments in the evolution of the universe that are marked by a dramatic change in the nature of the matter and forces that constitute it. (p. 641)

frequency The number of vibrations per second in oscillations and waves. (p. 290, 293)

frequency modulation (FM) The process of encoding a radio wave with information by varying its frequency. (p. 404)

frequency of rotation The number of times an object completes a rotation in a given amount of time. (p. 140)

fundamental or **first harmonic** The lowest frequency mode of a vibrating body. (p. 325)

fuse A device that prevents too much current from flowing through it by melting a piece of metal that is part of the circuit. (p. 382)

fusion The process in which two nuclei join together to form a larger nucleus. (p. 571)

g See **acceleration due to gravity**.

G See **gravitational constant**.

galaxy A collection of gas, dust, and millions or billions of stars all held together by gravity; there are billions of galaxies in the universe. (p. 630)

gamma radiation The spontaneous release of a high-energy photon from an atomic nucleus. (p. 562)

gamma rays Electromagnetic waves with the shortest wavelength; they are usually emitted in nuclear or particle reactions. (p. 413)

gas A material that retains neither its shape nor its volume, but expands to fill any container in which it is placed. (p. 193)

gauge particles Particles that regulate the forces between other particles by being exchanged. (p. 596)

general relativity The part of relativity theory that deals with accelerated reference frames and gravity. (p. 606)

geology The study of the history, evolution, and present state of our home, planet Earth. (p. 13)

geosynchronous orbit An orbit in which an object completes one revolution around the Earth in 24 hours; the object appears to hover over the same spot on the Earth's surface, because that spot also completes a revolution in 24 hours. (p. 108)

glasses Solids in which atoms that are near each other are arranged regularly, but in which there is no long range order. (p. 191)

gluons Gauge particles that hold quarks together. (p. 597)

gravitational constant (G) The exact numerical relation between the masses of two objects and the distance between them, on the one hand, and the gravitational force between them, on the other. (p. 98)

gravitational potential energy The energy a body has by virtue of its position in a gravitational field. (p. 169)

gravity The attractive force that acts between any two objects in the universe. (p. 97, 595)

ground state The lowest energy level in a system with quantized energy states. (p. 453)

grounding The process of connecting an element of a circuit to the ground to provide a safe path for the current in the case of an overload. (p. 385)

hadron Any particle that exists within the nucleus of the atom; hadrons interact with the strong force. (p. 589)

half-life The time it takes for one half of a sample of radioactive material to decay. (p. 565)

harmonics See **overtones**.

heat The energy transferred from one body to another due to a difference in temperature between the two bodies. (p. 234)

heat capacity A measure of the change in temperature of an object on adding or removing heat; the amount of heat required to raise the temperature of the object by 1° C. (p. 235)

heat insulator A material that does not conduct heat well; it has a low thermal conductivity. (p. 241)

heat transfer The process by which thermal energy moves from one place to another. (p. 240)

Heisenberg uncertainty principle See **uncertainty principle**.

hertz The unit of measure of rotational frequency, corresponding to one complete period every second; the physical unit equal to one cycle per second. (p. 140, 293)

high-energy physics or **elementary-particle physics** The study of elementary particles and their properties. (p. 584)

high-level nuclear waste Radioactive materials that are a direct byproduct of the fission process in nuclear reactors and in nuclear weapons production. (p. 575)

high-temperature reservoir See **temperature reservoir**.

hole A defect in a crystal formed by the absence of an electron. (p. 518)

Hooke's law The law that states that the harder you pull on a material, the more it stretches. (p. 218)

horsepower The unit of power in the English system, defined as 550 foot-pounds per second. (p. 167)

Hubble's law The law that relates the distance between Earth and a galaxy to the galaxy's recession speed. (p. 634)

hydrogen bond A weak chemical bond due to polarization forces; developed when hydrogen forms a covalent bond with another atom. (p. 500)

hypothesis A tentative, educated guess, after summarizing experimental and observational results, about how the world works for the behavior under study. (p. 4)

ideal gas law The law that relates the pressure, volume, and temperature of a gas. (p. 217)

impulse The product of a force multiplied by the time over which it acts. (p. 121)

impulse-momentum relationship Restatement of Newton's second law, in which impulse equals the change in momentum. (p. 121)

incompressible Not capable of being compressed; as in an *incompressible* fluid. (p. 209)

index of refraction Defined for a specific material, the ratio of the speed of light in a vacuum to the speed of light in that material; it is a measure of how much light slows down as it enters the material. (p. 428)

inertia The tendency of an object to remain in uniform motion—to resist changes in its state of motion. (p. 82)

inflation A short period of rapid expansion early in the history of the universe. (p. 642)

infrared radiation Electromagnetic waves with wavelengths in the range of about 1 micron to 1 millimeter; they are what we feel as radiant heat. (p. 407)

instantaneous velocity The velocity at a specific time. (p. 61)

insulator See **electrical insulator**; **heat insulator**.

integrated circuit Electronic circuit containing many transistors. (p. 538)

intensity A measure of the energy of a wave; it is measured in watts per square meter. (p. 319)

interference The result of having two or more waves in the same place; constructive interference results in a wave with a larger amplitude; destructive interference results in a wave with a smaller amplitude. (p. 296)

internal energy See **thermal energy**.

internal reflection See **total internal reflection**.

International System or **SI** (*Système International*) A widely used, internally consistent system of units within the metric system; also known as the *metric system*. (p. 35)

inverse relationship The relationship between two variables in which one variable increases as another decreases, and vice versa. (p. 31)

inverse square relationship The relationship between two variables in which one variable increases to a squared amount as another variable decreases, and vice versa. (p. 34)

inversely proportional The relationship between two variables in which one variable increases in the same measure as another variable decreases, and vice versa. (p. 32)

ion An atom that has lost or gained electrons, thus acquiring an electric charge. (p. 337)

ionic bond Chemical bond formed when one atom gives up one or more electrons to another atom, creating an electrical attraction between the atoms. (p. 494)

ionization The stripping away of one or more of an atom's electrons. (p. 563)

isotopes Atoms of the same element whose nuclei have the same number of protons but a different number of neutrons. (p. 555)

joule The SI unit of work, corresponding to a force of 1 newton acting through 1 meter. (p. 164)

Kepler's laws of planetary motion Three basic mathematical statements about the solar system: *Kepler's first law of planetary motion* states that the planets have elliptical orbits with one focus at the Sun; *Kepler's second law* says that for a given time interval, the swept-out area is the same, no matter where the planet is in its orbit; *Kepler's third law* expresses the relationship between a planet's distance from the Sun and its period as a simple equation that allows scientists to predict the behavior of orbiting objects. (p. 53, 54)

kilogram The SI unit of mass. (p. 35)

kilowatt The unit of 1000 watts (corresponding to an expenditure of 1000 joules per second). (p. 167)

kinetic energy The energy a body has by virtue of its motion. (p. 169)

laser Acronym for *light amplification by stimulated emission of radiation*; a device that creates a very intense, coherent, and collimated beam of light. (p. 460)

latent heat of fusion The amount of heat required to change 1 gram of a solid material to a liquid when the solid is at its melting temperature; equivalently, the amount of heat that must be removed from 1 gram of liquid material to turn it into a solid when the liquid is at its freezing temperature. (p. 238)

latent heat of vaporization The amount of heat required to change 1 gram of a liquid material to a gas when the liquid

is at its boiling temperature; equivalently, the amount of heat that must be removed from 1 gram of a gaseous material to turn it into a liquid when the gas is at its condensation temperature. (p. 238)

law of compound motion Galileo's proposition that motion in one dimension has no effect on motion in another dimension. (p. 67)

law of conservation of energy The law that states that in a closed system, the total amount of all forms of energy remains the same. (p. 174)

law of conservation of momentum The law that states that if no external forces act on a system, then the total momentum of that system remains the same. (p. 124)

law of nature An overarching statement of how the universe works, following repeated and rigorous observation and testing of a hypothesis or group of related hypotheses. (p. 6)

laws of thermodynamics See **first law**; **second law**.

length contraction The observed shortening of an object that is moving with respect to the observer. (p. 612)

lens A piece of transparent material designed to bend and focus light. (p. 432)

Lenz's law The physical law that allows one to determine the direction of the induced current during electromagnetic induction. (p. 362)

lepton Elementary particle that does not participate in the strong nuclear force; the electron and the neutrino are examples of leptons. (p. 589)

lift The net upward force on a wing due to the pressure difference between the top and the bottom of that wing. (p. 215)

light Electromagnetic radiation detectable by the human eye, with wavelengths from about 400 to 700 nanometers in length. (p. 399)

linear accelerator A type of particle accelerator in which the particles are accelerated in a straight line. (p. 587)

linear momentum Another term used for *momentum* (the product of mass times velocity) when the object is understood to move in a straight line. (p. 118)

liquid A material that maintains a constant volume, but assumes the shape of its container. (p. 192)

liter The SI unit of volume. (p. 35)

load The place where useful work gets done in a circuit. (p. 379)

longitudinal wave A wave in which the motion of the medium is in the same direction as the wave propagation. (p. 295)

Lorentz factor The factor $\sqrt{1 - (v/c)^2}$ that often occurs in relativity when quantities in different frames of reference are related to one another. (p. 611)

loudness A measure of how loud a sound is perceived by humans. (p. 319)

low-temperature reservoir See **temperature reservoir**.

machine Device that changes the direction or magnitude (or both) of an applied force. (p. 177)

maglev See **magnetic levitation**.

magnet Material or object that possesses a magnetic property such that it is attracted to or repelled from another magnet. (p. 343)

magnetic field A measure of the effect that a magnet has on the space surrounding it, or the effect that would be felt by a magnet if it were at a particular location in space. (p. 344)

magnetic field lines Imaginary lines in space that give the direction of a compass needle. (p. 344)

magnetic force The force that a magnet exerts on other magnets or on moving electric charges. (p. 343)

magnetic levitation (maglev) The magnetic repulsion between a permanent magnet and a metal due to the motion of the permanent magnet. (p. 523)

magnetism The group of phenomena related to magnets and magnetic fields. (p. 343)

mass The amount of matter contained in an object, independent of where that object is found. (p. 84)

mass number The number of protons plus the number of neutrons in the nucleus of an atom. (p. 555)

mechanics The branch of physics that deals with motions of material objects. (p. 56)

meltdown The melting of the fuel rods in a nuclear reactor during an uncontrolled heating of the core. (p. 571)

metallic bond Chemical bond formed when many atoms share the same electrons. (p. 496)

meter The SI unit of length. (p. 35)

metric system See **International System**.

microchip A complex array of *p*-type (positive) and *n*-type (negative) semiconductors that constitutes a tiny integrated circuit. (p. 537)

microscope A device designed to magnify images, usually with a series of lenses. (p. 433)

microwaves Electromagnetic waves with wavelengths between about 1 millimeter and 1 meter. (p. 405)

Milky Way The galaxy that is home to Earth and our solar system. (p. 627)

mirage An optical illusion created by the refraction of light. (p. 430)

mirror A device that scatters light by reflection. (p. 421)

mixture A combination of two or more substances in which each substance retains its own chemical identity. (p. 188)

modern physics The study of relativity, quantum mechanics, and nuclear and particle physics. (p. 367)

molecule Two or more atoms bound together by electric forces (chemical bonds). (p. 187)

moment of inertia The quantity that describes the distribution of mass around an axis of rotation. (p. 146)

momentum The product of an object's mass and velocity. (p. 118)

monsoon The seasonal wind of the Indian Ocean and southern Asia. (p. 236)

nanotechnology The scientific field devoted to developing technologies based on devices that have atomic-scale sizes. (p. 543)

National Science Foundation A federal government agency, with an annual budget of almost \$5 billion, that supports research and education in all areas of science. (p. 17)

net force The unbalanced force on an object. (p. 82)

neurotransmitters Molecules that carry signals between cells in the nervous system. (p. 386)

neutrino A very light, neutral particle that interacts very weakly with matter. (p. 589)

neutron One of the two particles that make up the atomic nucleus; it has no electric charge. (p. 451, 554)

newton (N) The SI unit of force that accelerates a 1-kilogram mass at the rate of 1 meter per second per second. (p. 35, 85)

Newton's law of universal gravitation Newton's law that states that between any two objects in the universe there is an attractive force (gravity) that is proportional to the masses of the objects and inversely proportional to the square of the distance between them. (p. 98)

Newton's laws of motion Three laws that describe how any object in the universe behaves when acted on by any force; the *first law* states that a moving object will continue moving in a straight line at a constant speed, and a stationary object will remain at rest, unless acted on by an unbalanced force; the *second law* states that the acceleration produced on a body by a force is proportional to the magnitude of the force and inversely proportional to the mass of the object; the *third law* states that for every action (force) there is an equal and opposite reaction (force). (p. 80)

Newtonian mechanics The area of physics concerned with Newton's discoveries and their development. (p. 80)

Newtonian worldview The philosophical ideas that grew from Newton's contributions to the development of physics. (p. 80)

noble gases Elements in the far right-hand column of the periodic table; they have filled outer shells, so they do not readily react with other elements. (p. 463)

nodes The points of a standing wave where the displacement of the medium is always zero. (p. 299)

north pole See **poles**.

northern lights See **aurora borealis**.

nuclear fission See **fission**.

nuclear fusion See **fusion**.

nuclear reactor A device that allows us to extract energy from nuclear fission in a controlled fashion. (p. 570)

nucleus A very small, dense, positively charged object at the center of every atom; nuclei are made up of protons and neutrons. (p. 450)

observation The act of noting nature without manipulating it. (p. 3)

Ockham's Razor The idea that the simplest solution to a problem is most likely to be right. (p. 50)

octave Two frequencies are an octave apart when the higher frequency is twice the lower frequency. (p. 322)

ohm The physical unit that defines the amount of electrical resistance. (p. 375)

Ohm's law The relationship among voltage, current, and resistance in a circuit. (p. 378)

opaque materials Materials that absorb or scatter electromagnetic radiation. (p. 426)

open circuit An incomplete electric circuit; it is incapable of carrying electric current. (p. 382)

optical devices or optics Devices used to alter and control electromagnetic radiation. (p. 419)

optics The branch of physics dealing with the manipulation and analysis of electromagnetic waves. (p. 419)

orbitals See **shells**.

organic chemistry The study of carbon-based molecules. (p. 499)

overtones (harmonics) A series of oscillations in which the frequency of each oscillation is an integral multiple of the fundamental frequency. (p. 325)

parabola The shape of the curve followed by an object thrown in a gravitational field. (p. 67)

parallel circuit A circuit, or part of a circuit, that consists of two or more loads linked together along different loops of wire. (p. 391)

paramagnetism The magnetic properties of a material associated with the alignment of atoms in the presence of an applied magnetic field; in paramagnetism the induced field reinforces the applied field. (p. 525)

parsec A unit of length equal to 3.3 light years. (p. 629)

particle accelerator A scientific instrument that increases the speed of charged particles. (p. 586)

Pascal's principle The statement that an increase of pressure of a static fluid in one place is transmitted immediately to every part of the fluid. (p. 211)

Pauli exclusion principle The statement that no two electrons in an atom can occupy the same state at the same time. (p. 463)

peak load The maximum demand on a power-generating source. (p. 535)

period The time it takes a planet to complete one full orbit around the Sun, or a vibrating object to complete one full oscillation. (p. 54, 289)

period of rotation The time it takes for an object to make one complete rotation. (p. 140)

periodic A term that describes phenomena that occur at regular intervals. (p. 8)

periodic table of the elements The systematic organization of the known chemical elements in terms of their electron configurations. (p. 462)

PET See **positron emission tomography**.

phase transitions See **freezings**.

phases of matter The different forms that matter can take; solid, liquid, and gas are the most common. (p. 190)

photoelectric effect The ejection of electrons from a material due to electromagnetic radiation (photons) striking that material. (p. 482)

photon The quantum of electromagnetic radiation; a particlelike bundle of light. (p. 453)

photosynthesis The process of using sunlight as a form of energy to form complex organic molecules. (p. 251)

photovoltaic cell (solar cell) A semiconductor device that converts sunlight into electric energy. (p. 534)

physics The branch of science devoted to the search for laws that describe the most fundamental aspects of nature: matter, energy, forces, motion, heat, light, and other phenomena. (p. 12)

pitch A measure of how the frequency of sound waves is perceived by humans; high pitch means high frequency. (p. 320)

Planck's constant A fundamental physical constant that specifies the extent to which quantum behavior affects nature. (p. 474).

plasma An energetic gaslike state of matter made up of ions, electrons, and neutral particles. (p. 195)

plastics Synthetic polymer materials formed primarily from petroleum. (p. 192)

polar molecules Clusters of atoms that have a positive end and a negative end. (p. 500)

polarization The occurrence of equal but opposite amounts of charge separated from each other; the shift of electrons within atoms or molecules giving them a positive end and a negative end. (p. 341, 500)

poles (north and south) The two ends of a magnet; one is called the *north pole* and one is called the *south pole*. (p. 343)

polymers Very long molecules commonly found in biological materials and plastics. (p. 192)

positron (from *positive electron*) The antiparticle of the electron. (p. 590)

positron emission tomography (PET) A medical technique used to study the brain by injection of positron-emitting isotopes into the bloodstream. (p. 591)

pound The basic unit of weight in the English system. (p. 35)

power The amount of work done divided by the time it takes to do it, or the energy expended divided by the time it takes to expend it. (p. 166)

power stroke The downward motion of a piston when the spark plug fires during the operation of an internal combustion engine. (p. 274)

prediction The use of hypotheses to test how a particular system will behave. (p. 5)

pressure A force divided by the area over which the force acts. (p. 207)

primary additive colors The three colors (red, blue, and green) which, if added together in the right proportions, can create any color. (p. 436)

principle of relativity The statement that the laws of nature are the same in all frames of reference. (p. 606)

probability The likelihood that a certain event or outcome will occur. (p. 477)

proportional In a direct relationship, when both variables increase or decrease together. (p. 31)

proton One of the two particles that make up the atomic nucleus; it has a charge of +1. (p. 451, 554)

pseudoscience The types of inquiry, such as extrasensory perception (ESP), unidentified flying objects (UFOs), astrology, crystal power, reincarnation, and the myriad claims of psychic phenomena, that fail the elementary test that defines science. (p. 9)

quadrant An observational instrument shaped like a large sloping device, something like a gunsight, that determines each star's or planet's position. (p. 53)

quanta Discrete bundles of energy; fundamental amounts of discrete physical quantities. (p. 452)

quantize To restrict a variable to discrete values. (p. 472)

quantum leap or **quantum jump** The process of changing location without having to traverse any of the positions in between; usually in reference to electrons changing energy levels in an atom. (p. 453)

quantum mechanics The branch of physics devoted to the study of very small systems in which physical quantities come in discrete bundles called quanta. (p. 472)

quark The fundamental particle that is the building block of all hadrons. (p. 592)

quasar An unusually active galaxy that pours vast amounts of energy into space. (p. 630)

radian A unit of measure of an angle, equal to the length of a circular arc subtended by the angle divided by the radius of the circle. (p. 142)

radiation Heat transfer due to the emission and absorption of electromagnetic waves between two bodies at different temperatures; also, particles emitted in radioactive decay. (p. 244, 557)

radio waves Electromagnetic waves with the longest wavelength, used to broadcast radio signals. (p. 403)

radioactivity or **radioactive decay** The spontaneous release of energetic particles from an atomic nucleus. (p. 557)

radiometric dating The determination of the age of materials using the known half-lives of radioactive elements. (p. 566)

ray The path taken by a beam of electromagnetic radiation; a line drawn perpendicular to the wavefront. (p. 419)

rectifier An electric device that converts alternating current to direct current; an element in an electric circuit that allows electric current to pass in only one direction. (p. 386, 533)

redshift The shift toward lower frequencies of the spectra of galaxies moving away from us. (p. 631)

reductionism An attempt to reduce the seeming complexity of nature by first looking for underlying simplicity and then trying to understand how that simplicity gives rise to the observed complexity. (p. 583)

reference frame *See* **frame of reference**.

reflecting telescope A telescope that uses a mirror arrangement to focus the incoming light. (p. 433)

reflection The return of light from a surface on which it falls. (p. 421)

refracting telescope A telescope that uses a lens arrangement to focus the incoming light. (p. 433)

refraction The change in direction and speed of a wave as it enters a different medium. (p. 313, 427)

relativity *See* **theory of relativity; general relativity; special relativity**.

reproducible A term referring to the method of conducting and reporting of observations and experiments so that anyone with the proper equipment can verify the results. (p. 7)

research and development (R&D) The process of bringing new discoveries to practical use, often in industrial or governmental laboratories. (p. 14)

resonance The buildup of large vibrations in an oscillating system, due to the application of a force with a frequency that matches the natural or resonant frequency of the oscillator. (p. 302)

resonant frequency The frequency at which a system will vibrate if left to itself. (p. 302)

restoring force A force that always pushes an object towards its equilibrium position. (p. 290)

resultant force The net force in those situations in which two or more forces act in different directions. (p. 82)

right-hand rule Any rule that gives the direction of a vector quantity by using the fingers of the right hand. (p. 345)

rotational motion The spinning motion that occurs when an object rotates about an axis located within it, such as an axis through its center of mass. (p. 139)

scalar Any quantity that can be expressed as a single number and without a direction. (p. 26)

scale In music, a specific sequence of frequencies used for playing music. (p. 322)

scattering The process of changing the direction (and sometimes the properties) of a wave as it encounters an obstacle. (p. 421)

Schrödinger equation The equation that is used to calculate the wave function of a quantum system. (p. 478)

science A method for answering questions about the working of the physical world. (p. 2)

scientific method A cycle of collecting observations (data), identifying patterns and regularities in the data (synthesis), forming hypotheses, and making predictions, which lead to more observations. (p. 2)

scientist A person who studies questions about our world. (p. 2)

second The basic unit of time in both the SI and English systems. (p. 35)

second law of thermodynamics The law of physics that places restrictions on the ways heat and other forms of energy can be transformed and used to do work. (p. 271)

seismic waves Waves in the Earth's crust generated by earthquakes. (p. 294)

semiconductor A material that is neither a good electrical conductor nor a good insulator. (p. 517)

series circuit A circuit, or part of a circuit, that consists of two or more loads linked together along a single loop of wire. (p. 391)

shear strength The ability of a material to withstand twisting. (p. 503)

shells The pattern of arrangements into which electrons organize themselves in an atom; also known as *orbitals*. (p. 463)

shielding The effect that causes electric fields to be significantly less strong inside a conductor. (p. 342)

short circuit A low-resistance path that causes potentially dangerous amounts of current in the circuit. (p. 385)

SI *See* **International System**.

simple harmonic motion The oscillatory motion caused by the action of a restoring force; the restoring force must be proportional to the displacement from equilibrium in order to produce simple harmonic motion. (p. 290)

simple harmonic oscillator An oscillator that exhibits simple harmonic motion. (p. 290)

single bond A covalent bond in which one electron from each atom is shared. (p. 498)

solar cell, solar panel *See* **photovoltaic cell**.

solid A rigid material that has a definite shape and volume. (p. 190)

south pole *See* **poles**.

special relativity The part of relativity theory that deals with events in reference frames moving at constant velocities. (p. 606)

specific heat The quantity of heat required to raise the temperature of 1 gram of a material by 1° C. (p. 235)

spectroscopy The analysis of emission and absorption spectra of materials to determine their chemical properties. (p. 458)

spectrum The total collection of photons emitted by an atom; the distribution of the frequencies of photons emitted by a radiating system. (p. 457)

speed The distance an object travels divided by the time that it takes to travel that distance. (p. 58)

speed of light, c The speed at which all electromagnetic waves travel when in a vacuum, 3.00×10^8 m/s. (p. 401)

spontaneously Resulting from a natural impulse or tendency. (p. 272)

squared A term describing a number multiplied by itself. (p. 32)

standard candle Any object whose energy output is known; used in astronomy to estimate distances to extraterrestrial objects. (p. 627)

standard model The theory that predicts the unification of the strong and the electroweak forces. (p. 598)

standing wave A wave pattern that can be created by the interference of two waves moving in opposite directions; as the name implies, the wave pattern does not move. (p. 299)

static electricity Electric charges that are at rest; also used to describe the force due to electric charges that are at rest. (p. 334)

step-down transformer, step-up transformer See **transformer**.

strength The ability of a solid to resist changes in shape. (p. 502)

string theory A theory that pictures the quarks and leptons as vibrations on tiny stringlike structures. (p. 598)

strong force One of the four fundamental forces; it is the force that binds the nucleus together. (p. 557, 595)

superconductivity The property of having no electrical resistance. (p. 519)

synchrotron A type of particle accelerator in which strong magnets force the particles to follow a circular track while it is accelerated. (p. 587)

system A collection of matter and energy that is controlled in such a way that its physical properties can be studied; systems can be *open*, *closed*, or *isolated*. (p. 260)

system of units Units assigned to fundamental quantities such as mass (or weight), length, time, and temperature. (p. 35)

Système International (SI) See **International System**.

technology The application of science to specific commercial or industrial goals. (p. 14)

temperature A quantity that reflects how vigorously atoms or molecules are moving and colliding in a material. (p. 228)

temperature reservoir A body so large that large quantities of heat can be added to it (**high-temperature reservoir**), or removed from it (**low-temperature reservoir**), without changing its temperature; the Atlantic ocean is a good approximation of a temperature reservoir. (p. 275)

temperature scale A standard of measurement for estimating temperature; familiar examples are the Fahrenheit and the Celsius scales. (p. 228)

tensile strength The ability of a solid to withstand pulling apart. (p. 503)

tension The condition in which the atoms of a material are pulled further apart, due to an external force. (p. 219)

terminal velocity The speed attained by an object falling under the influence of gravity, when the downward pull of gravity is balanced by the upward force of the resistance of the medium through which the body moves. (p. 83)

theorist A scientist who spends time imagining how the universe might work in areas where no detailed explanations exist. (p. 11)

theory A description of the world that covers a relatively large number of phenomena and has met and explained many observational and experimental tests. (p. 4)

theory of everything A theory in which all of the fundamental forces are seen as different aspects of a single force. (p. 598)

theory of relativity The physical laws that govern the measurement of time and space as observed in differing reference frames. (p. 606)

thermal conductivity The ability of a material to transfer heat. (p. 241)

thermal energy or internal energy The energy of an object that results from the vibrations of individual atoms and molecules. (p. 234, 252)

thermocouple A temperature sensor based on the electric properties of metals. (p. 231)

thermodynamics The study of heat and energy. (p. 185)

thermometer A device used to measure temperature. (p. 229)

timbre The characteristic quality of sound that depends on the relative strength of the different frequencies that make up that sound. (p. 326)

time dilation The slowing of time relative to an observer in a different reference frame. (p. 608)

torque The force applied perpendicular to a line from the axis of rotation, multiplied by the distance from the axis of rotation; the application of torque changes angular momentum. (p. 143)

total internal reflection The process in which light, if it is at a great enough incident angle, will totally reflect from a surface with a lower density than the one in which it is traveling. (p. 425)

total momentum The sum of the momenta of all the objects in a system. (p. 122)

transformer A device that converts a high voltage to a low voltage (**step-down transformer**), or a low voltage to a high voltage (**step-up transformer**). (p. 387)

transistor A semiconducting element in an electric circuit that regulates current flow. (p. 535)

transmission The process by which a wave passes through a material (even though it may lose some of its energy). (p. 427)

transparent materials Materials that transmit electromagnetic waves. (p. 427)

transverse wave A wave in which the motion of the medium is perpendicular to the direction of the wave propagation. (p. 295)

trophic level A level in the food chain hierarchy. All organisms that get their food from the same source belong to the same trophic level. (p. 258)

trough The lowest point of a wave; commonly associated with water waves. (p. 293)

ultraviolet radiation Electromagnetic waves with wavelengths from about 100 nanometers to 400 nanometers; they are known to cause sunburn. (p. 411)

unbalanced force A force, not cancelled by another force, acting on an object and causing an acceleration. (p. 82)

uncertainty principle A physical law that places limits on the accuracy to which certain quantities (momentum and position, for example) can be measured simultaneously. (p. 474)

unified field theory A theory that sees the fundamental forces as different aspects of the same force. (p. 597)

uniform motion Motion at a constant speed in a single direction. (p. 61)

Van Allen belts The path of cosmic rays curved by the Earth's magnetic field; named after American physicist James Van Allen. (p. 346)

van der Waals force The force due to the polarization of electrically neutral atoms or molecules that are not themselves polar. (p. 501)

vector A quantity that requires two numbers in its definition—a magnitude and a direction. (p. 26)

velocity A vector quantity that has the same numerical value as speed but also includes information about the direction of travel. (p. 60)

vibrations The oscillating, periodic motions of a medium or body forced from a position of stable equilibrium. (p. 289)

virtual image An image created by a diverging lens where light rays do not actually originate on the object itself. (p. 432)

visible light The specific frequencies of electromagnetic waves that can be detected by the human eye; they include all colors of the rainbow. (p. 409)

volt The physical unit used to quantify the amount of electric potential. (p. 375)

voltage (measured in **volts**) Synonymous with *electric potential*. (p. 375)

volume The quantity of space an object occupies. (p. 33)

W and Z particles Very massive gauge particles that mediate the weak force. (p. 597)

watt The SI unit of power, defined as the expenditure of 1 joule of energy in 1 second. (p. 167)

wave A disturbance of a medium that travels without a net displacement of the medium itself, as in a sound wave. (p. 291)

wave function A mathematical formula that is related to the probability of finding a particle in a particular location. (p. 478)

wave mechanics See **quantum mechanics**.

wave-particle duality The aspect of subatomic entities by which they sometimes exhibit the properties of particles and sometimes exhibit the properties of waves. (p. 479)

wavelength The distance between two adjacent corresponding points (crests, for example) of a wave. (p. 293)

weak force One of the four fundamental forces in nature; it is responsible for some kinds of radioactive decay. (p. 595)

weight The force of gravity on an object. (p. 100)

work The product of the force exerted on an object times the distance over which it is exerted. (p. 163)

work-energy theorem The statement that the total potential and kinetic energy of an object in a given state is equal to the work that was done to bring the object to that state. (p. 175)

X rays Electromagnetic waves with wavelengths from about 0.1 nanometer to 100 nanometers. (p. 411)

Z particles See **W and Z particles**.

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