

GLOSSARY/INDEX

Glossary terms, printed in **boldface**, are defined here as well as in the text (location indicated by boldface page numbers) and in Key Terms. Page numbers followed by *i* indicate illustrations or their captions; page numbers followed by *t* indicate tables.

Absolute entropy (of a substance) The entropy of a substance relative to its entropy in a perfectly ordered crystalline form at 0 K (where its entropy is zero) *See also* **Standard entropy**, **616**, **A22–A23**

Absolute zero The zero point on the absolute temperature scale; -273.15°C or 0 K; theoretically, the temperature at which molecular motion is a minimum, **436**

Absorption spectrum The spectrum associated with absorption of electromagnetic radiation by atoms (or other species) resulting from transitions from lower to higher electronic energy states, **194–195**, **195*i***

Accelerator(s)
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Accuracy How closely a measured value agrees with the correct value, **23**

Acetaldehyde, **1113**

Acetaminophen, **1076**

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Acetone, **1067**

Acetylene, **282**, **338**, **339*i***, **1052–1053**, **1053*i***, **1114**, **1115**

Achiral Describes an object that *can* be superimposed with its mirror image, **1104**

Acid A substance that produces $\text{H}^+(\text{aq})$ ions in aqueous solution. Strong acids ionize completely or almost completely in dilute aqueous solution. Weak acids ionize only slightly, **129**, **370**, **371**, **384**, **966**

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Acid anhydride A nonmetal oxide that reacts with water to form an acid, **255**

Acid halides, **1073**, **1115**. *See also* **Acyl halide**.

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Acidic oxide *See* **Acid anhydride**.

Acidic salt A salt that contains an ionizable hydrogen atom and can neutralize additional base; does not necessarily produce acidic solutions, **382–384**, **383**

Actinides Elements 90 through 103 (after *actinium*)

Activation energy (or Barrier) The kinetic energy that reactant molecules must have to allow them to reach the transition state so that a reaction can occur, **670**, **675**, **675*i***, **678–679**, **679*i***

Active metal A metal that readily loses electrons to form cations, **152**, **165**

Activity (of a component of an ideal mixture)

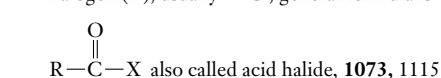
A dimensionless quantity whose magnitude is equal to molar concentration in an ideal solution, equal to partial pressure (in atmospheres) in an ideal gas mixture, and defined as 1 for pure solids or liquids, **704**, **736**

Activity series A listing of metals (and hydrogen) in order of decreasing activity, **153**, **153*t***

Actual yield The amount of a specified pure product actually obtained from a given reaction, **99**. Compare with **Theoretical yield**.

Acyl group The group of atoms remaining after removal of an $-\text{OH}$ group of a carboxylic acid, **1073**

Acyl halide A compound derived from a carboxylic acid by replacing the $-\text{OH}$ group with a halogen (X), usually $-\text{Cl}$; general formula is



Addition polymers, **1086**

Addition reaction A reaction in which two atoms or groups of atoms are added to a molecule, one on each side of a double or triple bond.

The number of groups attached to carbon *increases*, and the molecule becomes more nearly saturated, **1082–1084**

Adhesive force Force of attraction between a liquid and another surface, **488**

Adsorption Adhesion of species onto surfaces of particles, **570**

Air, dry, composition of, **427**

Air bag, automobile, **454**

Air pollution, damage caused by, **899**, **899*i***
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Alcohol A hydrocarbon derivative in which an H attached to a carbon atom not part of an aromatic ring has been replaced by an —OH group, 326, **1061**–1064

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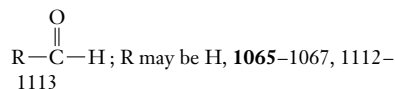
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Aldehyde A compound in which an alkyl or aryl group and a hydrogen atom are attached to a carbonyl group; general formula is



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Aldose A monosaccharide that contains an aldehyde group, **1118**

Aliphatic hydrocarbons Hydrocarbons that do not contain aromatic rings, **1036**

Alkali metal(s) Elements of Group IA in the periodic table, except hydrogen, **126**. *See also* **Metals, Group IA**.

Alkali metal chlorates, 151

Alkali metal halides, 149*t*

Alkaline cell A dry cell in which the electrolyte contains KOH, 880*i*, **881**

Alkaline earth metals Group IIA elements in the periodic table, **126**, 246. *See also* **Metals, Group IIA**.

Alkanes, 1037. *See also* *Saturated hydrocarbons*.

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Alkenes Unsaturated hydrocarbons that contain a carbon–carbon double bond, **1047**–1052

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Alkybenzenes, 1055*i*, 1056

Alkyl group A group of atoms derived from an alkane by the removal of one hydrogen atom, **1043**

Alkyl hydrogen sulfates, 1082

Alkylbenzene A compound containing an alkyl group bonded to a benzene ring, **1056**

oxidation of, 1114

Alkynes Unsaturated hydrocarbons that contain a carbon–carbon triple bond, **1052**–1054, 1084

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Allotropic modifications (allotropes) Different forms of the same element in the same physical state, **51**

Alloying Mixing of a metal with other substances (usually other metals) to modify its properties, **10**, **900**

Alpha emission, 1005

α -Amino acids, 1123

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Alpha particle (α) A particle that consists of two protons and two neutrons; identical to a helium nucleus, i.e., a helium ion with a 2+ charge, 179, **1005**, 1003*t*

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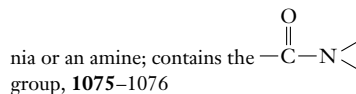
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Amide A derivative of an organic acid and ammo-



Amine A compound that can be considered a derivative of ammonia, in which one or more hydrogens are replaced by alkyl or aryl groups

Amines Derivatives of ammonia in which one or more hydrogen atoms has been replaced by alkyl or aryl groups, 133, **954**, 973, **1068**–1069

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Amino acid A compound containing both an amino group and a carboxylic acid group

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Amino group The —NH₂ group, 1068

Ammine complexes Complex species that contain ammonia molecules bonded to metal ions, **970**–971, 973

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Ammonium ion, 285

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Ammonium sulfide, 825

Amorphous solid A noncrystalline solid with no well-defined, ordered structure, 503–505, **504**

Amount(s), SI unit for, 58

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Ampere Unit of electric current; 1 ampere equals 1 coulomb per second, **849**

Amphiprotism The ability of a substance to exhibit amphoterism by accepting or donating protons, **375**

Amphoteric hydroxides, 376*t*

Amphoteric oxide An oxide that shows some acidic and some basic properties, **253**, 253*i*

Amphoterism The ability of a substance to react with both acids and bases, **375**, 922

amu *See* **Atomic mass unit**.

Amylopectin, 1121, 1121*i*

Amylose, 1121

Analytical balance, 18*i*

Analytical chemistry, definition of, 3

Angstrom (\AA) 10^{−10} meter, 10^{−1} nm, or 100 pm, **237**

Angular momentum quantum number (ℓ)

The quantum mechanical solution to a wave equation that designates the subshell, or set of orbitals (*s*, *p*, *d*, *f*), within a given main shell in which an electron resides, **205**

Angular A term used to describe the molecular geometry of a molecule that has two atoms bonded to a central atom and one or more unshared pairs on the central atom (AB₂U or AB₃U₂). Also called *V-shaped* or *bent*. **306**

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Anhydrous Without water, **79**

Anhydrous aluminum chloride, 385

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Anion An ion with a negative charge; that is, an ion in which the atom or group of atoms has more electrons than protons, **53**, 129, 241, 268

complex, metals in, 973*t*

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Anode (1) In a cathode-ray tube, the positive electrode, **178**

Anode (2) The electrode at which oxidation occurs, **844**, 855

Anode, sacrificial, 868, 869

Anode mud, 908

Antacids, 774

Antibonding electrons, 354

Antibonding orbital A molecular orbital higher in energy than any of the atomic orbitals from which it is derived; when populated with electrons, lends instability to a molecule or ion. Denoted with an asterisk (*) superscript on its symbol, **350**, 352

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 - of acids and bases, properties of, 369–370
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- Aromatic hydrocarbons** Benzene and similar condensed ring compounds; contain delocalized rings of electrons, **1036**, 1054–1058
- Arrhenius, Svante, 370
- Arrhenius equation** An equation that relates the specific rate constant to activation energy and temperature, 676–679, **676**, **677**
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- Arsenic pentoxide, oxygen in, 78
- Artificial kidney, 569
- Artificial transmutation** An artificially induced nuclear reaction caused by bombardment of a nucleus with subatomic particles or small nuclei, **1015**
- Aryl group** The group of atoms remaining after a hydrogen atom is removed from an aromatic system, **1058**
- Asbestos, 960
- Aspartame, 1123
- Aspirin molecules, 52
- Associated ions** Short-lived species formed by the collision of dissolved ions of opposite charge, **560**
- Atmosphere (atm)** A unit of pressure; the pressure that will support a column of mercury 760 mm high at 0°C; 760 torr, **432**
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- Atmospheric pressure, 429–432
- Atom** The smallest particle of an element that maintains its chemical identity through all chemical and physical changes, **48**
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- Atomic mass unit (amu)** One twelfth of the mass of an atom of the carbon-12 isotope; a unit used for stating atomic and formula weights, **57**, **157**
- Atomic nucleus, electron cloud around, 207*i*
- Atomic number (Z)** The number of protons in the nucleus of an atom; defines the identity of an element, **49**, **125**, 181–182, 188
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- Atomic orbital** The region or volume in space in which the probability of finding electrons is highest, **205**, 210*i*, 206–211
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 - overlapping, 303
- Atomic radius** The radius of an atom, **236**–238, 237*i*
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- Atomic weight** Weighted average of the masses of the constituent isotopes of an element; the relative mass of atoms of different elements, 57, **188**
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- Aufbau (“building up”) Principle** A guide for predicting the order in which electrons fill subshells and shells in atoms, **211**–212, 354, 930
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- Autoionization** An ionization reaction between identical molecules, 374–375, **385**
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- Avogadro’s Law** At the same temperature and pressure, equal volumes of all gases contain the same number of molecules, 440
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- Avogadro’s number** 6.022×10^{23} units of a specified item, **58**, 61, 62, 64, 65, 178, 854. *See also Mole.*
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- Ball-and-stick molecular model, definition of, 53*i*, 52
- Balmer–Rydberg equation** An empirical equation that relates wavelengths in the hydrogen emission spectrum to simple integers, **197**, 198
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- Band** A series of very closely spaced, nearly continuous molecular orbitals that belong to the material as a whole, 519
- Band gap** An energy separation between an insulator’s highest filled electron energy band and the next higher-energy vacant band, **522**
- Band of stability** A band containing stable (non-radioactive) nuclides in a plot of number of neutrons versus number of protons (atomic number), **998**, 999*i*
- Band theory of metals** A theory that accounts for the bonding and properties of metallic solids, **518**–523, 519*i*
- Bar** A unit of pressure, 1.00 bar is equal to 100. kPa (or 0.987 atm), **432**
- Barium, uses of, 925
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- Barometer** A device for measuring atmospheric pressure. *See* Figures 12-1 and 12-2. The liquid is usually mercury, **428**–429, 429*i*, 432*i*
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- Base** A substance that produces OH[−](aq) ions in aqueous solution. Strong bases are soluble in water and are completely *dissociated*. Weak bases ionize only slightly, **129**, **132**–**133**, **370**
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- Base pairing** The complementary hydrogen bonding of cytosine with guanine and of adenine with thymine (in DNA) or with uracil (in RNA), **1128**, 1128*i*
- Base solution, standardization of, 405–406
- Basic anhydride** A metal oxide that reacts with water to form a base, **253**–254
- Basic oxide** *See Basic anhydride.*
- Basic salt** A salt containing a basic OH group, 382–384, **383**
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Beta particle (β) An electron emitted from the nucleus when a neutron decays to a proton and an electron, 1003*t*, **1004**
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Binary acid A binary compound in which H is bonded to a nonmetal in Group VIIA or a non-metal other than oxygen in Group VIA, **143**
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Binary compound A compound consisting of two elements; may be ionic or molecular, **140**–143
 ionic, 273, 273*t*
 naming of, 140–143
Binding energy (nuclear binding energy) The energy equivalent ($E = mc^2$) of the mass deficiency of an atom, **1000**
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Biodegradability The ability of a substance to be broken down into simpler substances by bacteria, **574**
Biopolymer Polymers found in biological systems, **1117**–1128
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 Blast furnace, 905, 905*i*
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Boiling point The temperature at which the vapor pressure of a liquid is equal to the external pressure; also the condensation point, **492**
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Boiling point elevation The increase in the boiling point of a solvent caused by dissolution of a nonvolatile solute, 555*i*, **555**–556
Boiling point elevation constant, K_b A constant that corresponds to the change (increase) in boiling point produced by a one-molal *ideal* solution of a nonvolatile nonelectrolyte, **555**
Bomb calorimeter A device used to measure the heat transfer between system and surroundings at constant volume, **608**–609, 609*i*
 Bond(s), covalent. *See* **Covalent bond(s)**.
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Bond energy The amount of energy necessary to break one mole of bonds in a gaseous substance, to form gaseous products at the same temperature and pressure, **275**, **355**, **601**–604, 602*t*
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Bond order Half the number of electrons in bonding orbitals minus half the number of electrons in antibonding orbitals, **354**–357, 357*t*
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 Bonding. *See also* **Chemical bonding and specific types of bonding**.
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Bonding orbital A molecular orbital lower in energy than any of the atomic orbitals from which it is derived; when populated with electrons, lends stability to a molecule or ion, **350**–360
Bonding pair A pair of electrons involved in a covalent bond. Also called *shared pair*, **277**, 321–322, 325
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Boyle's Law At constant temperature, the volume occupied by a given mass of a gas is inversely proportional to the applied pressure, **433**–**436**, 438–439, 459
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Breeder reactor A fission reactor that produces more fissionable material than it consumes, **1022**–1023
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Brønsted–Lowry acid A species that acts as a proton donor, **1107**–1110
Brønsted–Lowry base A species that acts as a proton acceptor, **1107**–1110
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 Buffer(s), 787, 788
Buffer solution A solution that resists changes in pH when strong acids or strong bases are added. A buffer solution contains an acid and its conjugate base, so it can react with added base or acid. Common buffer solutions contain either (1) a weak acid and a soluble ionic salt of the weak acid *or* (2) a weak base and a soluble ionic salt of the weak base, **788**–801
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Buret A piece of volumetric glassware, usually graduated in 0.1-mL intervals, that is used in titrations to deliver solutions in a quantitative (dropwise) manner, 22*i*, **23**, 401*i*, 402
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Calorie Defined as exactly 4.184 joules. Originally defined as the amount of heat required to raise the temperature of one gram of water from 14.5°C to 15.5°C, **37**
Calorimeter A device used to measure the heat transfer that accompanies a physical or chemical change, **588**, **608**
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 coffee-cup, **588**, 589*i*
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Canal ray A stream of positively charged particles (cations) that moves toward the negative electrode in a cathode-ray tube; observed to pass through canals (holes) in the negative electrode, **178**
Capillary action The drawing of a liquid up the inside of a smallbore tube when adhesive forces exceed cohesive forces, or the depression of the surface of the liquid when cohesive forces exceed adhesive forces, **488**–489
Carbohydrate A biopolymer made up of saccharide units, **1118**–1121
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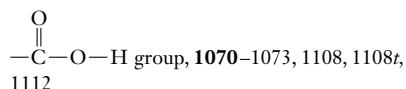
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Carbonic acid, 132

Carbonyl compounds, reduction of, 1113

Carbonyl group The $\text{—}\overset{\text{O}}{\parallel}\text{C—}$ group

Carboxylic acid A compound containing a



aliphatic, 1070*t*

derivatives of, 1073–1076

formation of, 1115–1116

isomeric, 1070

Cast iron The brittle iron obtained when the pig iron from the blast furnace is remelted, run into molds, and cooled; contains much iron carbide, Fe_3C , **906**

Catalysis

heterogeneous, 682–688

homogeneous, 681–682

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Catalyst A substance that increases the rate at which a reaction occurs. It remains unchanged when the reaction is complete, **680**

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heterogeneous, 682–683

homogeneous, 681

Catalytic converter(s), 683*i*, 683–684, 956

Catalytic cracking, 1048

Cathode, definition of, 844, 855

Cathode (1) In a cathode-ray tube, the negative electrode, **178**

Cathode (2) The electrode at which reduction occurs, **844**, 855

Cathode protection Protection of a metal against corrosion by making it a cathode (attaching it to a sacrificial anode of a more easily oxidized metal), **868–870**

Cathode ray The beam of electrons going from the negative electrode toward the positive electrode in a cathode-ray tube

Cathode-ray tube A closed glass tube containing a gas under low pressure, with electrodes near the ends and a luminescent screen at the end near the positive electrode; produces cathode rays when high voltage is applied, 176*i*, **176–177**

Cation An ion with a positive electric charge, that is, an ion in which the atom or group of atoms has fewer electrons than protons, **53**, 129, 240–241, 268

small highly charged, salts containing, 776*i*, 776–779

Cavendish, Henry, 247

Cell potential Potential difference, E_{cell} , between reduction and oxidation half-cells; may be at *nonstandard* conditions. *See also* **Voltaic cell(s)**, **potentials of**, **871**

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Celsius, Anders, 35

Celsius temperature scale, 35, 35*i*

Kelvin temperature scale, and Fahrenheit temperature scale, relationships among, 35*i*, 35–36

Centimeters, and inches, and centimeters, relationship between, 19*i*

Central atom An atom in a molecule or polyatomic ion that is bonded to more than one other atom; the atom or ion to which the ligands are bonded in a complex species, **305**, **971**

CERN, Geneva, Switzerland, 1003

Chadwick, James, 178

Chain initiation step The first step in a chain reaction; produces reactive species (such as radicals) that then propagate the reaction, **943**

Chain propagation step An intermediate step in a chain reaction; in such a step one or more reactive species is consumed, and another reactive species is produced, **943**

Chain reaction A reaction in which reactive species, such as radicals, are produced in more than one step. Consists of an initiation step, one or more propagation steps, and one or more termination steps, **687**, **943**

involving ozone, 687

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Chain termination step The combination of reactive species (such as radicals) which terminates the chain reaction, **943**

Charge A sample of crushed ore as it is admitted to a furnace for smelting, **905**

Charge density, 311, 539

Charge(s), formal, 285–286

definition of, 285

rules for assigning, 285–286

Charge-to-mass ratio, 178

Charles, Jacques, 427, 436

Charles's Law At constant pressure, the volume occupied by a definite mass of a gas is directly proportional to its absolute temperature, **436–439**

calculation of, 438

molecular interpretation of, 459, 459*i*

Chelate A ligand that utilizes two or more connected donor atoms in bonding to metals

Chelate complexes, definition of, **971**

Chemical bonds Attractive forces that hold atoms together in elements and compounds, 265–300, **266**

as continuum, 295

classes of, 266–267

molecular orbitals and, 348–366

Chemical change A change in which one or more new substances are formed, **9**

spontaneity of, 612–627

Chemical communication, 1111

Chemical energy, 5

Chemical equation Description of a chemical reaction by placing the formulas of reactants on the left and the formulas of products on the right of an arrow. A chemical equation must be balanced; that is, it must have the same number of each kind of atom on both sides, 89–92, **90** and experimental observations, 90

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calculations based on, 93–96

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Chemical equilibrium A state of dynamic balance in which the rates of forward and reverse reactions are equal; there is no net change in concentrations of reactants or products while a system is at equilibrium. *See also*

Equilibrium(a), **701–735**

Chemical formula Combination of element symbols that indicates the chemical composition of a substance, **51**, **52**

and composition stoichiometry, 46–82

interpretations of, 77

Chemical kinetics The study of rates and mechanisms of chemical reactions and of the factors on which they depend, 638–698

Chemical periodicity The variation in properties of elements with their positions in the periodic table, **123**, 230–260

Chemical properties, definition of, 6. *See also* **Properties**.

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measurements in, 16–17

nuclear, 995–1032

organic, 1033–1099, 1100–1132

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Chiral Describes an object that *cannot* be superimposed with its mirror image, **982**, **1104**

Chlorine, 7*i*, 415

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Chloroform, 283

Chlorophyll, 968

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Chromate-dichromate equilibrium, 932–933

Chromium hexacarbonyl, 216

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oxidation-reduction of, 931–932

cis-trans isomerism See **Geometric isomerism**.

Clausius, Rudolf, 456

Clausius-Clapeyron equation, 495

Cloud chamber A device for observing the paths of speeding particles as vapor molecules condense on the ionized air molecules in their tracks, **1006**, **1006i**

Coal tar, 1054

fractions from, 1057–1058, **1058i**

Coal, composition of, **259t**

Cobalt, 272, 921

Cohesive forces All the forces of attraction among particles of a liquid, **488**

Colligative properties Physical properties of solutions that depend on the number but not the kind of solute particles present, **548**

and dissociation of electrolytes, 560–562

determination of molecular weight from, 558–559 of solutions, 548–566

Collision(s), effective, requirements for, 668–669, **669i**

Collision theory A theory of reaction rates that states that effective collisions between reactant molecules must take place for reaction to occur, **668**–**669**

Colloid A heterogeneous mixture in which solute-like particles do not settle out; also called *colloidal dispersion*, **567**–**574**

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hydrophobic, 571–572

stabilization of, **571i**

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definition of, 988

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spectral, definition of, 988

Combination reaction Reaction in which two substances (elements or compounds) combine to form one compound, **149**–**150**

Combined Gas Law equation, 438–440

Combustion reaction The reaction of a substance with oxygen in a highly exothermic reaction, usually with a visible flame, 248, **257**–**260**

Combustion, definition of, 248, **1114**

of organic compounds, 1114–1115

Common ion effect Suppression of ionization of a weak electrolyte by the presence in the same solution of a strong electrolyte containing one of the same ions as the weak electrolyte, 787–794, **788**

Complementary color The color associated with the wavelengths of light that are not absorbed—that is, the color transmitted or reflected, **988**

Complete units, writing of, 107

Complex ions Ions resulting from the formation of coordinate covalent bonds between simple cations and other ions or molecules (ligands), **835**–**836**, **967**

Composition stoichiometry Describes the quantitative (mass) relationships among elements in compounds, **478**

chemical formulas and, 46–82

Compound A substance composed of two or more elements in fixed proportions.

Compounds can be decomposed into their constituent elements, **14**, **15**

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organic. See **Organic compounds**.

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structure and bonding in, analysis of, 303

Concentration cell A voltaic cell in which the two half-cells are composed of the same species but contain different ion concentrations, **876**–**877**, **877i**

Concentration The amount of solute per unit volume or mass of solvent or of solution, **103**–**107**

Concentration(s), changes in, LeChatelier's

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of solutions, 102–107

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Condensation Liquefaction of vapor, 490, 494

Condensation polymer A polymer that is formed by a condensation reaction, **1087**–**1090**

Condensation reaction A reaction in which a small molecule, such as water or hydrogen chloride, is eliminated and two molecules are joined, **1087**

Condensed phases The liquid and solid phases; phases in which particles interact strongly, **479**

Condensed states The solid and liquid states, **427**

Conduction band A partially filled band or a band of vacant energy levels just higher in energy than a filled band; a band within which, or into which, electrons must be promoted to allow electrical conduction to occur in a solid, **522**

Conformation One specific geometry of a molecule. The conformations of a compound differ from one another only by rotation about single bonds, **1106i**, **1106**–**1107**, **1107i**

Conjugate acid-base pair In Brønsted-Lowry terminology, a reactant and product that differ by a proton, H^+ , **372**, 373–374 relative strengths of, **378t**

Conjugated double bonds Double bonds that are separated from each other by one single bond, as in $C=C-C=C$, **1050**

Conservation of Matter, Law of, 5, 48, 90

Constant Composition, Law of, 15, 52

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Constitutional isomers Compounds that contain the same numbers of the same kinds of atoms but that differ in the order in which their atoms are bonded together. Also known as *structural isomers*, **976**–**978**, **1039**–**1041**

Contact catalyst See **Heterogeneous catalyst**.

Contact process An industrial process by which sulfur trioxide and sulfuric acid are produced from sulfur dioxide, **949**

Continuous spectrum The spectrum that contains all wavelengths in a specified region of the electromagnetic spectrum, **191**, **192i**

Control rods Rods of materials such as cadmium or boron steel that act as neutron absorbers (not merely moderators), used in nuclear reactors to control neutron fluxes and therefore rates of fission, **1021i**, **1022**

Conversion factors, **A8**–**A10**

relating to length, volume, and mass units, **19t**, **29**

Cooling by evaporation, 489

Coordinate covalent bond A covalent bond in which both shared electrons are furnished by the same species; the bond between a Lewis acid and a Lewis base, **384**–**386**, **966**–**968**

Coordinate covalent bond formation, 285, 384

Coordination compound or complex A compound containing coordinate covalent (dative) bonds between electron pair donors (ligands) and a metal, 965–994, **967**

bonding in, 985–989

colors of, 969

isomerism in, 975–984

ligands in, 971

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structures of, 975

Coordination isomers Isomers involving exchange of ligands between a complex cation and a complex anion of the same coordination compound, **977**

Coordination number The number of nearest neighbors of an atom or ion, **511**, **971** idealized geometries for, **974t**

Coordination sphere The metal ion and its coordinated ligands, but not any uncoordinated counterions, **971**

ligands and, **972t**

Copolymer A polymer formed from two different compounds (monomers), **1087**

Copper deficiency, 921

Copper wire, and silver nitrate solution, 135, **136i**

Copper(II) hydroxide, 836

Copper(II) sulfate, 850–851

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Copper-SHE cell, 860, **861i**

Copper-silver cell, **856i**, 856–857

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- Corrosion** Oxidation of metals in the presence of air and moisture, 867*i*, 867–868, 868*i*
protection from, 868–869
- Coulomb** Unit of electric charge; the amount of charge that passes a given point when 1 ampere of electric current flows for 1 second, 177, 849
- Coulomb's Law, 240, 270, 481
- Coulometry** The use of electrochemical cells to relate the amount of reactant or product to the amount of current passed through the cell, 849–851
- Covalent bond** A chemical bond formed by the sharing of one or more electron pairs between two atoms, 275
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double, 276
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polar, 293
definition of, 292
single, 276
triple, 276
- Covalent bonding, 275–295
definition of, 266
- Covalent bonding theories, structure of molecules and, 301–347
- Covalent compound** A compound containing predominantly covalent bonds, 267
- Covalent solids, 517, 518*i*
- Critical mass** The minimum mass of a particular fissionable nuclide, in a given volume, that is required to sustain a nuclear chain reaction, 1020
- Critical point** The combination of critical temperature and critical pressure of a substance, 502
- Critical pressure** The pressure required to liquefy a gas (vapor) at its critical temperature, 502
- Critical temperature** The temperature above which a gas cannot be liquefied; the temperature above which a substance cannot exhibit distinct gas and liquid phases, 502
- Crystal field splitting energy, 986
- Crystal field theory** A theory of bonding in transition metal complexes in which ligands and metal ions are treated as point charges; a purely ionic model. Ligand point charges represent the crystal (electric) field perturbing the metal's *d* orbitals that contain nonbonding electrons, 985–988
- Crystal lattice** The pattern of arrangement of particles in a crystal, 507
- Crystal lattice energy** The energy change when one mole of formula units of a crystalline solid is formed from its ions, atoms, or molecules in the gas phase; always negative, 270–271, 274
definition of, 537
- Crystalline solid** A solid characterized by a regular, ordered arrangement of particles, 503–505
- Crystals, cubic, nearest neighbors in, 511–513
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Cubic. *See* **Unit cell(s)**, **cubic**.
- Curie, Marie Skłodowska, 68, 997
- Curie, Pierre, 997
- Cycloalkanes** Cyclic saturated hydrocarbons, 1036, 1042
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substituted, names of, 1046
- Cycloalkenes, 1052
naming of, 1049, 1051
- Cyclohexane, 1107, 1107*i*
- Cyclone separator, 897, 898*i*
- Cyclotron** A device for accelerating charged particles along a spiral path, 1015–1016, 1016*i*
- Δ_{oct} The energy separation between e_g and t_{2g} sets of metal *d* orbitals caused by six ligands bonding in an octahedral geometry, 986–987
- d* orbitals** Beginning in the third shell, a set of five degenerate orbitals per shell, higher in energy than *s* and *p* orbitals in the same shell, 209*i*
- d*-Transition elements (metals)** The B group elements in the periodic table; sometimes called simply transition elements, 232, 929–933
- d*-Transition metal ions, 272
- d*-Transition metals** Metals that have partially filled sets of *d* orbitals; the B groups of the periodic table, 232, 929–933
- Dacron, 1089
- Dalton, John, 48, 448
- Dalton's Atomic Theory, 48, 175
- Dalton's Law of Partial Pressures** The total pressure exerted by a mixture of gases is the sum of the partial pressures of the individual gases, 448–453
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of Partial Pressures, 448*i*, 448–453, 551, 551*i*
Dash formulas, 277
- Dative bond** *See* **Coordinate covalent bond** (also known as *coordination bond*), 966–967
- Daughter nuclide** A nuclide that is produced in a nuclear decay, 1009
- Davisson, C., 201, 202
- Davy, Humphry, 176
- de Broglie, Louis, 201, 202
- de Broglie equation, 201–202
- de Broglie wavelength, 201
- Definite Proportions, Law of, 15, 48, 52, 67
- Debye** The unit used to express dipole moments, 293
- Decay(s), radioactive, 1002–1003
rates of, 1007–1009
- Decomposition reaction** Reaction in which a compound decomposes to form two or more products (elements, compounds, or some combination of these), 150–152
- Degenerate orbitals** Two or more orbitals that have the same energy, 241
- Dehydration** The reaction in which H— and —OH are eliminated from adjacent carbon atoms to form water and a more unsaturated bond, 1085
- Dehydrohalogenation** An elimination reaction in which a hydrogen halide, HX (X = Cl, Br, I), is eliminated from a haloalkane. A C=C double bond is formed, 1084
- Delocalization** The formation of a set of molecular orbitals that extend over more than two atoms; important in species that valence bond theory describes in terms of *resonance*, 361–364
- Delocalization of electrons** Refers to bonding electrons distributed among more than two atoms that are bonded together; occurs in species that exhibit resonance, 361–364
- Democritus, 48
- Density** Mass per unit volume, $D = m/V$, 31
and specific gravity, 31–34, 33
mass, and volume, 31, 32
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- Deoxyribonucleic acid (DNA), 1069, 1127*i*
base-pairing in, 1128, 1128*i*
bases in, 1127*i*, 1127–1128
definition of, 1126–1127
- 2-Deoxyribose** The carbohydrate found in DNA, 1127
- Deposition** The direct solidification of a vapor by cooling; the reverse of sublimation, 8*i*, 500
- Detergent** A soap-like emulsifier that contains a sulfonate, —SO₃[−], or sulfate, —OSO₃[−], group instead of a carboxylate, —COO[−], group, 573
- Deuterium, 1026
- Dextrorotatory** Describes an optically active substance that rotates the plane of plane-polarized light to the right; also called *dextro*, 983
- Diagonal similarities** Chemical similarities of elements of Period 2 to elements of Period 3 one group to the right; especially evident toward the left of the periodic table, 917
- Dialysate, 569
- Dialysis, 569
- Diamagnetism** *Weak* repulsion by a magnetic field; associated with all electrons in an atom, molecule, or substance being paired, 217
and paramagnetism, 217–218
- Diatomic molecules, 292
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homonuclear, 355–358
heavier, 358
- Diethyl ether, 490*t*, 491, 491*i*
- Diffraction, X-ray, 504–505, 505*i*
- Diffusion** The movement of a substance (e.g., a gas) into a space or the mixing of one substance (e.g., a gas) with another, 462
- Digital camera, 195
- Dilution** The process of reducing the concentration of a solute in solution, usually simply by adding more solvent, 107–109, 109*i*
- Dimensional analysis. *See* **Unit factor method**.
- Dimethyl ether, 91
- Dinitrogen oxide, 954

- Dinitrogen pentoxide, 642
 Dinitrogen tetroxide, 955
 Diodes, 521
Dipeptide A compound in which two amino acid monomers have joined to form the peptide, **1123**
Dipole Refers to the separation of charge between two covalently bonded atoms, **292**
Dipole–dipole interactions Interactions between polar molecules, that is, between molecules with permanent dipoles, **292–293**, **482–483**, **483*i***, **486**
Dipole moment (μ) The product of the distance separating opposite charges of equal magnitude and the magnitude of the charge; a measure of the polarity of a bond or molecule. A measured dipole moment refers to the dipole moment of an entire molecule, **294**, **306**
Dipole-induced dipole interaction See *Dispersion forces*.
 Dirac, Paul A.M., 204
Disaccharide A molecule consisting of two monosaccharides joined together by a glycosidic bond, **1119**, **1120*i***
 Disintegration series, 1009
 Dispersed particles, size of, **567*t***
Dispersed phase The solute-like species in a colloid, **567**
Dispersing medium The solvent-like phase in a colloid, **567**
Dispersion forces Very weak and very short-range attractive forces between short-lived temporary (induced) dipoles; also called London forces, **465**, **485*i***, **485–486**
 Dispersions, colloidal, **567–569**. See also **Colloid**.
Displacement reaction A reaction in which one element displaces another from a compound, **152–157**
 double. See **Metathesis reaction(s)**.
 troublesome, **154**
Disproportionation reaction A redox reaction in which the oxidizing agent and the reducing agent are the same element, **147**
Dissociation constant, K_d The equilibrium constant that applies to the dissociation of a complex ion into a simple ion and coordinating species (ligands), **836**, **A18**
Dissociation In aqueous solution, the process in which a solid *ionic compound* separates into its ions, **129**
 Dissolution, and saturation, rates of, **542–543**
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 of liquids in liquids, **540*i***, **540–541**, **541*i***
 of solids in liquids, **537–540**
 process of, **535–548**
 spontaneity of, **535–537**
Distillation The separation of a liquid mixture into its components on the basis of differences in boiling points, **492–493**
 boiling points and, **492–493**
 fractional, **553–554**
 laboratory setup for, **492*i***
DNA Deoxyribonucleic acid; a nucleic acid consisting of phosphate, 2-deoxyribose, and the four bases adenine, cytosine, guanine, and thymine
 Donor, semiconductor and, **520**
Donor atom A ligand atom whose electrons are shared with a Lewis acid
 Doping, of semiconductors, **520–521**
Double bond A covalent bond resulting from the sharing of four electrons (two pairs) between two atoms
Downs cell An electrolytic cell for the commercial electrolysis of molten sodium chloride, **845*i***, **845–846**
 Driving force, **157**
Dry cells Ordinary batteries (voltaic cells) for flashlights, radios, and so on; many are Leclanché cells, **880*i***, **880–883**
Dynamic equilibrium A situation in which two (or more) processes occur at the same rate so that no net change occurs, **490**

 e_g orbitals A set of $d_{x^2-y^2}$ and d_{z^2} orbitals; those d orbitals within a set with lobes directed along the x , y , and z axes, **985**
 Earth metals, alkaline, **126**
 Earth's crust, elements in, **15**, **16*t***
Effective collision A collision between molecules that results in reaction; one in which molecules collide with proper orientations and with sufficient energy to react, **668–669**, **669*i***
Effective molality The sum of the molalities of all solute particles in solution, **560**
Effective nuclear charge (Z_{eff}) The nuclear charge experienced by the outermost electrons of an atom; the actual nuclear charge minus the effects of shielding due to inner shell electrons, **236**
Effusion The escape of a gas through a tiny hole or a thin porous wall, **462**
 Einstein, Albert, **194**, **201**
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 Theory of Relativity of, **1**
 Electric field, polar molecules in, **294*i***
 Electric field strength, **184**
 Electrical conduction, **844**
 Electrochemical cell(s), to determine concentrations, **875–877**
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Electrochemistry The study of the chemical changes produced by electric current and the production of electricity by chemical reactions, **146–147**, **841–893**, **843**
 scope of, **843**
Electrode potentials Potentials, E , of half-reactions as reductions versus the standard hydrogen electrode, **861–867**
 effect of concentration on, **871–879**
 standard, **858–870**
 for half-reactions, **865–867**
 uses of, **862–864**
Electrodes Surfaces on which oxidation and reduction half-reactions occur in electrochemical cells, **843**, **844**
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 polarization of, **881**

Electrolysis The process that occurs in electrolytic cells, **13**, **850–851**
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 of aqueous sodium sulfate, **848**, **848*i***
 of molten sodium chloride, **845*i***, **846–848**
 of water, **848**
Electrolyte A substance whose aqueous solutions conduct electricity, **129**, **745–746**
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 strong, **129**, **745–746**
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Electrolytic cell An electrochemical cell in which electrical energy causes nonspontaneous redox reactions to occur, **843**, **845–852**, **864**
 commercial applications of, **851–852**
 for copper refining, **908*i***, **908–909**
 Electrolytic conduction, **844**, **844*i***. See also **Ionic conduction**.
Electromagnetic radiation Energy that is propagated by means of electric and magnetic fields that oscillate in directions perpendicular to the direction of travel of the energy, **190–193**
Electron A subatomic particle having a mass of 0.00054858 amu and a charge of $1-$, **49**, **54**, **175**
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 unpaired, **221**
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Electron affinity The amount of energy absorbed in the process in which an electron is added to a neutral isolated gaseous atom to form a gaseous ion with a $1-$ charge; has a negative value if energy is released, **241–244**
 trends in, **243–244**
 values of elements, **243**
 versus atomic number, **242*i***
Electron capture Absorption of an electron from the first energy level (K shell) by a proton as it is converted to a neutron; also K capture, **1004–1005**
 Electron cloud, **522–523**, **523*i***
 around atomic nucleus, **207*i***

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- Electron configuration** The specific distribution of electrons in the atomic orbitals of atoms and ions, 205, 211–217, 220–221, A5–A7 and quantum numbers, 216–217 for elements, Appendix B ground state, 211 periodic table and, 218–221, 219*i*, 220*i*, A5 prediction of, 212, 213*i*
- Electron-deficient compound** A compound containing at least one atom (other than H) that has fewer than eight valence shell electrons, **288**
- Electron density distributions, 207*i*
- Electron density, 292
- Electron microscope, 202
- Electron pairing energy, 986
- Electron pressure, 860
- Electron transition** The transfer of an electron from one energy level to another, **197–198**, 988
- Electronegative element, least, 279
- Electronegativity** A measure of the relative tendency of an atom to attract electrons to itself when chemically combined with another atom, **246–247** trends in, 247
- Electronegativity difference, 269
- Electronegativity values, of elements, 244
- Electronic energies, 203
- Electronic geometry** The geometric arrangement of orbitals containing the shared and unshared electron pairs surrounding the central atom of a molecule or polyatomic ion, 304, **306** of central atoms, 306, 307*t* of molecule, hybridization and, 310, 310*t*
- Electronic top-loading balance, 18*i*
- Electroplating** Plating a metal onto a (cathodic) surface by electrolysis, 851*i*, **851–852**
- Element** A substance that cannot be decomposed into simpler substances by chemical means, **14** activity series, 152, 153*t* artificial transmutations of, 1015–1018 atomic number of, 125–126 classification of, 232–235 electron affinity of. *See* **Electron affinity**. electronegative, 279 electronegativity values of, 244 electronic structure of, 215 exhibiting ferromagnetism, 218 Group VA, properties of, 951*t* Group VIA, hydrides of, 484, 484*i*, 948 properties of, 945*t*, 945–946 reactions of, 947*t* Group VIIA, 232 in Earth's crust, 15, 16*t* Lewis dot formulas for, 268*t* mole of atoms of, 59, 60*i* names of, 15, 68–69 natural sources of, 897*i* outermost electrons of, 233 periodic properties of, 235–247 properties of, 231, 232 representative, 232, 241, 277 second-period, of heteronuclear diatomic molecules, 358–359, 359*t* symbols representing, 15, 16*t* *d*-transition, 232 *f*-transition, 232
- Elementary step** An individual step in the mechanism by which a reaction occurs. For each elementary step, the reaction orders *do* match the reactant coefficients in that step. *See* **Fundamental step**. **673–675**.
- Elimination reaction** A reaction in which the number of groups attached to carbon *decreases*. The degree of unsaturation in the molecule increases, **1084–1085**
- Emission, atomic, 194, 195*i*
- Emission spectrum** The spectrum associated with emission of electromagnetic radiation by atoms (or other species) resulting from electron transitions from higher to lower energy states, **190–193**
- Empirical formula, 70–72, 75. *See also* **Simplest formula**.
- Emulsifiers, 571. *See also* **Emulsifying agent**.
- Emulsifying agent** A substance that coats the particles of a dispersed phase and prevents coagulation of colloidal particles; an emulsifier, 571
- Emulsion** A colloidal dispersion of a liquid in a liquid, 572
- Enantiomers** Stereoisomers that differ only by being nonsuperimposable mirror images of each other, like left and right hands; also called optical isomers, **1104**. *See also* **Optical isomers**.
- End point** The point at which an indicator changes color and a titration is stopped, **402, 804**
- Endothermic** Describes processes that absorb heat energy, **5**
- Endothermic process** A process that absorbs heat, **5, 37, 536–537**
- Endothermic reaction(s), 585, 586*i*
- Energy** The capacity to do work or transfer heat, **4, 584, 620, 670**. *See also* *specific types of energy*. activation, 657*i*, 675, 678–679, 679*i* definition of, 670 and work, SI units of, 37 binding, nuclear stability and, 999–1002 bond. *See* **Bond energy(ies)**. changes in, with physical changes for water, 10*i* chemical, **5** crystal field splitting, 986 electron pairing, 986 forms of, 584–585 free. *See* **Free energy**. heat, **5** in atoms and molecules, 203 internal, and enthalpy change, relationship between, 610–612 changes in, 604–610, 606*i* definition of, 604 ionization. *See* **Ionization energy(ies)**. kinetic. *See* **Kinetic energy**. Law of Conservation of, **5, 586** of attraction, 481 of light, 193, 196 potential, versus progress of reaction, 670, 670*i* quantum, 193 release or absorption of, **9** versus distance, 275, 276*i*
- Energy conversion, unit factors and, 29, A10
- English-metric conversion, unit factor method of, 30
- Enkephalins, 1123
- Enthalpy, as state function, 596–597 definition of, 610, 616 of fusion, 497–498 of solidification, 498 of vaporization, 493
- Enthalpy change, ΔH** The quantity of heat transferred into or out of a system as it undergoes a chemical or physical change at constant temperature and pressure, **588** and internal energy, relationship between, 610–612 estimation of, 603, 603*i* standard, 594
- Entropy, S** A thermodynamic state property that measures the degree of disorder or randomness of a system, **613–620**, 614*i*, 616*i* absolute, 616, 616*t* changes in, and heat flow, 615, 615*i* definition of, 616 melting and freezing and, 616*t* of universe, 614
- Entropy change, processes resulting in, 618–620, 619*t* standard, 617 calculation of, 617
- Enzyme(s)** A protein that acts as a catalyst in a biological system, 565, **688**, 1124 as biological catalysts, 688–689, 689*i* denatured, 1125
- Equation(s), Arrhenius, 676–679 balanced, 411 equilibrium constant and, 707–708 Balmer–Rydberg, 197, 198 Bohr theory and, 198–200 Bragg, 505 chemical. *See* **Chemical equation(s)**. Clausius–Clapeyron, 495 de Broglie, 201–202 for nuclear reactions, 1004 formula unit, 135 Henderson–Hasselbalch, 791, 794, 797–798, 799, 801 ideal gas, 442–445, 459–461 integrated rate, 656, 662–665 ionic, writing of, 137 Nernst, 871–875 net ionic, 136–137 quadratic, 712 simplifying of, 758–759 Schrödinger, 204 thermochemical. *See* **Thermochemical equation(s)**. total ionic, 135–136 van der Waals, 465, 466 van't Hoff, 734
- Equation of state** An equation that describes the

- behavior of matter in a given state; for example, the van der Waals equation describes the behavior of the gaseous state, **465**
- Equilibrium** A state of dynamic balance in which the rates of forward and reverse processes (reactions) are equal; the state of a system when neither the forward nor the reverse process is thermodynamically favored, **699–743**
 basic concepts of, **700–703**
 disturbing of, **713–719**
 calculations of, **721–725**
 dynamic, definition of, **701, 701i**
 free energy and, **732, 732i**
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 ionic, **744–785**
 problems, solving of, **725**
 simultaneous, **831–833**
 slightly soluble compounds and, **831–833**
 system at, **615, 621, 623**
 Equilibrium concentrations, calculation of, **709–712**
- Equilibrium constant, *K*** A quantity that indicates the extent to which a reversible reaction occurs. *K* varies with temperature, **703–706**
 and standard free energy change, **730–734**
 calculation of, **705–706**
 partial pressure, **725–728**
 temperature and, **734–735**
 thermodynamic, **731**
 uses of, **709–713**
 variation of form of, **707–708**
- Equilibrium mixture, **621**
- Equivalence point** The point at which chemically equivalent amounts of reactants have reacted, **402, 804**
- Equivalent. *See* **Equivalent weight(s)**.
- Equivalent weight in acid–base reactions** The mass of an acid or base that furnishes or reacts with 6.022×10^{23} H_3O^+ or OH^- ions, **407**
- Equivalent weight(s), and normality, **407–411**
 of acid, **407, 408t**
 of base, **407, 408t**
- Error, systematic, definition of, **23**
- Ester** A compound of the general formula
- $$\begin{array}{c} \text{O} \\ \parallel \\ \text{R}-\text{C}-\text{O}-\text{R}', \text{ where R and R' may be the} \\ \text{same or different and may be either aliphatic} \\ \text{or aromatic. R may be H. R' cannot be H,} \\ \text{1073–1075, 1074t} \end{array}$$
- hydrolysis of, **1116–1117**
 inorganic, **1082**
 names of, **1074**
- Estimate, best, **22**
- Ethane, **282, 1083, 1106, 1106i**
 structure of, **1037, 1038i**
- Ethanol, **1061, 1061, 1083**
- Ethene, **282, 336**
- Ether** A compound in which an oxygen atom is bonded to two alkyl or two aryl groups, or one alkyl and one aryl group, **1064–1065**
- Ethyl acetate, **1073, 1073i**
- Ethylene glycol, **558**
- Ethylene, **282, 336, 1047, 1083**
- Ethylenediamine, **980, 980i**
- Ethyne, **282, 338, 339i**
- Eutrophication** The undesirable overgrowth of vegetation caused by high concentrations of plant nutrients in bodies of water, **574**
- Evaporation** Vaporization of a liquid below its boiling point, **489i, 489–490**
- Excess reactant, **97**
- Excited state** Any energy state other than the ground state of an atom, ion, or molecule, **195**
- Exothermic** Describes processes that release heat energy, **5**
- Exothermic process** A process that gives off (releases) heat, **5, 37**
- Exothermic reaction(s), **585, 585i, 639**
 definition of, **585**
- Expanded valence shell** Describes an atom that contains more than eight valent shell electrons, **287, 290–291**
- Exponential decay curve, **1008**
- Exponentials, in scientific notation**, **A1–A2**
- Extensive property** A property that depends on the amount of material in a sample, **7**
- f* orbitals Beginning in the fourth shell, a set of seven degenerate orbitals per shell, higher in energy than *s*, *p*, and *d* orbitals in the same shell, **210i, 235**
- f*-Transition elements (metals) Elements 58 through 71 and 90 through 103; also called inner transition elements (metals), **235**
- Factor-label method. *See* **Unit factor method**.
- Fahrenheit, Gabriel, **35**
- Fahrenheit temperature scale, **35, 35i**
 Kelvin temperature scale, and Celsius temperature scale, relationships among, **35i, 35–36**
- Fallout, **1020**
- Faraday, Michael, **176, 849, 1054**
- Faraday** An amount of charge equal to 96,485 coulombs; corresponds to the charge on one mole of electrons, 6.022×10^{23} electrons, **849**
- Faraday's Law of Electrolysis** The amount of substance that undergoes oxidation or reduction at each electrode during electrolysis is directly proportional to the amount of electricity that passes through the cell, **849**
- Fast neutron** A neutron ejected at high kinetic energy in a nuclear reaction, **1018**
- Fat** A solid triester of glycerol and (mostly) saturated fatty acids, **1074–1075, 1077**
- Fatty acid** A long-chain aliphatic acid; many can be obtained from animal fats, **1074, 1075, 1076i**
- Fermentation, definition of, **1064**
- Ferromagnetism** The property that allows a substance to become permanently magnetized when placed in a magnetic field; exhibited by iron, cobalt, and nickel and some of their alloys, **217, 218**
- Ferrosilicon, **960**
- First Law of Thermodynamics** The total amount of energy in the universe is constant (also known as the Law of Conservation of Energy); energy is neither created nor destroyed in ordinary chemical reactions and physical changes, **586**
- Flotation** A method by which hydrophobic (water-repelling) particles of an ore are separated from hydrophilic (waterattracting) particles in a metallurgical pretreatment process
 of ores, **898, 898i**
- Fluids** Substances that flow freely; gases and liquids, **427**
 supercritical, **502**
- Fluorescence** Absorption of high-energy radiation by a substance and the subsequent emission of visible light
 detection of, **1006**
- Fluorescent substances, **1006**
- Fluorine molecule, molecular orbitals, **357t, 358**
- Fluorine, occurrence and uses of, **940**
- Fluorocarbons, **1059**
- Flux** A substance added to react with the charge, or a product of its reduction, in metallurgy; usually added to lower a melting point, **906**
- Foam** A colloidal dispersion of a gas in a liquid, **567t, 574**
- Food additives, nitrites and nitrates as, **958**
- Formal charge** The hypothetical charge on an atom in a covalently bonded molecule or ion; bonding electrons are counted as though they were shared equally between the two bonded atoms, **285, 292**
- Formaldehyde, **283, 1065, 1066, 1066i, 1113**
- Formula** Combination of element symbols that indicates the chemical composition of a substance
 from elemental composition, **70–74**
- Formula unit** The smallest repeating unit of a substance—for non-ionic substances, the molecule, **271**
 of sodium chloride, **54, 64**
- Formula unit equation** An equation for a chemical reaction in which all formulas are written as complete formulas, **135, 413, 414**
- Formula weight** The mass, in atomic mass units, of one formula unit of a substance. Numerically equal to the mass, in grams, of one mole of the substance (see *Molar mass*). This number is obtained by adding the atomic weights of the atoms specified in the formula, **63**
 molecular weights, and moles, **63–66**
- Fossil fuels, combustion of, **256, 256i**
 and air pollution, **258–260**
- Fractional distillation** The process in which a fractionating column is used in a distillation apparatus to separate components of a liquid mixture that have different boiling points, **553–554**
 apparatus for, **554, 554i**
- Fractional precipitation** Removal of some ions from solution by precipitation while leaving other ions, with similar properties, in solution, **828–831**
- Fractions, in decimal form, **72**
- Frasch process** A method by which elemental sulfur is mined or extracted. Sulfur is melted with superheated water (at 170°C under high

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- pressure) and forced to the surface of the earth as a slurry, **946**, **946i**
- Free energy, equilibrium and, **732**, **732i**
- Gibbs, **620**
- standard molar, **621**
- calculation of, **622**
- Freezing point, definition of, **497**
- Freezing point depression constant, K_f** A constant that corresponds to the change in freezing point produced by a one-molal *ideal* solution of a nonvolatile nonelectrolyte, **557**
- Freezing point depression** The decrease in the freezing point of a solvent caused by the presence of a solute, **556–558**
- Freons, **1059–1061**
- Frequency (ν)** The number of crests of a wave that pass a given point per unit time, **190** of water waves, **190–191**, **191i**
- “Frequency doubling,” **232**
- Fuel cell** A voltaic cell in which the reactants (usually gases) are supplied continuously and products are removed continuously, **884**
- hydrogen-oxygen, **884**, **885i**
- Functional group** A group of atoms that represents a potential reaction site in an organic compound, **1058–1079**, **1078i**
- Fundamental particles** Subatomic particles of which all matter is composed; protons, electrons, and neutrons are fundamental particles, **48–49**, **49t**, **175t**, **175–176**
- Fundamental step** See **Elementary step**.
- Fusion bomb(s), **1026**
- Fusion, molar heat of, **497–498**
- Gallium, **927**
- Galvani, Luigi, **852**
- Galvanic cell** See **Voltaic cell**.
- Galvanizing, for corrosion protection, **869**, **870i**
- Gamma ray (γ)** High-energy electromagnetic radiation, **1002**
- Gangue** Sand, rock, and other impurities surrounding the mineral of interest in an ore, **896**
- Gas(es), amounts in mixtures, **449–450** and kinetic molecular theory, **425–476**
- characteristics of, **479t**
- collected over water, **453**
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- dissolution in liquids, **541–542**
- effusion of, **462**, **463i**
- electronegativity differences and dipole moments and, **293t**
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- partial pressure of, **448**, **450–451**
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- nonideal behavior of, **463–465**, **464i**, **465i**
- speeds of molecules of, temperature and, **457**
- volume in chemical reaction, **454–455**
- Gas ionization counter(s), **1006**, **1007i**
- Gas laws, summary of, **442**, **445**
- Gasoline, octane number of, **1048**
- Gay-Lussac, Joseph, **370**, **436**
- Gay-Lussac's Law of Combining Volumes** At constant temperature and pressure, the volumes of reacting gases (and any gaseous products) can be expressed as ratios of small whole numbers, **455**
- Geiger counter, **1006**
- Geiger, Hans, **180**
- Geiger-Müller counter** A type of gas ionization counter used to detect radiation, **1006**, **1007i**
- Gel** A colloidal dispersion of a solid in a liquid; a semirigid sol, **571**
- Geometric isomerism** Occurs when atoms or groups of atoms can be arranged in different ways on two sides of a rigid structure; also called *cis-trans* isomerism. In geometric isomers of coordination compounds, the same ligands are arranged in different orders within the coordination sphere, **1047**, **1047i**
- Geometric isomers** Compounds with different arrangements of groups on the opposite sides of a bond with restricted rotation, such as a double bond; for example, *cis-trans* isomers of certain alkenes, **1103i**, **1103–1104**. See also **Isomer(s), geometric**.
- Geometrical arrangements, **52**
- Geometry, molecular. See **Molecular geometry**.
- Germanium, properties of, **125**, **125t**
- Germer, L.H., **201**, **202**
- Gibbs, J. Willard, **620**
- Gibbs free energy, G** The thermodynamic state function of a system that indicates the amount of energy available for the system to do useful work at constant T and P . It is defined as $G = H - TS$., **620**
- Gibbs free energy change, ΔG** The indicator of spontaneity of a process at constant T and P . $\Delta G = \Delta H - T\Delta S$. If ΔG is negative, the process is product-favored (spontaneous), **620**
- calculation from cell potentials, **878–879**
- spontaneity and, **620–623**
- standard cell potential, and thermodynamic equilibrium constant, related, **878–879**
- Glass, **960–961**
- Glucose, **1118i**
- composition of, calculation of, **74**
- elemental composition of, **74**
- molecular formula of, **75**
- Glutathione, **1123**
- Glyceride** A triester of glycerol, **1075**
- simple, **1075**
- Glycine, **1073**
- Glycogen, **1121**, **1121i**
- Glycols, **1063**
- Glycosidic bond** A bond linking monomers in a polysaccharide, **1119**, **1120i**
- Gold, metallurgy of, **909**
- Goldstein, Eugen, **178**
- Graham, Thomas, **427**
- Graham's Law, **1111**
- Greenhouse effect, **430–431**
- Ground state** The lowest energy state or most stable state of an atom, molecule, or ion
- electron configuration, **211**
- Group (family)** The elements in a vertical column of the periodic table, **126**
- Haber, Fritz, **720**
- Haber process** An industrial process for the catalyzed production of ammonia from N_2 and H_2 at high temperature and pressure, **688**, **689**, **720i**, **720–721**
- Half-cell** The compartment in a voltaic cell in which the oxidation or reduction half-reaction occurs, **852**, **853i**
- Half-life
- of first-order reactions, **656–658**, **659i**
- of second-order reactions, **658–661**, **659i**
- Half-life of a radionuclide** The time required for half of a given sample to undergo radioactive decay, **1007–1009**, **1010t**
- Half-life of a reactant** The time required for half of that reactant to be converted into product(s), **656–657**, **659i**, **661t**
- Half-reaction** Either the oxidation part or the reduction part of a redox reaction, **411**
- Half-reaction method, **411–412**
- Half-wavelengths, **203**
- Halides, **938**
- acyl, **1073**, **1115**
- hydrogen, and hydrohalic acids, **942–944**
- preparation of, **943**
- organic, **1059–1061**, **1060t**
- Hall-Héroult process** A process in which a molten mixture of Al_2O_3 , NaF , and AlF_3 is electrolyzed to obtain pure aluminum, **904**, **904i**, **905**
- Halogenation reactions, **1080–1081**
- Halogens** Group VIIA elements; F, Cl, Br, I, and At, **126–127**, **293**, **938**
- free reactions of, **942**
- occurrence, production, and uses of, **940–942**
- oxoacids of, **944t**, **944–945**
- properties of, **939**, **939t**
- Hard water** Water containing Fe^{3+} , Ca^{2+} , or Mg^{2+} ions, which form precipitates with soaps, **573**
- Harmonic generation, **232**
- Hatchett, C., **68**
- Heat** A form of energy that flows between two samples of matter because of their difference in temperature, **34**
- absorption at constant volume, **607**, **607i**
- and temperature, **34–36**
- changes in, thermochemistry and, **584–612**
- flow of, changes in entropy and, **615**, **615i**

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 of solidification, 498
 of vaporization, 494, 494*t*, 495
 specific, 493
 transfer of, and measurement of heat, 37–40
 in liquids, 493–497
 in solids, 497–500, 498*i*
 work and, 605, 605*i*

Heat capacity The amount of heat required to raise the temperature of a body (of whatever mass) one degree Celsius, 37

Heat change. *See* **Enthalpy change(s)**.

Heat energy, 5

Heat of condensation The amount of heat that must be removed from a specific amount of a vapor at its condensation point to condense the vapor with no change in temperature; usually expressed in J/g or kJ/mol; in the latter case it is called the *molar heat of condensation*, 494

Heat of formation. *See* **Molar enthalpy of formation, standard**, 595, A22–A23

Heat of fusion The amount of heat required to melt a specific amount of a solid at its melting point with no change in temperature; usually expressed in J/g or kJ/mol; in the latter case it is called the *molar heat of fusion*, 497–499

Heat of reaction. *See* **Enthalpy change(s)**.

Heat of solidification The amount of heat that must be removed from a specific amount of a liquid at its freezing point to freeze it with no change in temperature; usually expressed in J/g or kJ/mol; in the latter case it is called the *molar heat of solidification*, 498

Heat of solution (molar) The amount of heat absorbed in the formation of a solution that contains one mole of solute; the value is positive if heat is absorbed (endothermic) and negative if heat is released (exothermic), 536

Heat of vaporization The amount of heat required to vaporize a specific amount of a liquid at its boiling point with no change in temperature; usually expressed in J/g or kJ/mol; in the latter case it is called the *molar heat of vaporization*, 493–496, A12, 493*t*

Heat summation, law of, 596

Heavy water Water containing deuterium, a heavy isotope of hydrogen, ${}^2\text{H}$, 1022

Heisenberg Uncertainty Principle It is impossible to determine accurately both the momentum and position of an electron simultaneously, 203

Helium, 185, 212, 937

Helium molecule, energy level diagram for, 354*i*, 355*i*, 356, 357*t*

Hemodialysis, 569

Hemoglobin, 968
 molecule of, 968*i*

Henderson–Hasselbalch equation An equation that enables us to calculate the pH or pOH of a buffer solution directly

$$\text{For acid-salt buffer pH} = \text{p}K_a + \log \frac{[\text{conjbase}]}{[\text{acid}]}$$

$$\text{For base-salt buffer pOH} = \text{p}K_b + \log \frac{[\text{conjbase}]}{[\text{acid}]},$$

791, 794, 797–798, 799, 801

Henry's Law The pressure of the gas above a solution is proportional to the concentration of the gas in the solution, 546, 546*i*

Hertz, Heinrich, 190

Hess, G.H., 596

Hess's Law of heat summation The enthalpy change for a reaction is the same whether it occurs in one step or a series of steps, 596–601, 600*i*, 617

Heteroatoms, definition of, 1058

Heterocyclic amine An amine in which nitrogen is part of a ring, 1069

Heterogeneous catalyst A catalyst that exists in a different phase (solid, liquid, or gas) from the reactants; a contact catalyst, 682–684

Heterogeneous equilibria Equilibria involving species in more than one phase, 729

Heterogeneous mixture A mixture that does not have uniform composition and properties throughout, 10*i*, 12*i*, 13

Heteronuclear Consisting of different elements, 292

Hexane, 1115

High spin complex The crystal field designation for a complex in which all t_{2g} and e_g orbitals are singly occupied before any pairing occurs, 986–987

octahedral configurations, 987*t*

Homogeneous catalyst A catalyst that exists in the same phase (liquid or gas) as the reactants, 681

Homogeneous equilibria Equilibria involving only species in a single phase, that is, all gases, all liquids, or all solids, 729

Homogeneous mixture A mixture that has uniform composition and properties throughout, 10, 12*i*

Homologous series A series of compounds in which each member differs from the next by a specific number and kind of atoms, 1039

Homonuclear Consisting of only one element, 292

Hund's Rule Each orbital of a given subshell is occupied by a single electron before pairing begins, 214, 311, 354. *See* **Aufbau Principle**.

Hybrid orbitals Orbitals formed on an atom by the process of hybridization, 309

need for description of, 324

number and kind of, 312

Hybridization The mixing of a set of atomic orbitals on an atom to form a new set of hybrid orbitals with the same total electron capacity and with properties and energies intermediate

between those of the original unhybridized orbitals, 309

electronic geometry of molecule and, 310, 310*t*

Hydrate A crystalline sample that contains water, H_2O , and another compound in a fixed mole ratio. Examples include $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ and $(\text{COOH})_2 \cdot 2\text{H}_2\text{O}$, 79, 269*i*, 544*i*, 968*i*

Hydrate isomers Isomers of crystalline complexes that differ in terms of the presence of water inside or outside the coordination sphere, 975–977

Hydration The interaction (surrounding) of solute particles with water molecules, 537

heat of, 537

in dissolution process, 539

Hydration energy (molar) of an ion The energy change accompanying the hydration of a mole of gaseous ions, 537, 539, 539*t*

Hydration reaction A reaction in which the elements of water, H and OH, add across a double or triple bond, 1083

Hydride A binary compound of hydrogen, 248–250, 249*i*

boiling points of, 484, 484*i*

definition of, 248

ionic, 248, 249

molecular, 248, 249, 250

Hydrofluoric acid, 761

production of, 943, 943*i*

Hydrocarbon A compound that contains only carbon and hydrogen, 282, 1037–1042

acetylenic, 1052–1054

aliphatic, 1036

aromatic, 1036, 1054–1058

classification of, 1036*i*, 1059*i*

combustion of, 257–258, 1115

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- Hydrogen atom(s), 182
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Hydrogen bomb(s), 1026
Hydrogen bond A fairly strong dipole–dipole interaction (but still considerably weaker than covalent or ionic bonds) between molecules containing hydrogen directly bonded to a small, highly electronegative atom, such as N, O, or F, **483**–484, 484*i*
acceptor, 483
donor, 483
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Hydrogen chloride, 51–52
Hydrogen electrode, standard, 858, 858*i*
Hydrogen fluoride molecule, energy level diagram for, 360, 360*i*
Hydrogen halides, 541–542
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Hydrogen ion concentration, and hydroxyl concentration, calculations using, 752
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Hydrogen ion, hydrated, 370–371
range for common substances, 748–753
Hydrogen ion concentration meter, 752, 752*i*
Hydrogen molecule, 355
molecular orbital diagram for, 353*i*, 355*i*, 357*t*
Hydrogen–oxygen fuel cell A fuel cell in which hydrogen is the fuel (reducing agent) and oxygen is the oxidizing agent, **884**, 885*i*
Hydrogen sulfide, 325
Hydrogenation The reaction in which hydrogen adds across a double or triple bond, **1083**, 1083*i*
Hydrohalic acids, halides, hydrogen and, 942–944
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strengths of, 944
uses of, 943
Hydrolysis The reaction of a substance with water, **681**, 768
calculations based on, 771–772, 772*t*
effects of, on solubility, 825
of esters, 1116–1117
percent, 777–778
Hydrolysis constant An equilibrium constant for a hydrolysis reaction, **770**, 778*t*
for anion of weak acid, 770–771
Hydronium ion H_3O^+ , the usual representation of the hydrated hydrogen ion, **370**–371, 377
Hydrophilic colloids Colloidal particles that attract water molecules, **571**
Hydrophobic colloids Colloidal particles that repel water molecules, **571**
Hydroxides, 378
amphoteric, 376*t*
Hydroxyl concentration, and hydrogen ion concentration, calculations using, 752
scales of, 748–753
Hypervalent *See* **Expanded valence shell**.
Hypohalites, 944–945
Ideal Gas Equation The product of the pressure and volume of an ideal gas is directly proportional to the number of moles of the gas and the absolute temperature, **442**–445, 459–461
Ideal Gas Law, 442–445, 459–461
Ideal gas A hypothetical gas that obeys exactly all postulates of the kinetic–molecular theory, **442**
Ideal mixture, activity of component of, 704
Ideal solution A solution that obeys Raoult's Law exactly, **550**
Inches, and centimeters, relationship between, 19*i*
Indicator For acid–base titrations, an organic compound that exhibits its different colors in solutions of different acidities; used to determine the point at which the reaction between two solutes is complete, **802**, 802*i*, 804*t*
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definition of, 402
range and color changes of, 804*t*
definition of, 802
universal, 803, 803*i*
Indium, 927
Inert s-pair effect The tendency of the two outermost *s* electrons to remain nonionized or unshared in compounds; characteristic of the post-transition metals, **929**
Inner transition elements *See* **f-Transition elements**.
Inorganic acids, bases, and salts, production of, 158*t*
Inorganic chemistry, definition of, 3
Inorganic compounds, 52
naming of, 140
Inorganic esters, 1082
Insects, chemical communication by, 1111
Insulator A poor conductor of electricity and heat, **522**
Integrated rate equation An equation that relates the concentration of a reactant remaining to the time elapsed; has different mathematical forms for different orders of reaction, **656**
calculus derivation of, 662–664
to determine reaction order, 664–665
Intensive property A property that is independent of the amount of material in a sample, **7**
Intermolecular attractions, and phase changes, 481–486
Intermolecular forces Forces *between* individual particles (atoms, molecules, ions) of a substance, 275, **481**–486
Internal energy, *E* All forms of energy associated with a specific amount of a substance. *See also* **Energy, internal**. **604**–609
International System of Units (SI), 17, A8–A10
International Union of Pure and Applied Chemistry (IUPAC), 15, 69
naming of inorganic compounds, 140, 141
Intramolecular forces Forces between atoms (or ions) *within* molecules (or formula units), **275**
Iodine, occurrence and uses of, 941
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Iodine chloride, and hydrogen, rate of reaction of, 643–645, 644*i*, 644*t*, 645*i*
Iodine deficiency, 919–921
Ion An atom or group of atoms that carries an electric charge, **53**, 268
and ionic compounds, 53–55
association in solution, 560
common, concentration of, 827–828
complex, 967
formation of, 835–836
concentrations of, calculation of, 746, 747–748
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spectator, 136
stabilities and bond orders of, prediction of, 357–358
Ion effect, common, definition of, 788
in solubility calculations, 823–825
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Ion product for water An equilibrium constant for the ionization of water, $K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14}$ at 25°C, **746**
temperature and, 747*t*
Ionic bonding The attraction of oppositely charged ions (cations and anions) in large numbers to form a solid. Ions result from the transfer of one or more electrons from one atom or group of atoms to another, **266**, **268**–275
energy relationships in, 273–275, 274*i*
Ionic compound A compound that is composed of cations and anions containing predominantly ionic bonding. An example is sodium chloride, NaCl, **267**, 269
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formation of, 268–275
in water, solubility guidelines for, 135
melting points of, 482
mole of, 65
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pseudobinary, 141
Ionic conduction Conduction of electric current by ions through a pure liquid or a solution, **844**, 844*i*
Ionic equation(s), balanced, 416
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total, 135–136, 413, 414
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Ionic equilibrium(a), 744–785, 786–815, 816–840
Ionic hydrides, 248, 249
Ionic radius The radius of an ion, **236**, 237, 244–246
trends in, 245–246

- Ionic salts, solubility of, 134
- Ionic solids, 268, 514–517
crystal structure of, 514, 515*i*
- Ion–ion interactions, 481–482
- Ionization** In aqueous solution, the process in which a *molecular compound* separates to form ions, **129**
- Ionization constant** An equilibrium constant for the ionization of a weak electrolyte, **754**, 757
calculation of weak acid from, 755
for weak monoprotic acids and bases, 753–764, 754*t*, A14–A15
- Ionization energy** The amount of energy required to remove the most loosely held electron of an isolated gaseous atom or ion, **238–241**, 239*i*, 239*t*
trends in, 239
- Ionization isomers** Isomers that result from the interchange of ions inside and outside the coordination sphere, **976**
- Ionization potential, first, 238
- Iron, 557
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protection from oxidation, 869, 870*i*
- Iron deficiency, 919
- Iron(III) chloride, 147
- Iron(III) oxide, formation of, 253*i*
- Isobutane, 1038
- Isoelectronic** Having the same number of electrons, **244**
- Isoelectronic series, 244
of ions, 245
- Isoelectronic species, 271
- Isomer(s)** Different compounds that have the same molecular formula, **975**, 1101
classes of, 975
constitutional. *See* **Structural isomers**.
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ionization (ion–ion exchange), 976
linkage, 977–978
optical. *See* **Optical isomers**.
- Isomerism, geometric, 979–980, 980*i*, 1047, 1047*i*
in coordination compounds, 975–984
- Isomorphous** Refers to crystals having the same atomic arrangement, **508**
- Isomorphous substances, 507–508
- Isotopes** Two or more forms of atoms of the same element with different masses; that is, atoms containing the same number of protons but different numbers of neutrons, **182**, 185
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- Isotope effects, 186
- Janet, Charles, 233
- Joliot, Frederick, 997
- Joliot-Curie, Irene, 997
- Joule** A unit of energy in the SI system. One joule is $1 \text{ kg} \cdot \text{m}^2/\text{s}^2$, which is also 0.2390 cal, **37**
- K_p Equilibrium constant with amounts of reactants and products expressed as partial pressures, **725**
- K_c Equilibrium constant with amounts of reactants and products expressed as molar concentrations, **703**
- Kekulé, Friedrich, 1055
- Kelvin, Lord (William Thompson), 436
- Kelvin temperature scale, 35, 35*i*
Celsius temperature scale, and Fahrenheit temperature scale, relationships among, 35*i*, 35–36
- Kelvins, 36
- Ketone** A compound in which a carbonyl group is bound to two alkyl or two aryl groups, or to one alkyl and one aryl group, 1065, 1067, 1112–1113
- Ketose** A monosaccharide that contains a ketone group, 1118
- Kilogram, definition of, 18
- Kinetic energy** Energy that matter possesses by virtue of its motion, **4**, 456–457, 461, 584
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- Kinetic–molecular theory** A theory that attempts to explain macroscopic observations on gases in microscopic or molecular terms, 456–462
- Kinetics, chemical, 638–698
- Lactic acid, 561–562
- Lanthanides** Elements 58 through 71 (after *lanthanum*), **235**
- Lattice, 508
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- Lattice point, 507
- Lavoisier, Antoine, 68
- Law
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Raoult's, 549*i*, 549–550, 550*i*, 551*i*, 552*i*, 552–553, 555
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scientific (natural), definition of, **5**
- Law of Conservation of Energy** Energy cannot be created or destroyed in a chemical reaction or in a physical change; it may be changed from one form to another, **5**, 586
- Law of Conservation of Matter** No detectable change occurs in the total quantity of matter during a chemical reaction or during a physical change, **5**, 48, 90
- Law of Conservation of Matter and Energy** The combined amount of matter and energy available in the universe is fixed, **5–6**
- Law of Constant Composition** *See* **Law of Definite Proportions**.
- Law of Definite Proportions** Different samples of any pure compound contain the same elements in the same proportions by mass; also known as the *Law of Constant Composition*, **15**, 48, 52, 67
- Law of Multiple Proportions** When two elements, A and B, form more than one compound, the ratio of the masses of element B that combine with a given mass of element A in each of the compounds can be expressed by small whole numbers, **76**
- Lawrence, E.O., 1015
- Lead storage battery** A secondary voltaic cell that is used in most automobiles, 882*i*, **882–883**
- LeChatelier's Principle** A system at equilibrium, or striving to attain equilibrium, responds in such a way as to counteract any stress placed upon it, **490**, 544, **713–719**, 724, 748, 788, 823, 872
- Leclanché, Georges, 880*i*, 880–881
- Leclanché cell** A common type of dry cell (battery), **880**, 880*i*
- Length, 18
units of, A8–A10
- Leveling effect** The effect by which all acids stronger than the acid that is characteristic of the solvent react with the solvent to produce that acid; a similar statement applies to bases. The strongest acid (base) that can exist in a given solvent is the acid (base) characteristic of that solvent, **377**
- Levorotatory** Refers to an optically active substance that rotates the plane of plane-polarized light to the left; also called *levo*, **983**
- Lewis acid** A substance that accepts a share in an electron pair to form a coordinate covalent bond, **287**
- Lewis acid–base reaction, 384
- Lewis base** A substance that makes available a share in an electron pair to form a coordinate covalent bond. *See also* **Ligand**. **287**, **384**, 835
- Lewis formula** The representation of a molecule, ion, or formula unit by showing atomic symbols and only outer-shell electrons; does not represent the shape of the molecule or ion, **267**, 276, 277
- AB₃, AB₄U, AB₃U₂, and AB₂U₃ molecules and, 328–329
- AB₆, AB₅U, and AB₄U₂ molecules and, 331
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- Lewis structure(s), for nitric acid, 957
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- Lewis theory, 384–386
- Ligand** A Lewis base in a coordination compound, 287, **835**, 967, 971
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- Lightning strikes, 854
- Lime, slaked, 925
- Limestone, 161, 925
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- Limiting reactant** A substance that stoichiometrically limits the amount of product(s) that can be formed, **96**–99
 calculations, 399
 choosing of, 98
 concept of, 96–99
- Line spectrum** An atomic emission or absorption spectrum, **194**–196
- Linear** A term used to describe the electronic geometry around a central atom that has two regions of high electron density. Also used to describe the molecular geometry of a molecule or polyatomic ion that has one atom in the center bonded to two atoms on opposite sides (180°) of the central atom (AB₂ or AB₃U₃), **310**–312, 335*t*
- Linear accelerator** A device used for accelerating charged particles along a straight-line path, **1015**, 1017, 1017*i*
- Linkage isomers** Isomers in which a particular ligand bonds to a metal ion through different donor atoms, **977**–978
- Liquid(s)
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 dissolution of gases in, 541–542
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 solid state of, 497
 solidification of, 480
 surface tension of, 487*i*, 487–488
 vapor pressure of, 491*i*, 492
 viscosity of, 487, 487*t*
 volatile, 491
- Liquid aerosol** A colloidal dispersion of a liquid in a gas, **567*t***
- Liquid state
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- Lithium, 272, 918
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- Lithium bromide, crystallization of, 516, 516*i*
- Lithium oxide, 271
- Livingston, M.S., 1015
- London, Fritz, 485
- London forces, 485–486. *See also* **Dispersion forces**.
- Lone pair** A pair of electrons residing on one atom and not shared by other atoms; unshared pair, **277**
- Low spin complex** The crystal field designation for a complex in which pairing occurs to fill the *t_{2g}* orbitals before any electrons occupy the *e_g* orbitals, **986**, 987
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- Lowry, T.M., 371
- Lye, 774
- Lysozyme, 688
- Magnesium fluoride, 823–824
- Magnesium nitrate, 831
- Magnesium oxide, formation of, 5, 5*i*
- Magnesium, metallurgy of, 902*i*, 902–903, 903*i*
 ocean as source of, 11
 uses of, 924
- Magnetic field strength, 184
- Magnetic quantum number (*m_l*)** Quantum mechanical solution to a wave equation that designates the particular orbital within a given subshell (*s*, *p*, *d*, *f*) in which an electron resides. The *p_x*, *p_y*, and *p_z* orbitals have different magnetic quantum numbers, **205**
- Manganese, 900, 921
- Manometer** A two-armed barometer. **429**, 429*i*, 491*i*
- Margarine, 1077
- Marine organisms, in extraction of elements from sea water, 11
- Marsden, Ernst, 180
- Mass** A measure of the amount of matter in an object. Mass is usually measured in grams or kilograms, **4**, 18
 density, and volume, 31, 32
 molar, 58
 definition of, 64
 of atoms, 62
 of molecules, 65
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 SI units of, 18*t*
- Mass action expression** For a reversible reaction,

$$aA + bB \rightleftharpoons cC + dD$$
 the product of the molar concentrations of the products (species on the right), each raised to the power that corresponds to its coefficient in the balanced chemical equation, divided by the product of the concentrations of the reactants (species on the left), each raised to the power that corresponds to its coefficient in the balanced chemical equation. At equilibrium the mass action expression is equal to *K_c*; at other conditions, it is *Q*.

$$\frac{[C]^c[D]^d}{[A]^a[B]^b} = Q$$
 or, at equilibrium, *K_c*, **708**–709
- Mass conversion, unit factors and, 28
- Mass deficiency** The amount of matter that would be converted into energy if an atom were formed from constituent particles, **999**–1002
- Mass number** The integral sum of the numbers of protons and neutrons in an atom, **183**, 188 and isotopes, 182
- Mass spectrometer** An instrument that measures the charge-to-mass ratios of charged particles, **184**, 184*i*, 185, 185*i*
- Mass spectrometry, and isotopic abundance, 184–187
- Mass-volume relationships, in reactions involving gases, 454–456
- Matter** Anything that has mass and occupies space, **3**, 4
 chemical and physical properties of, 6–9
 classification of, 12*i*
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- Matter and Energy, Law of Conservation of, 5–6
- Maxwellian distribution function, 457*i*
- McFarland, D.F., 937
- McMillan, E.M., 1018
- Mean-square speed, 460
- Measurement(s), fundamental units of, 17*t*
 in chemistry, 16–17
 numbers obtained from, 22
 units of, 18–19, 26
- Melting curve, 502
- Melting point** The temperature at which liquid and solid coexist in equilibrium; also the freezing point, **497**, A12
 and heats of fusion, 499*t*
 of ionic compounds, 482
- Membrane, semipermeable, 562–563, 563*i*
- Mendeleev, Dmitri, 123, 233
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- Meniscus** The upper surface of a liquid in a cylindrical container, **221**, 401*i*, **488**
 of water, 488, 488*i*
- Mercury battery, 881
- Mercury thermometer, 34–35, 35*i*
- Mercury(II) oxide, decomposition of, 151
- Metal** An element below and to the left of the stepwise division (metalloids) of the periodic table; about 80% of the known elements are metals, **894**–912, 913–934
 alkali, 126. *See* **Metals, Group IA**.
 alkaline earth. *See* **Metals, Group IIA**.

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 3*d*-transition, nonzero oxidation states of, 931*t*
- Metal ions, *d*-transition, 272
 Metal oxides, high oxidation state transition, 387–388
 reactions with nonmetal oxides, 256
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- Metallic bonding** Bonding within metals due to the electrical attraction of positively charged metal ions for mobile electrons that belong to the crystal as a whole, **518**
- Metallic conduction** Conduction of electric current through a metal or along a metallic surface, **844**, 844*i*
- Metallic silver, formation of, 147–148
 Metallic solids, 509–514, 510*i*
- Metalloids** Elements with properties intermediate between metals and nonmetals: B, Si, Ge, As, Sb, Te, Po, and At, **127**
 nonmetals and, 935–964
 properties of, 129
- Metallurgy** The overall processes by which metals are extracted from ores, **894**–912
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 of specific metals, 902–909
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- Metathesis reaction** A reaction in which the positive and negative ions in two compounds “change partners,” with no change in oxidation numbers, to form two new compounds, **157**–162
- Meter, definition of, 18
 Methane, 89, 90, 282, 466, 640
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 reaction with oxygen, 90, 90*i*
 structure of, 1037, 1037*i*
- Methanol, 302, 326
- Method of initial rates** A method of determining the rate-law expression by carrying out a reaction with different initial concentrations and analyzing the resulting changes in initial rates, **650**–655
- Methyl orange, color changes of, 111
 Methylene group, 1039
 Metric system, conversions within, 28–29
 prefixes used in, 17*t*
- Meyer, Lothar, 123, 233
- Micelle** A cluster of a large number of soap or detergent molecules or ions, assembled with their hydrophobic tails directed toward the center and their hydrophilic heads directed outward, **572**, 573*i*
- Microelectrodes, 876
 Microscope, scanning and tunneling, 50, 51*i*
 Milliequivalent weight, 408
 Millikan, Robert A., 177
- Millimole** 1/1000 mole, 397
- Mineral** A naturally occurring inorganic solid substance having a definite chemical composition and characteristic crystalline structure, color, and hardness; contains a metal that can be extracted in a metallurgical process, 11–12, 507*i*, 819*i*, 896*i*, 897–908
- Mineral acids, 132
 Minerals, in ores, 896
- Mirror images
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- Miscibility** The ability of one liquid to mix with (dissolve in) another liquid, **540**–541
- Mixture** A sample of matter composed of variable amounts of two or more substances, each of which retains its identity and properties, **10**
 composition of, 10
 heterogeneous, definition of, 10, 12*i*
 homogeneous, definition of, 10
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 separation of, 10, 12*i*
- Moderator** A substance such as hydrogen, deuterium, oxygen, or paraffin capable of slowing fast neutrons upon collision, **1018**, 1021–1022
- Modes, normal, 204*i*
- Molarity (m)** Concentration expressed as number of moles of solute per kilogram of solvent, **547**
 and mole fraction, 546–548
- Molar concentration. *See* **Molarity**.
- Molar enthalpy of formation, standard, 594–596, 595*t*, 599, 600
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 for elements, 601
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- Molar entropy, standard, 616
 Molar free energy, standard, 621
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- Molar heat capacity** The amount of heat necessary to raise the temperature of one mole of a substance one degree Celsius with no change in state; usually expressed in kJ/mol·°C, **493**, A12. *See also* **Specific heat**.
- Molar heat of condensation** The amount of heat that must be removed from one mole of a vapor at its condensation point to condense the vapor with no change in temperature; usually expressed in kJ/mol. *See* **Heat of condensation**. **494**
- Molar heat, of formation, standard. *See* **Molar enthalpy of formation, standard**. **595**, A22–A23
- Molar heat of fusion** The amount of heat required to melt one mole of a solid at its melting point with no change in temperature; usually expressed in kJ/mol, **497**–498. *See also* **Heat of fusion**.
- Molar heat of vaporization** The amount of heat required to vaporize one mole of a liquid at its boiling point with no change in temperature; usually expressed in kJ/mol, **493**, 493*t*, A12. *See also* **Heat of vaporization**.
- Molar mass** The mass, in grams, of one mole of a substance; numerically equal to the formula weight of the substance, **58**, 64. *See also* **Formula weight**, **Molecular weight**.
- Molar solubility** The number of moles of a solute that dissolve to produce a liter of saturated solution, **819**, 820–821, 822*t*
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- Molarity (M)** The number of moles of solute per liter of solution or the number of millimoles of solute per milliliter of solution, **105**–107, 398
 as unit factor, 110
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 mole method and, 404–407
- Mole fraction** The number of moles of a component of a mixture divided by the total number of moles in the mixture, **449**, 548
 molality and, 546–548
 of gases, 450–451
- Mole method, molarity and, 404–407
- Mole of reaction (mol rxn)** The amount of reaction that corresponds to the number of moles of each substance shown in the balanced equation, **590**, 593
- Mole** 6.022×10^{23} (Avogadro's number of) formula units (or molecules, for a molecular substance) of a substance. The mass, in grams, of one mole is numerically equal to the formula (molecular) weight of the substance, **57**–62, 65–66
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- Molecule** The smallest particle of an element or compound that can have a stable independent existence, **49**
 AB_6 , AB_5U , and AB_4U_2 species, octahedral electronic geometry of, **331–335**
 AB_2 species, linear electronic geometry of, **310–312**
 AB_3 species, trigonal planar electronic geometry of, **312–314**
 AB_4 species, tetrahedral electronic geometry of, **314–319**
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polar, **306, 308**
in electric field, **294i**
molecular geometry of, **306–309**
versus nonpolar, determination of, **309i**
polyatomic, **49, 50i**
shapes of, and bonding, **309–310**
structure of, and covalent bonding theories, **301–347**
trigonal bipyramidal, **327**
trigonal pyramidal, **320–321**
Molecular atoms, in compounds, **50, 51i**
Molecular compounds, binary, **141–142**
names and formulas of, **51t**
Molecular formula A formula that indicates the actual number of atoms present in a molecule of a molecular substance, **70**. Compare with **Simplest (empirical) formula**.
determination of, **74–76**
of gases, **446**
Molecular geometry The arrangement of atoms (*not* unshared pairs of electrons) around a central atom of a molecule or polyatomic ion, **304, 340t**
and electronic geometry, summary of, **339–341, 340t**
linear electronic, **310–312**
octahedral electronic, **331–335**
unshared valence electron pairs in, **332–333**
of central atoms, **306**
of molecules, **310**
of species with lone pairs on central atom, **334–335t**
square planar, **333, 333i**
square pyramidal, **333, 333i**
tetrahedral electronic, **314–326**
trigonal bipyramidal electronic, **327–330**
unshared valence electron pairs in, **329–330, 330i**
trigonal planar electronic, **312–314**
Molecular orbital (MO) An orbital resulting from overlap and mixing of atomic orbitals on different atoms. An MO belongs to the molecule as a whole, **350–352**
and chemical bonding, **348–366**
delocalization and shapes of, **361–364**
overlap of, **352i**
production of, **352, 352i**
sigma, **351**
Molecular orbital diagram, **351i**
Molecular orbital energy level diagrams, **353i, 353–354**
Molecular orbital theory A theory of chemical bonding based on the postulated existence of molecular orbitals, **276, 349, 355**
Molecular solids, **517, 517i**
Molecular speed, **461–462**
Molecular substances, mole of, **64t**
Molecular weight The mass, in atomic mass units, of one molecule of a nonionic (molecular) substance. Numerically equal to the mass, in grams, of one mole of such a substance. This number is obtained by adding the atomic weights of the atoms specified in the formula, **63**
determination from colligative property, **558–559**
determination from osmotic pressure, **565–566**
formula weights, and moles, **63–66**
of gases, **441, 446**
Molina, Mario, **687**
Molybdenum, **921**
Momentum, definition of, **203**
Monomers The small molecules from which polymers are formed, **1085–1087, 1088t**
Monoprotic acid An acid that can form only one hydronium ion per molecule; may be strong or weak, **160, 753**
Monosaccharide Simple sugars (monomers) from which more complex carbohydrates are constructed, **1118, 1119t**
Moseley, H.G.J., **181, 181i**
Multiple Proportions, Law of, **76**
Myoglobin, **1124, 1124i**
Nanometers, **237**
National Institute of Standards and Technology (NIST), **17**
Native ore A metal that occurs in an uncombined or free state in nature, **896**
Natural radioactivity Spontaneous decomposition of an atom, **997**
Neon, **269**
mass spectrum of, **185, 185i**
Neoprene, **1086–1087**
Neptunium, **1018**
Nernst equation An equation that corrects standard electrode potentials for nonstandard conditions, **871–875**
Net ionic equation The equation that results from canceling spectator ions and eliminating brackets from a total ionic equation, **136–137**
Neutral salt A salt formed from the reaction of an acid and a base of equal strength, **769**
Neutralization The reaction of an acid with a base to form a salt and (usually) water; usually, the reaction of hydrogen ions with hydroxide ions to form water molecules, **158–160, 370, 384**
volume required for, **410**
Neutralization reaction The reaction of an acid with a base to form a salt. Often, the reaction of hydrogen ions with hydroxide ions to form water molecules, **158–160, 370, 380**
Neutron A subatomic nuclear particle having a mass of 1.0087 amu and no charge, **182, 1022**
fast, **1018**
slow, **1018**
Neutron bomb, **1022**
Neutron bombardment, **1018**
Neutron-rich nuclei, **1004–1005**
Newlands, J.A.R., **233**
Newton, Sir Isaac, **191**
laws of, **202**
Nicaid battery. *See* **Nickel–cadmium cell**
Nickel–cadmium cell (nicad battery) A dry cell in which the anode is Cd, the cathode is NiO_2 , and the electrolyte is basic, **883–884**
Nitration, **1081**
Nitric acid, **768, 957, 958**
percent composition of, **67**
Nitric oxide, formation of, **259**
Nitrobenzene, preparation of, **100**
theoretical yield of, **100**
Nitrogen, **720, 951–958**
conversion to ammonia, **953**
hydrogen compounds of, **953–954**
occurrence of, **952–953**
oxidation states of, **952t**
oxoacids of, **957–958**
Nitrogen cycle The complex series of reactions by which nitrogen is slowly but continually recycled in the atmosphere, lithosphere, and hydrosphere, **952, 953**
Nitrogen dioxide, **955**
Nitrogen fixation, **953**
Nitrogen molecule, molecular orbitals for, **356, 357t**
Nitrogen oxide(s), **684, 685, 954–955**
and photochemical smog, **956**
energy level diagram for, **359, 359i**
Nitroglycerin, **1082**
Nitrosoamines, **958**
Nitrous acid, **957**
Nitrous oxide, **954**
Nobel, Alfred, **1082**
Noble gas(es) Group VIIIA elements in the periodic table; also called rare gases; formerly called inert gases; He, Ne, Ar, Kr, Xe, and Rn, **127, 232**
in atmosphere, **937t**
uses of, **938t**
Noble gas configuration The stable electron configuration of a noble gas, **219–221, 238**

- Nodal plane (node)** A region in which the probability of finding an electron is zero, **351**
Node, 203, 351
- Nonbonding orbital** A molecular orbital derived only from an atomic orbital of one atom; lends neither stability nor instability to a molecule or ion when populated with electrons, **360**
- Nonelectrolyte** A substance whose aqueous solutions do not conduct electricity, **129**, 746
formation of, 157
van't Hoff factors for, 561*t*
- Nonmetal oxides**
reactions with metal oxides, 256
reactions with water, 253*i*, 255, 255*i*
- Nonmetals** Elements above and to the right of the metalloids in the periodic table, **155–156**
and metalloids, 935–964
chemical properties of, 127*t*
Group VIA, 271–272, 272
Group VIIA, 269, 270
oxidation states of, 255
physical properties of, 127*t*
reactions of oxygen with, 254–255
- Nonpolar bond** A covalent bond between two atoms with the same electronegativity, so that the electron density is symmetrically distributed, **292**
- Nonspontaneous change** See **Reactant-favored change**.
- Nonspontaneous products, 612
- Normal boiling point** The temperature at which the vapor pressure of a liquid is equal to one atmosphere pressure, **492**
- Normal melting point** The melting (freezing) point at one atmosphere pressure, **497**
- Normal oxide** A metal oxide containing the oxide ion, O^{2-} (oxygen in the -2 oxidation state), **252**, 253*i*, 918
- Normal salt** A salt containing no ionizable H atoms or OH groups, **375**, 382–383
- Normality (N)** The number of equivalent weights (equivalents) of solute per liter of solution and equivalent weights, **407–411**
of solution, 408–409
definition of, 408
- Nuclear atoms, 179
- Nuclear binding energy** The energy equivalent of the mass deficiency; energy released in the formation of an atom from subatomic particles, **1000–1002**, 1002*i*
- Nuclear chain reaction, 1020, 1020*i*
- Nuclear charge, effective, 236, 240
- Nuclear chemistry, 995–1032
- Nuclear fission** The process in which a heavy nucleus splits into nuclei of intermediate masses and one or more neutrons are emitted, **1019–1020**
definition of, 997
- Nuclear fission reactor(s), 1020–1023
control rods of, 1022
cooling systems of, 1022
fuel for, 1021
moderator for, 1021–1022
shielding from, 1022
- Nuclear fusion** The combination of light nuclei to produce a heavier nucleus, **997**, **1026–1027**
- Nuclear fusion reactors, 1026
- Nuclear power, hazards and benefits of, 1023
- Nuclear power plants, advantages of, 1023
light water, 1021, 1021*i*
- Nuclear reaction** A reaction involving a change in the composition of a nucleus; it can evolve or absorb an extraordinarily large amount of energy, **997**
artificially induced, 1015
equations for, 1004
- Nuclear reactor** A system in which controlled nuclear fission reactions generate heat energy on a large scale. The heat energy is subsequently converted into electrical energy, **1018**
- Nuclear shielding** See **Shielding effect**.
- Nuclear stability, and binding energy, 999–1002
- Nuclear wastes, management of, 1023, 1024–1025
- Nucleic acid** A biopolymer consisting of repeating units of ribose or deoxyribose, phosphate, and selected bases, **1126–1128**, 1127*i*
base-pairing in, 1128, 1128*i*
bases in, 1127*i*, 1127–1128
- Nucleons** Particles comprising the nucleus; protons and neutrons, **998**, 1019
binding energy of, 1019, 1019*i*
- Nucleus** The very small, very dense, positively charged center of an atom containing protons and neutrons, except for ${}^1_1\text{H}$, **997–998**
atomic, 180
neutron-rich nuclei, 1004–1005
with atomic number greater than 83, 1005
- Nuclide(s)** Different atomic forms of all elements (in contrast to isotopes, which are different atomic forms of a single element), **998**
daughter, 1009
decaying, 1009
naturally occurring, 998, 998*t*
parent, 1009
stable, number of neutrons and protons in, 998, 999*i*
- Nuclide symbol** The symbol for an atom, ${}^A_Z\text{E}$, in which E is the symbol for an element, Z is its atomic number, and A is its mass number, **183**, 183*i*
- Number(s), atomic, 181–182
exact, 21, 21*i*
obtained from measurements, 22
oxidation. See **Oxidation numbers**.
quantum, 203, 204, 205–206
permissible values of, 206*t*
use of, 20–25
- Nylon, 1089, 1090*i*
- Ocean, resources of, 11
- Octahedral** A term used to describe the electronic geometry around a central atom that has six regions of high electron density. Also used to describe the molecular geometry of a molecule or polyatomic ion that has one atom in the center bonded to six atoms at the corners of an octahedron (AB_6), 307*t*, 310*t*, **331–333**
- Octahedron** A polyhedron with eight equal-sized, equilateral triangular faces and six apices (corners), 307*t*, 310*t*, **331–333**
- Octet rule** Many representative elements attain at least a share of eight electrons in their valence shells when they form molecular or ionic compounds; there are some limitations, **277–283**
limitations of, 287–292
- Oil** A liquid triester of glycerol and unsaturated fatty acids, **1074–1075**
- Oil-drop experiment, 177*i*, 177–178
- Oleum, 949
- Oligosaccharide** A molecule consisting of four to ten monosaccharides joined together by glycosidic bonds, **1121**
- Optical activity** The ability of one of a pair of optical isomers to rotate the plane of polarized light, **983**, **1104–1105**
- Optical isomers**, 982–984, 1104–1106, 1105*i*. See also **Enantiomers**.
dextrorotary, 983
interaction with polarized light, 983, 984*i*
levorotary, 983
- Optical resolution, 983
- Orbital approximation, 211
- Orbital(s), antibonding, 350, 352
atoms in, 210*i*
bonding, 350, 352
degenerate, 214
hybrid. See **Hybrid orbitals**.
molecular. See **Molecular orbitals**.
nonbonding, 360
- Order of a reactant** The power to which the reactant's concentration is raised to the rate-law expression, **648**
- Order of a reaction** The sum of the powers to which all concentrations are raised in the rate-law expression; also called overall order of a reaction, **648**
- Ore** A natural deposit containing a mineral of an element to be extracted, 68, **896**
chemical modification of, 898
classes of, 897*t*
composition of, 896
flotation of, 898, 898*i*
minerals in, 896
native, 895–896
pretreatment of, 897–899, 898*i*
roasting of, 898–899
- Organic acids, 132, 1108–1109
naturally occurring, 1072*t*
strengths of, 1109
- Organic bases, 1109–1110
strengths of, 1110
- Organic chemistry** The chemistry of substances that contain carbon–carbon or carbon–hydrogen bonds, **3**, **1033–1099**, 1100–1132
- Organic compounds, 52
classes of, 1078*i*
combustion of, 1114–1115
Lewis formulas for, 282–283
reactivity of, 1079
- Organic molecules, shapes of, 1101–1107
- Osmosis** The process by which solvent molecules pass through a semipermeable membrane

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- from a dilute solution into a more concentrated solution, **562**, **563i**, **565**
reverse, **568**
- Osmotic pressure** The hydrostatic pressure produced on the surface of a semipermeable membrane by osmosis, **562–566**, **564i**
calculation of, **564–565**, **566**
molecular weight determination from, **565–566**
- Ostwald process** An industrial process for the production of nitrogen oxide and nitric acid from ammonia and oxygen, **955**, **957**
- Ostwald viscometer, **487i**
- Overlap of orbitals** The interaction of orbitals on different atoms in the same region of space, **303**, **309**, **341**
- Oxalic acid, **1071**, **1071t**
two forms of, **79**, **79i**
- Oxidation (1)** An increase in oxidation number; corresponds to a loss of electrons, **146**
- Oxidation (2)** As applied to organic compounds, the increase of oxygen content or the decrease of hydrogen content of an organic molecule, **146**, **1110**
- Oxidation numbers** Arbitrary numbers that can be used as mechanical aids in writing formulas and balancing equations; for single-atom ions they correspond to the charge on the ion; less metallic atoms are assigned negative oxidation numbers in compounds and polyatomic ions, **137–140**, **411**
common, **139t**
determination of, **139–140**
rules for assigning, **138–139**
- Oxidation potential, **860**
- Oxidation–reduction reaction** A reaction in which oxidation and reduction occur; also called a redox reaction, **137**, **146–149**, **270**, **411–419**, **843**, **1110–1115**
examples of, **146**
- Oxidation states** See **Oxidation numbers**.
- Oxide** A binary compound of oxygen, **251**
acidic, **255**
acidic character of, **256**
basic, **253**, **253i**
basic character of, **256**
Group VIA, **948–949**
metal, reactions with nonmetal oxides, **256**
metallic, **252**
molecular, **254**
nonmetal, reactions with metal oxides, **256**
reactions with water, **253i**, **255**, **255i**
normal, **252**
oxygen and, **251–260**
- Oxidizing agent** The substance that oxidizes another substance and is reduced, **147**, **862**
- Oxoacids, and salts, naming of, **143–146**
of halogens, **944t**, **944–945**
of nitrogen, **957–958**
of sulfur, **950–951**
ternary, **279**
- Oxygen
addition of H^+ , OH^- , or H_2O to balance, **413–416**
and oxides, **251–260**
reactions of, **251–257**
and ozone, **251**
meaning of word, **251**
reactions with metals, **252**
reactions with nonmetals, **254–255**
uses of, **251**
- Oxygen atoms, **251**
and nitrogen atoms, in sodium O_3 , **76**
- Oxygen compounds, of IA and IIA metals, **252t**
- Oxygen molecule, molecular orbitals for, **354i**, **357t**
- Oxygen process furnace, **906**, **907i**
- Ozone, **686–687**
chain reaction involving, **687**
oxygen and, **251**
- Ozone hole, **687**
- p orbitals** Beginning with the second shell, a set of three degenerate mutually perpendicular, equal-arm, dumbbell-shaped atomic orbitals per shell, **208**, **208i**, **209i**, **222**
- pK_a** The negative logarithm of K_a , the ionization constant for a weak acid, **754–758**
- pK_b** The negative logarithm of K_b , the ionization constant for a weak base, **762**, **779**
- pK_w** The negative logarithm of the ion product for water, **749**
- Pairing energy** The energy required to pair two electrons in the same orbital, **986**
- Pairing of electrons** Interaction of two electrons with opposite *ms* values in the same orbital ($\uparrow\downarrow$), **214**, **215i**
- Pairs, shared, **280**
- PANs** Abbreviation for peroxyacyl nitrates, photochemical oxidants in smog, **956**
- Paraffins, **1079**
- Paramagnetism** Attraction toward a magnetic field, stronger than diamagnetism, but still very weak compared with ferromagnetism; due to presence of unpaired electrons and diamagnetism, **217–218**
measurement of, **218i**
- Parent nuclide** A nuclide that undergoes nuclear decay, **1009**
- Partial pressure** The pressure exerted by one gas in a mixture of gases, **448**
and equilibrium constant, **725–728**
effect on electrode potentials, **871–879**
- Particle accelerator(s), **1017i**, **1017–1018**
- Particles, alpha, definition of, **1005**
charges on, **185**
dispersed, size of, **567t**
fundamental, **48–49**, **49t**, **175t**, **175–176**
masses of, **184**
subatomic, **175–190**
- Particulate matter** Finely divided solid particles suspended in air, **10**, **258**, **567t**, **949**
- Pascal (Pa)** The SI unit of pressure; it is defined as the pressure exerted by a force of one newton acting on an area of one square meter, **432**
- Pasteur, Louis, **983**
- Pauli Exclusion Principle** No two electrons in the same atom may have identical sets of four quantum numbers, **212**, **354**
- Peptide bond** A bond formed by elimination of a molecule of water between the amino group of one amino acid and the carboxylic acid group of another, **1090**, **1122**
- Peptides** Compounds formed by the linking of small numbers of amino acids, **1122**
- Perfluorocarbons, **1059**
- Percent by mass** 100% multiplied by the mass of a solute divided by the mass of the solution in which it is contained, **103–104**
- Percent composition** The mass percentage of each element in a compound
calculation of, **67**, **73–74**
- Percent ionization of weak electrolytes** The percent of the weak electrolyte that ionizes in a solution of a given concentration, **561–562**, **759–763**
- Percent purity** The mass percentage of a specified compound or element in an impure sample, **80**
- Percent yield** 100% times actual yield divided by theoretical yield, **100**
from chemical reactions, **99–100**
- Percent, by mass, **103**
of solute, **103**
and density, **104**
- Percentage, **30–31**
- Perchloric acid, **945**
- Period** The elements in a horizontal row of the periodic table, **126**
- Periodic law** The properties of the elements are periodic functions of their atomic numbers, **126**, **231**
- Periodic repetition, regular, **123**
- Periodic table** An arrangement of elements in order of increasing atomic number that also emphasizes periodicity, **123–129**, **126t**, **218**, **219i**, **220t**, **221**, **231**, **233**, **234**
electron configurations and, **218–221**
groups and periods of, **126**
- Periodicity** Regular periodic variations of properties of elements with atomic number and position in the periodic table, **123**, **230–264**
chemical reactions and, **247–258**
- Peroxide** A compound containing oxygen in the -1 oxidation state. Metal peroxides contain the peroxide ion, O_2^{2-} , **252**
- Peroxyacyl nitrates, **956**
- Petroleum, **1048**, **1089**
- Petroleum fractions, **1048**
- pH** The negative logarithm of the concentration (mol/L) of the H_3O^+ (or H^+) ion; the commonly used scale ranges from 0 to 14, **748–752**
- pH meter, **875**
- Phase changes, intermolecular attractions and, **481–486**
- Phase diagram** A diagram that shows equilibrium temperature–pressure relationships for different phases of a substance, **501i**, **501–503**, **503i**
for carbon dioxide, **501i**
for water, **501**, **501i**

- Phenol** A hydrocarbon derivative that contains an —OH group bound to an aromatic ring, **1061**–1064, 1109
nomenclature for, 1063
physical properties of, 1064
Phenolphthalein, 403, 802, 917
Phenoxides, **1109**
Phenylalanine, 1106, 1106*i*
Pheromones, 1111
Phosphates, in detergents, 573–574
Phosphoric acid, 764, 767
in fertilizers and cola drinks, 102
Phosphorus, discovery of, 128
occurrence of, 958
preparation of, 958–959
uses of, 959
Phosphorus pentachloride, 150
Phosphorus pentafluoride, 289–290
Photochemical oxidants Photochemically produced oxidizing agents capable of causing damage to plants and animals, 956
Photochemical smog A brownish smog occurring in urban areas that receive large amounts of sunlight; caused by photochemical (light-induced) reactions among nitrogen oxides, hydrocarbons, and other components of polluted air that produce photochemical oxidants, 956
Photoelectric effect Emission of an electron from the surface of a metal, caused by impinging electromagnetic radiation of certain minimum energy; the resulting current increases with increasing intensity of radiation, **194**, 194*i*
Photon A “packet” of light or electromagnetic radiation; also called a quantum of light, **193**
Phthalic acid, 405–406
Physical change A change in which a substance changes from one physical state to another, but no substances with different compositions are formed, **9**
spontaneity of, 612–627
Physical chemistry, definition of, **3**
Physical constants, A11
Physical properties. *See also* **Properties**.
definition of, **6**
of common substances, 9*t*
Pi (π) bond A bond resulting from the side-on overlap of atomic orbitals, in which the regions of electron sharing are on opposite sides of and parallel to an imaginary line connecting the bonded atoms, **337**
Pi (π) orbital A molecular orbital resulting from side-on overlap of atomic orbitals, 352
Picometers, 237
Pig iron The iron obtained from the blast furnace, **906**
Planck, Max, 193
Planck’s constant (h), 193, A11
Plane-polarized light Light waves in which all the electric vectors are oscillating in one plane, 982, 984*i*
Plasma A physical state of matter that exists at extremely high temperatures, in which all molecules are dissociated and most atoms are ionized, 1026–1027
Plutonium-239, 234
pOH The negative logarithm of the concentration (mol/L) of the OH[−] ion; the commonly used scale ranges from 14 to 0, 748–751, 750*t*
Polar bond A covalent bond between two atoms with different electronegativities, so that the electron density is unsymmetrically distributed, **292**
Polar molecules, 306, 308
molecular geometry of, 306–309
versus nonpolar, determination of, 309*i*
Polarimeter A device used to measure optical activity, **983**, 984*i*, 1105
Polarizability, 485
Polarization, of anion, 916
of electrodes, 881
Polarization of an electrode Buildup of a product of oxidation or reduction at an electrode, preventing further reaction, **881**
Pollution, thermal, 545
Polonium, 945
Polyamide A polymeric amide, **1089**
Polyatomic Consisting of more than one atom.
Elements such as Cl₂, P₄, and S₈ exist as polyatomic molecules. Examples of polyatomic ions are the ammonium ion, NH₄⁺, and the sulfate ion, SO₄^{2−}, **49**
Polyatomic ion An ion that consists of more than one atom, **54**, 295
Lewis formulas for, 276–277
Polydentate Describes ligands with more than one donor atom, **971**
Polyene A compound that contains more than one double bond per molecule, **1050**
Polyester A polymeric ester, **1087**–1089
Polyethylene, 1086
Polyhydric alcohol An alcohol that contains more than one —OH group, 1063
Polymer(s) Large molecules formed by the combination of many small molecules (monomers), **1085**
addition, 1086
condensation, 1087
natural, 1085
synthetic, 1085
Polymerization The combination of many small molecules (monomers) to form large molecules (polymers), **1085**
Polymerization, addition, 1086–1087, 1088*t*
condensation, 1087–1090
definition of, 1085
Polymerization reactions, 1085
Polymorphous Refers to substances that crystallize in more than one crystalline arrangement, 508
Polyol, An alcohol that contains more than one —OH group, **1063**
Polypeptide A polymer composed of amino acids linked by peptide bonds, **1090**
and proteins, 1122–1126
Polypropylene, 1086
Polyprotic acid An acid that contains more than one ionizable hydrogen atom per formula unit, **378**, 764
Polysaccharide Carbohydrates that contain more than ten monosaccharide units, 1121
Positron A nuclear particle with the mass of an electron but opposite charge, 1005
Positron emission, 1004–1005
Positron emission tomography, **1013**–1014
Post-transition metals Representative metals in the “*p* block,” 915, **925**–929, 926*t*
Potassium chlorate, oxygen in, 78
Potassium chloride, 149
Potassium chromate, solution of, 109
Potassium dichromate, 418–419
Potassium hydrogen phthalate, 405–406
Potassium permanganate, 414, 416–417, 417*i*
preparation of, 105*i*
Potassium–argon, for radioactive dating, 1011
Potential energy Energy that matter possesses by virtue of its position, condition, or composition, **4**, **584**, 585*i*
versus progress of reaction, 670, 670*i*
Potential(s), electrode. *See* **Electrode potentials**.
oxidation, 860
Precipitate An insoluble solid that forms and separates from a solution, **157**, 160
detection of, 827
dissolving of, 834–836
formation of, prediction of, 825–826
Precipitation, fractional, 828–831
initiation of, 827
concentration for, 828–829
Precipitation reaction A reaction in which a solid (precipitate) forms, **160**–162, 161*i*
reaction quotient in, 825–828
solubility guidelines and, 162
Precision How closely repeated measurements of the same quantity agree with one another, **23**
Pressure Force per unit area, **428**–433
atmospheric, 429–432
changes in, and equilibrium, 715–717
critical, 502
effect of solubility, 546, 546*i*
electron, 860
one atmosphere, definition of, 9
one atmosphere of, 432
osmotic. *See* **Osmotic pressure**.
partial. *See* **Partial pressure**.
SI unit of, 432
vapor. *See* **Vapor pressure**.
Pressure–volume work Work done by a gas when it expands against an external pressure or work done on a system as gases are compressed or consumed in the presence of an external pressure, **607**–608
Priestley, Joseph, 251
Primary alcohol An alcohol with no or one R group bonded to the carbon bearing the —OH group, **1062**–1063
Primary amine An amine in which one H atom of ammonia has been replaced by an organic group, **1068**

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Primary standard A substance of a known high degree of purity that undergoes one invariable reaction with the other reactant of interest, **404**

Primary structure The sequence of the monomeric units in proteins, carbohydrates, and so on, **1024**

Primary voltaic cell A voltaic cell that cannot be recharged; no further chemical reaction is possible once the reactants are consumed, **880–881**

Principal quantum number (*n*) The quantum mechanical solution to a wave equation that designates the main shell, or energy level, in which an electron resides, **205**, **206**, **211**

Product-favored change A change for which the collection of products is more stable than the collection of reactants under the given conditions; also called *spontaneous change*, **612**, **704**, **863**

Products Substances produced in a chemical reaction, **90**
formed, mass of, **96**
Propane, structure of, **1037**, **1038i**

Properties Characteristics that describe samples of matter. Chemical properties are exhibited as matter undergoes chemical changes. Physical properties are exhibited by matter with no changes in chemical composition, **6–9**

Protein A naturally occurring polymeric chain of L-amino acids linked together by peptide bonds, **1076**, **1090**, **1124**
functions of, **1125**, **1126t**
polypeptides and, **1122–1126**
quaternary structure of, **1124**
secondary structure of, **1124**
subunits of, **1124**
tertiary structure of, **1124**

Protic acid (also Protonic acid) An Arrhenius acid, or a Brønsted–Lowry acid, **369**

Proton A subatomic particle having a mass of 1.0073 amu and a charge of 1+, found in the nuclei of atoms, **178**, **1107**

Pseudobinary ionic compound A compound that contains more than two elements but is named like a binary compound, **141**

Purity of samples, **80–81**

Quadratic equation(s), simplifying of, **758–759**, **A4**

Quantum A “packet” of energy. See **Photon**.
Quantum energy, **193**

Quantum mechanics A mathematical method of treating particles on the basis of quantum theory, which assumes that energy (of small particles) is not infinitely divisible, **203**, **206**

Quantum numbers Numbers that describe the energies of electrons in atoms; they are derived from quantum mechanical treatment electron configurations and, **205–206**, **216–217**
permissible values of, **206t**

Quartz, **960**

Quicklime, **925**

Racemic mixture A single sample containing equal amounts of the two enantiomers (optical isomers) of a compound; does not rotate the plane of polarized light, **1105**

Radiant energy See **Electromagnetic radiation**.

Radiation High-energy particles or rays emitted in nuclear decay processes, **1002**
electromagnetic, **190–193**
photographic detection of, **1005**
types of, **1003t**

Radical A species containing one or more unpaired electrons; many radicals are very reactive, **251**, **943**, **955**

Radioactive dating A method of dating ancient objects by determining the ratio of amounts of a parent nuclide and one of its decay products present in an object and relating the ratio to the object’s age via half-life calculations, **1011**

Radioactive decay, **1002–1003**
rate of, **1007–1009**

Radioactive emissions, types of, **1003t**

Radioactive series, emissions and half-lives of, **1010t**

Radioactive tracer A small amount of radioisotope that replaces a nonradioactive isotope of the element in a compound whose path (e.g., in the body) or whose decomposition products are to be monitored by detection of radioactivity; also called a radioactive label, **1013**

Radioactivity The spontaneous disintegration of atomic nuclei
induced, **997**

Radiocarbon dating, **1011–1112**

Radioisotope A radioactive isotope of an element, **997**

Radionuclide A radioactive nuclide, **997**
agricultural uses of, **1014**
industrial uses of, **1014–1015**
medical uses of, **1013–1014**
research applications of, **1015**
storage of, **1023**
uses of, **1011–1015**

Radon, **937**

Ramsay, Sir William, **68**

Raoult’s Law The vapor pressure of a solvent in an ideal solution is directly proportional to the mole fraction of the solvent in the solution, **549i**, **549–550**, **550i**, **551i**, **552i**, **552–553**, **555**

Rare earths Inner transition elements, **235**

Rate constant (also called **specific rate constant**)
An experimentally determined proportionality constant that is different for different reactions and that, for a given reaction, changes only with temperature or the presence of a catalyst; *k* in the rate-law expression, $\text{Rate} = k[\text{A}]^x[\text{B}]^y$, **648**

Rate-determining step The slowest elementary step in a reaction mechanism; the step that limits the overall rate of reaction, **672**

Rate law, **648–655**

Rate-law expression (also called **rate law**) An equation that relates the rate of a reaction to the concentrations of the reactants and the specific rate constant; $\text{rate} = k[\text{A}]^x[\text{B}]^y$. The exponents of reactant concentrations *do not necessarily* match the coefficients in the overall balanced chemical equation. The rate-law expression must be determined from experimental data, **648–655**
alternative approach to, **651–653**
checking of, **654**
interpretation of, **649**
mechanism of reaction and, **672–675**
method of initial rates and, **653**

Rate of reaction The change in concentration of a reactant or product per unit time, **640**
expressions for, signs and divisors for, **643**
initial, method of, **650**, **653**, **655**
Rayleigh, Baron, **68**

Reactants Substances consumed in a chemical reaction, **90**
concentration versus time for, **656–667**, **659i**
concentrations of, **648–655**
excess, **97**
limiting, choosing of, **96–99**
concept of, **96–99**
nature of, **647**
required, mass of, **94–96**
transition state of, **670**

Reactant-favored change A change for which the collection of reactants is more stable than the collection of products under the given conditions; also called *nonspontaneous change*, **612**, **704**, **863**

Reactant-favored products, **612**

Reaction
addition, **1082–1084**
chemical. See **Chemical reaction(s)**.
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elementary steps of, **672**
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endothermic, **585**, **586i**
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first-order, half-life of, **656–658**, **659i**
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mechanism(s) of, and rate-law expression, **672–675**
definition of, **672**
nuclear, **997**
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polymerization, **1085**
precipitation. See **Precipitation reaction(s)**.

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 rate of, 640–646, 673
 collision theory of, 668–669
 factors affecting, 646–689
 instantaneous, 645, 645*i*
 reactants and, 647
 spectroscopic method and, 641*i*, 641–642
 redox. *See* **Redox reaction(s)**.
 reversible, 132, 700–701
 second-order, half-life of, 658–661, 659*i*
 spontaneous, 864
 stoichiometry of, 673
 substitution, **1079**–1082
 zero-order, half-life of, 661
- Reaction coordinate** The progress along the pathway from reactants to products; sometimes called “progress of reaction”, **670**
- Reaction intermediate** A species that is produced and then entirely consumed during a multi-step reaction; usually short-lived, **673**, 674
- Reaction mechanism** The sequence of fundamental steps by which reactants are converted into products, **672**
- Reaction products, predicting of, 256–257
- Reaction quotient, Q** The mass action expression under any set of conditions (not necessarily equilibrium); its magnitude relative to K determines the direction in which reaction must occur to establish equilibrium, **708**–709
 in precipitation reactions, 825–828
- Reaction ratio** The relative amounts of reactants and products involved in a reaction; may be the ratio of moles, or masses, **94**, 97, 111, 397
- Reaction stoichiometry** Description of the quantitative relationships among substances as they participate in chemical reactions, **89**–112
- Reaction summary, definition of, 702
- Reactor(s), nuclear fission, 1020–1023
- Real gases** Gases that deviate from ideal gas behavior, 463–466
- Redox equations, balancing of, 412, 415
- Redox reaction, **137**, 146, 147–148. *See also* **Oxidation–reduction reaction**.
 conversion of ions by, 834–835
 recognition of, 148
 stoichiometry of, 416–419
- Redox titration** The quantitative analysis of the amount or concentration of an oxidizing or reducing agent in a sample by observing its reaction with a known amount or concentration of a reducing or oxidizing agent, 416–419
- Reducing agent** The substance that reduces another substance and is oxidized, **147**, 862
- Reduction (1)** A decrease in oxidation number; corresponds to a gain of electrons, **148**
- Reduction (2)** As applied to organic compounds, the decrease of oxygen content or the increase of hydrogen content of an organic molecule, **1010**
- Reduction, definition of, 146, 1110
- Reduction potentials, standard, for half-cells, 865*t*
 standard aqueous, in aqueous solution, 863*t*
- Refining** Purifying of a substance, 900
- Representative elements** The A group elements in the periodic table, 232
- Representative metals** Metals in the A groups in the periodic table; their outermost electrons are in s and p orbitals, 915
- Required ratio, 98
- Resonance** A concept in which two or more Lewis formulas for the same arrangement of atoms (resonance structures) are used to describe the bonding in a molecule or ion, 283–284
- Resonance structures, 283
 guidelines for, 284
- Reverse osmosis** The forced flow of solvent molecules through a semipermeable membrane from a concentrated solution into a dilute solution. This is accomplished by application of hydrostatic pressure on the concentrated side greater than the osmotic pressure that is opposing it, 568–569
- Reversible reaction** A reaction that does not go to completion and occurs in both directions; described with double arrows (\rightleftharpoons), **132**, 700–701
- Ribonucleic acid (RNA), bases in, 1127*i*, 1127–1128
 definition of, 1126–1127
- Ribose** The carbohydrate found in RNA, 1127
- RNA** Ribonucleic acid, a nucleic acid consisting of phosphate, ribose, and the four bases adenine, cytosine, guanine, and uracil, 1126–1128
- Roasting** Heating a compound, especially an ore of an element, below its melting point in the presence of air, 259
 of ores, 898–899
- Robotics, 1003
- Root-mean-square speed, u_{rms}** The square root of the mean-square speed, $\sqrt{u^2}$. This is equal to $\sqrt{3RT/M}$ for an ideal gas. The root-mean-square speed is slightly different from the average speed, but the two quantities are proportional, 461
- Rounding off, 25, 62, 70
- Rowland, Sherwood, 687
- Rubber(s), natural and synthetic, 1086–1087
 vulcanization of, 1086
- Rutherford, Ernest, 178, 179, 180, 198, 997, 998, 1015
- Rydberg, Johannes, 197
- Rydberg constant, 197, A11
- s orbital** A spherically symmetrical atomic orbital; one per shell, 207–208, 208*i*
- Saccharide(s), 1118, 1119
- Sacrificial anode** A more active metal that is attached to a less active metal to protect the less active metal cathode against corrosion, 868, 869, 870*i*
- Salt** A compound that contains a cation other than H^+ and an anion other than OH^- or O^{2-} , **382**
 acidic, 382–384
 acidic and basic, prediction of, 776
 basic, 382–384
 definition of, 383
 containing small highly charged cations, 776*i*, 776–779
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 of weak bases, and solutions of weak base, 796–797
 and strong acids, 772–773
 and weak acids, 775–776
 and weak bases, 792
 preparation of, 382
 table, production of, 15, 15*i*
- Salt bridge** A U-shaped tube containing an electrolyte that connects two half-cells of a voltaic cell, **852**, 853*i*
- Saponification** The hydrolysis of esters in the presence of strong bases, 1116
- Saturated hydrocarbons** Hydrocarbons that contain only single bonds. They are also called *alkanes* or *paraffin hydrocarbons*, 1036, 1037–1046, 1039*i*, 1040*t*
- Saturated solution, 543
- Saturated solution** A solution in which no more solute will dissolve at a given temperature, 542*i*, **543**
- Saturation, dissolution and, rates of, 542–543
- Scanning and tunneling microscope, 50, 51*i*
- Scanning electron micrograph, 202
- Scattering experiment, 179, 180*i*
- Schrödinger, Erwin, 204
- Schrödinger equation, 204, 211, 350
- Scientific (natural) law** A general statement based on the observed behavior of matter, to which no exceptions are known, **5**
- Scientific notation, 20–21, A1–A2
 use of calculator for, 20–21
- Scintillation counter** A device used for the quantitative detection of radiation, 1006
- Screening effect, 236
- Sea water, as complicated solution, 11
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- Seaborg, Glenn, 234
- Seaborgium, 234
- Seashells, 161
- Second Law of Thermodynamics** The universe

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- tends toward a state of greater disorder in spontaneous processes, **613**
- Secondary alcohol** An alcohol with two R groups bonded to the carbon bearing the —OH group, **1062**
- Secondary amine** An amine in which two H atoms of ammonia have been replaced by organic groups, **1068**
- Secondary standard** A solution that has been titrated against a primary standard. A standard solution in a secondary standard, **404**
- Secondary voltaic cell** A voltaic cell that can be recharged; the original reactants can be regenerated by reversing the direction of current flow, **882**
- Sedenham, Thomas, **919**
- Seesaw** A term used to describe the molecular geometry of a molecule or polyatomic ion that has four atoms bonded to a central atom and one unshared pair on the central atom (AB₄U), **330, 330i**
- Selenium, **921**
- occurrence and uses of, **946–947**
- Semiconductor** A substance that does not conduct electricity well at low temperatures but does so at higher temperatures, **129, 165, 520–521**
- bands of, **522**
 - colors of, **521**
 - donor level and, **520**
 - doping and, **520–521**
 - electron hole pair in, **520**
 - intrinsic, **520**
- Semimetals, **127**
- Semipermeable membrane** A thin partition between two solutions through which certain molecules can pass but others cannot, **562–563, 563i, 575**
- Sequential reaction** A chemical process in which several reaction steps are required to convert starting materials into products, **101–102**
- Shared pairs, **280**
- Shielding effect** Electrons in filled sets of *s* and *p* orbitals between the nucleus and outer shell electrons shield the outer shell electrons somewhat from the effect of protons in the nucleus; also called screening effect, **236**
- SI system, conversions within, **28–29**
- prefixes used in, **17t**
- SI unit(s), for amount, **58**
- of energy and work, **37**
 - of mass, **18t**
 - of pressure, **432**
- Side reactions, **99**
- Sigma (σ) bond** A bond resulting from the head-on overlap of atomic orbitals, in which the region of electron sharing is along and (cylindrically) symmetrical to an imaginary line connecting the bonded atoms, **336, 364**
- Sigma (σ) orbital** A molecular orbital resulting from head-on overlap of two atomic orbitals, **351, 364**
- Significant figures** Digits that indicate the precision of measurements—digits of a measured number that have uncertainty only in the last digit, **21–25**
- defined quantities and, **27**
 - in calculated number, addition and subtraction, **24**
 - multiplication, **25**
 - rounding off of, **25**
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- Silicon dioxide, **960**
- Silver acetate, **823**
- Silver bromide, **829**
- Silver chloride, **828, 829, 830**
- Silver nitrate, **828–829, 830**
- Silver, density of, **513**
- Simplest formula** The smallest whole-number ratio of atoms present in a compound; also called empirical formula, **70–71. Compare with Molecular formula, 74–75.**
- Single bond** A covalent bond resulting from the sharing of two electrons (one pair) between two atoms, **276, 602t**
- Slag** Unwanted material produced during smelting, **906, 910**
- Slow neutron** A fast neutron slowed by collision with a moderator, **1018**
- Smelting** Chemical reduction of a metal from its ore by treating the molten ore with a reducing agent, **899, 910**
- Soap** An emulsifier that can disperse nonpolar substances in water; the sodium salt of a long-chain organic acid; consists of a long hydrocarbon chain attached to a carboxylate group, —CO₂[−]Na⁺, **572, 1116–1117**
- making of, **1116–1117**
- Sodium, **8i, 918**
- ocean as source of, **11**
 - reaction with chlorine, **269**
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- Sodium acetate, **132, 769**
- Sodium carbonate, **405**
- Sodium chloride, **558, 769**
- aqueous, electrolysis of, **846–848, 847i**
 - chloride ions in, **78–79**
 - crystal structure of, **271i, 514, 515i**
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 - molten, electrolysis of, **845i, 845–846**
 - production of, **15, 15i**
- Sodium hydrogen carbonate, **383**
- Sodium hydroxide, formula weight for, **63**
- purity of, **80–81**
 - reaction with solvent, **535**
- Sodium hypochlorite, **415**
- Sodium stearate, **572, 573**
- Sodium sulfate, **825–826**
- aqueous, electrolysis of, **848, 848i**
- Sol** A colloidal dispersion of a solid in a liquid, **567t, 570–571**
- Solid**
- amorphous, **503–505**
 - bonding in, **509–518**
 - characteristics of, **479t, 509t**
 - covalent, **517, 518i**
 - crystalline, **503–505**
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 - liquids, and gases, compared, **427, 427t**
 - metallic, **509–514, 510i**
 - density and cell volume of, **513**
 - molecular, **517, 517i**
 - vapor pressure of, sublimation and, **500**
 - volatile, purification of, **500, 500i**
- Solid aerosol** A colloidal dispersion of a solid in a gas, **567t, 575**
- Solid emulsion** A colloidal dispersion of a liquid in a solid, **567t, 576**
- Solid foam** A colloidal dispersion of a gas in a solid, **567t, 576**
- Solid sol** A colloidal dispersion of a solid in a solid, **567t, 576**
- Solid state, definition of, **6**
- Solidification, enthalpy of, **498**
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 - common ion effect and, **823–824**
- Solubility guidelines, for compounds in aqueous solution, **133–135**
- for ionic compounds in water, **135**
 - precipitation reactions and, **162**
- Solubility product, expression for, **818**
- Solubility product constant, K_{sp}** The equilibrium constant that applies to the dissolution of a slightly soluble compound, **817–819, 818, A16–A18**
- determination of, **820–822**
 - molar solubility and, **820–821, 822t, 822–823**
 - uses of, **822–828**
- Solubility product principle** The solubility product constant expression for a slightly soluble compound is the product of the concentrations of the constituent ions, each raised to the power that corresponds to the number of ions in one formula unit, **818**
- Solute** The dispersed (dissolved) phase of a solution, **102–103, 112, 535**
- amount of, calculation of, **109–110**
 - classification of, **129**
 - dissolution of, **535–536, 536i**
 - in water, bonding, solubility, and electrolyte characteristics of, **136t**
 - mass of, **104**
 - nonelectrolyte, **548**

- nonvolatile, solution of, vapor pressure of, 550
percent of, 103
and density, 104
- Solution stoichiometry**, 110–112
- Solution** A homogeneous mixture of two or more substances, 10, 102, **112**, 533–581
acid, standardization of, 405, 410–411
acidic, pH and pOH of, 751
aqueous. *See* **Aqueous solution(s)**.
base, standardization of, 405–406
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nonneutral aqueous, review of, 811t
normality of, 408–409
required volume of, calculation of, 111–112
saturated, 543
supersaturated, 543, 543i
use in chemical reactions, 109–112
- Solvation** The process by which solvent molecules surround and interact with solute ions or molecules, 535, **537**
- Solvent** The dispersing medium of a solution, **103**, 535
acetone as, 1067
leveling, 376
properties of, 556t
- Solvolysis** The reaction of a substance with the solvent in which it is dissolved, **768–769**
- Sommerfeld, Arnold, 200
- Soot, 258
- sp^2 Hybridization, 314
 sp^3 Hybridization, 318
 sp^3d^2 Hybridization, 332
 sp^3U^2 Hybrid orbitals, 332
 sp Hybrid orbitals, 311
 sp Hybridization, 312
 sp^2 Hybrid orbitals, 313–314, 336, 336i
- Space-filling molecular model**, definition of, *i53*, 52
- Specific gravity** The ratio of the density of a substance to the density of water at the same temperature, **33**
volume, and percentage by mass, 34
- Specific heat** The amount of heat required to raise the temperature of one gram of a substance one degree Celsius with no change in state; usually expressed in J/g·°C, **37–40**, A12.
See also **Molar heat capacity**.
comparison of, 39–40
- Spectator ions** Ions in solution that do not participate in a chemical reaction. They do not appear in net ionic equations, 136
- Spectral color** The color associated with the wavelengths of light that are absorbed, **988**
- Spectral line** Any of a number of lines corresponding to definite wavelengths in an atomic emission or absorption spectrum; these lines represent the energy difference between two energy levels, 194–195, 195i, 199i
- Spectrochemical series** An arrangement of ligands in order of increasing ligand field strength, **988–989**, 988i
- Spectrometry**, mass, and isotopic abundance, 184–187
- Spectroscopic method**, reaction rate and, 641i, 641–642
- Spectroscopy**, X-ray fluorescence, 181
- Spectrum** Display of component wavelengths of electromagnetic radiation
absorption, 194–195, 195i
atomic, 195, 196i
and Bohr atom, 194–201
continuous, **191**, 192i
emission, definition of, 190–193
- Speed of Light**, 191 A11
- Spin quantum number (m_s)** The quantum mechanical solution to a wave equation that indicates the relative spins of electrons (“spin up” and “spin down”), **206**, 206t
- Spontaneity**, 864
Gibbs free energy change and, 620–623
of chemical and physical changes, 612–627
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of physical and chemical changes, 612
temperature dependence of, 623–627
two aspects of, 612–613
- Spontaneous change** *See* **Product-favored change**.
- Spontaneous products**, 612
- Sports drinks, 566
- Square planar** A term used to describe molecules and polyatomic ions that have one atom in the center and four atoms at the corners of a square, 332i, 335t
- Square planar complex** A complex in which the metal atom or ion is in the center of a square plane, with a ligand donor atom at each of the four corners, 974t, **990**
- Square pyramidal** A term used to describe the molecular geometry of a molecule or polyatomic ion that has five atoms bonded to a central atom and one unshared pair on the central atom (AB₅U) reactants specified in the balanced chemical equation, all at standard states, is converted completely to the specified number of moles of products, all at standard states, 974t, **990**
- Stable isotope ratio analysis**, 186
- Standard cell** A cell in which all reactants and products are in their thermodynamic standard states (1 M for solution species and 1 atm partial pressure for gases), **852**
- Standard cell potential** The potential difference, E_{cell}^0 , between standard reduction and oxidation half-cells, **858–859**
Gibbs free energy change, and thermodynamic equilibrium constant, related, 878–879
Standard change, 594
Standard conditions, definition of, 866
- Standard electrochemical conditions** 1 M concentration for solution species, 1 atm partial pressure for gases, and pure solids and liquids, 866
- Standard electrode** A half-cell in which the oxidized and reduced forms of a species are present at unit activity: 1 M solutions of dissolved species, 1 atm partial pressure of gases, and pure solids and liquids, 866
- Standard electrode potential** By convention, the potential (E^0) of a half-reaction as a reduction relative to the standard hydrogen electrode, when all species are present at unit activity, 862, 863t, A19–A21
- Standard enthalpy change, ΔH_{rxn}^0** The enthalpy change in which the number of moles of reactants specified in the balanced chemical equation, all at standard states, is converted completely to the specified number of moles of products, all at standard states, **594**
- Standard entropy, S^0 (of a substance)** The absolute entropy of a substance in its standard state at 298 K, 616, **628**, A22–A23
- Standard entropy change, ΔS^0** The entropy change in which the number of moles of reactants specified in the balanced chemical equation, all at standard states, is converted completely to the specified number of moles of products, all at standard states, **617**
- Standard Gibbs free energy of formation (ΔG_f^0)**
- Standard hydrogen electrode (SHE)** An electrode consisting of a platinum electrode that is immersed in a 1 M H⁺ solution and that has H₂ gas bubbled over it at 1 atm pressure; defined as the reference electrode, with a potential of exactly 0.0000 . . . volt, 858
- Standard molar enthalpy of formation, ΔH_f^0 (of a substance)** The enthalpy change for the formation of one mole of a substance in a specified state from its elements in their standard states, **594–595**, A22–A23
- Standard molar volume** The volume occupied by one mole of an ideal gas under standard conditions; 22.414 liters, **441**
- Standard reaction** A reaction in which the numbers of moles of reactants shown in the balanced equation, all in their standard states, are completely converted to the numbers of moles of products shown in the balanced equation, also all at their standard states, **621**
spontaneity of, 622, 623
- Standard reduction potentials (E^0)**, 861–866, 863t, A19–A21
- Standard solution** A solution of accurately known concentration, **404**
- Standard state** (of a substance), 594. *See also* **Thermodynamic standard state of a substance**.
- Standard temperature and pressure (STP)** Standard temperature 0°C (273.15 K), and standard pressure, one atmosphere, are standard conditions for gases, **438**, 441
- Standard**, primary, 404
secondary, 404
- Standardization** The process by which the

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- concentration of a solution is accurately determined by titrating it against an accurately known amount of a primary standard, **404**
- Standing wave, definition of, **203**
- State function** A variable that defines the state of a system; a function that is independent of the pathway by which a process occurs, **587**
- differences in levels of, **587**
- Statue of Liberty, **154**
- Steam cracking, **248**
- Steel** Iron alloyed with other metals, such as Mn, Cr, Ni, W, Mo, and V, and sometimes with C and Si, **906, 907i**
- Stereochemistry, **1102**
- Stereoisomers** Isomers that differ only in the way in which atoms are oriented in space; they include geometric and optical isomers, **975, 978–982, 1103–1106**
- Stoichiometry** Description of the quantitative relationships among elements in compounds (composition stoichiometry) and among substances as they undergo chemical changes (reaction stoichiometry), **47**
- composition, chemical formulas and, **46–82**
- of reaction, **673**
- of redox reactions, **416–419**
- reaction, chemical equations and, **88–112**
- definition of, **89**
- solution, **110–112**
- Stoney, George, **176**
- Strong acid** An acid that ionizes (separates into ions) completely, or very nearly completely, in dilute aqueous solution. *See also* **Acid(s), strong. 130, 131t, 746t**
- Strong base** Metal hydroxide that is soluble in water and dissociates completely in dilute aqueous solution, **132–133, 133t, 746t**
- Strong electrolyte** A substance that conducts electricity well in dilute aqueous solution, **129, 745–746**
- Strong field ligand** A ligand that exerts a strong crystal or ligand electric field and generally forms low spin complexes with metal ions when possible. A ligand that forms a strong dative bond, **989, 991**
- Strontium, uses of, **925**
- Structural (constitutional) isomers** (Applied to coordination compounds.) Isomers whose differences involve more than a single coordination sphere or else different donor atoms; they include ionization isomers, hydrate isomers, coordination isomers, and linkage isomers, **975, 976–978, 1039, 1056, 1102–1103**
- of alkanes, numbers of, **1041t**
- Structural formula** A representation that shows how atoms are connected in a compound, **52**
- Styrene butadiene rubber, **1087**
- Subatomic particles, **175–190**
- Sublimation** The direct vaporization of a solid by heating without passing through the liquid state, **8i, 499i, 500, 502–503**
- vapor pressure of solids and, **500**
- Substance** Any kind of matter all specimens of which have the same chemical composition and physical properties, **13**
- common, densities of, **32t**
- physical properties of, **9t**
- Substitution reaction** A reaction in which an atom or a group of atoms attached to a carbon atom is replaced by another atom or group of atoms. No change occurs in the degree of saturation at the reactive carbon, **1079–1082**
- Substrate** A reactant in an enzyme-catalyzed reaction, **688**
- Sugar(s), and sucrose, relative sweetness of, **1120t**
- simple, **1118, 1119t**
- Sulfates, alkyl hydrogen, **1082**
- Sulfur, mining of, **946, 946i**
- occurrence of, **946, 947**
- oxoacids of, **950–951**
- uses of, **946**
- Sulfur dioxide, **948–949**
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- pollution caused by, **259, 260i**
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- Sulfur tetrafluoride, **290–291**
- Sulfur trioxide, **685, 688, 948–949**
- Sulfuric acid, **291–292, 378, 950–951**
- commercial, molarity of, **106–107**
- fuming, **949**
- Sulfurous acid, **378, 950**
- Supercritical fluid** A substance at a temperature above its critical temperature. A supercritical fluid cannot be described as either a liquid or gas, but has the properties of both, **502–503**
- Superoxide** A compound containing the superoxide ion, O_2^- (oxygen in the $-\frac{1}{2}$ oxidation state), **252**
- Supersaturated solution** A (metastable) solution that contains a higher-than-saturation concentration of solute; slight disturbance or seeding causes crystallization of excess solute, **542i, 543**
- Surface tension** The result of inward intermolecular forces of attraction among liquid particles that must be overcome to expand the surface area, **487–488**
- Surfactant** A “surface-active agent”; a substance that has the ability to emulsify and wash away oil and grease in an aqueous suspension, **573**
- Surroundings** Everything in the environment of the system, **586**
- Symbol (of an element)** A letter or group of letters that represents (identifies) an element, **15, 16t**
- Symmetrical ring structure, **1055**
- Synthetic polymers, **1085**
- System** The substances of interest in a process; the part of the universe under investigation, **586**
- at equilibrium, **615, 621, 623**
- thermodynamic state of, **587**
- t_{2g} orbitals** A set of d_{xy} , d_{yz} , and d_{zx} orbitals; those d orbitals within a set with lobes bisecting (midway between) the x , y , and z axes, **985**
- Table salt, production of, **15, 15i**
- Taconite, **905**
- Tannic acid, **574**
- Teflon, **1086**
- Tellurium, **945, 947**
- Temperature** A measure of the intensity of heat, that is, the hotness or coldness of a sample or object, **34, 676–679**
- and heat, **34–36**
- and vapor pressure, **490, 491i, 496**
- changes in, and equilibrium, **717–718**
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- effect of solubility, **544i, 544–546**
- equilibrium constant and, **734–735**
- kinetic energy and, **489, 489i**
- measurement of, **34**
- speeds of molecules of gas and, **457**
- spontaneity and, **623–627**
- Temperature conversion, **36**
- Terephthalic acid, **1114**
- Ternary acid** A ternary compound containing H, O, and another element, usually a nonmetal. *See also* **Acid, ternary. 143–145, 255**
- Ternary compound** A compound consisting of three elements; may be ionic or molecular, **143–145**
- Ternary oxoacids, **279**
- Ternary salts, definition of, **144**
- naming of, **144**
- Tertiary alcohol** An alcohol with three R groups bonded to the carbon bearing the —OH group, **1062**
- Tertiary amine** An amine in which three H atoms of ammonia have been replaced by organic groups, **1068**
- Tetrahedral** A term used to describe the electronic geometry around a central atom that has four regions of high electron density. Also used to describe the molecular geometry of a molecule or polyatomic ion that has one atom in the center bonded to four atoms at the corners of a tetrahedron (AB_4), **307t, 314–316**
- Tetrahedron** A polyhedron with four equal-sized, equilateral triangular faces and four apices (corners), **307t, 314–316**
- Theoretical yield** The maximum amount of a specified product that could be obtained from specified amounts of reactants, assuming complete consumption of the limiting reactant according to only one reaction and complete recovery of the product, **99**. Compare with **Actual yield**.
- Thermal equilibrium, **38, 38i**
- Thermal pollution** Introduction of heated waste water into natural waters, **545**
- Thermite reaction, **583, 926, 927i**
- Thermochemical equation** A balanced chemical equation together with a designation of the corresponding value of ΔH_{rxn} , **590–593**.

- Sometimes used with changes in other thermodynamic quantities, 590–593
 combining of, 597–598
 conventions for, 591
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 Thermochemistry, definition of, 584
 heat changes and, 584–612
 Thermodynamic equilibrium constant, calculation from cell potentials, **879**
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Thermodynamic standard state of a substance
 The most stable state of the substance at one atmosphere pressure and at some specific temperature (25°C unless otherwise specified), **593–594**
 conventions for, 594
Thermodynamic state of a system A set of conditions that completely specifies all of the properties of the system, **587**
Thermodynamically favorable (spontaneous) reaction A reaction that occurs with a net release of free energy, G ; a reaction for which ΔG is negative (see Section 15-15), 621
Thermodynamics The study of the energy transfers accompanying physical and chemical processes, **584**
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 third law of, 616, 617
 Thermometer, mercury, 34–35, 35*i*
 Thermonuclear bomb(s), 1026
Thermonuclear energy Energy from nuclear fusion reactions, 1024–1025
Third Law of Thermodynamics The entropy of a hypothetical pure, perfect, crystalline substance at absolute zero temperature is zero, **616–617**
 Thomson, J.J., 177, 179, 198
 Three Mile Island, 154
 Time, concentration versus, for reactant, 656–667, 659*i*
 Tire gauge, 432*i*
 Titanium, density of, 514
Titration The process by which the volume of a standard solution required to react with a specific amount of a substance is determined, **401–404**
 process of, 401, 401*i*
 redox, 416–419
Titration curve (for acid–base titration) A plot of pH versus volume of acid or base solution added, **804–806**, 807*i*
 strong acid/strong base, 804–806, 807*i*
 weak acid/strong base, 807–808, 809*i*, 809*t*
 TNT, 1081
Torr A unit of pressure; the pressure that will support a column of mercury 1 mm high at 0°C, 428–429
 Torricelli, Evangelista, 427
Total ionic equation An equation for a chemical reaction written to show the predominant form of all species in aqueous solution or in contact with water, **135–136**
 Trace elements, 919–921
 biological functions of, 921
 classification of, 919
 dietary, 920
 Transition metals, 232
Transition state A relatively high-energy state in which bonds in reactant molecules are partially broken and new ones are partially formed, 669–670
Transition state theory A theory of reaction rates that states that reactants pass through high-energy transition states before forming products, 669–672, **671**
 Transistors, 521
Transuranium elements The elements with atomic numbers greater than 92 (uranium); none occurs naturally and all must be prepared by nuclear bombardment of other elements, **1005**
Trigonal bipyramid A six-sided polyhedron with five apices (corners), consisting of two pyramids sharing a common triangular base, 310*t*, **327–330**, 335*t*
Trigonal bipyramidal A term used to describe the electronic geometry around a central atom that has five regions of high electron density. Also used to describe the molecular geometry of a molecule or polyatomic ion that has one atom in the center bonded to five atoms at the corners of a trigonal bipyramid (AB_5), 310*t*, **327–330**, 335*t*
Trigonal planar (also plane triangular) A term used to describe the electronic geometry around a central atom that has three regions of high electron density. Also used to describe the molecular geometry of a molecule or polyatomic ion that has one atom in the center bonded to three atoms at the corners of an equilateral triangle (AB_3), 340*t*
Trigonal pyramidal A term used to describe the molecular geometry of a molecule or polyatomic ion that has three atoms bonded to a central atom and one unshared pair on the central atom (AB_3U), 320–324, 334*t*
Triple bond A covalent bond resulting from the sharing of six electrons (three pairs) between two atoms, **338–339**, 339*i*
Triple point The point on a phase diagram that corresponds to the only pressure and temperature at which three phases (usually solid, liquid, and gas) of a substance can coexist at equilibrium, **502**
 Triple-beam balance, 181
Trisaccharide A molecule consisting of three monosaccharides joined together by glycosidic bonds, 1121
 Tritium, 1026
T-shaped A term used to describe the molecular geometry of a molecule or polyatomic ion that has three atoms bonded to a central atom and two unshared pairs on the central atom (AB_3U_2), **330**, 335*t*
Tyndall effect The scattering of light by colloidal particles, **570**, 570*i*
Unit cell The smallest repeating unit showing all the structural characteristics of a crystal
 cubic, **508**, 508*i*
 of crystals, 506*i*, 506*t*, 506–507, 507*i*, 508*i*
 Unit conversions, 27–28
Unit factor A factor in which the numerator and denominator are expressed in different units but represent the same or equivalent amounts. Multiplying by a unit factor is the same as multiplying by one, **26–27**
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 Unit factor approach, 81
 Unit factor method, definition of, 26–30
 Units, in measurements, 26
Universal gas constant R , the proportionality constant in the ideal gas equation, $PV = nRT$, **442**
 units of, 442–443
 Universal indicator papers, 753, 753*i*
Universe The system plus the surroundings, 586
 entropy of, **614**
Unsaturated hydrocarbons Hydrocarbons that contain double or triple carbon–carbon bonds, **1036**, 1042, 1047–1058
Unshared pair See **Lone pair**.
 Uranium, for nuclear fission reactors, 1021
 Uranium–lead, for radioactive dating, 1011, 1012–1013
Valence bond (VB) theory Assumes that covalent bonds are formed when atomic orbitals on different atoms overlap and electrons are shared, **276**, 303, 309
 AB_3 , AB_4U , AB_3U_2 , and AB_2U_3 molecules and, 328–329
 AB_6 , AB_5U , and AB_4U_2 molecules and, 331–332
 AB_3 molecules and, 313
 AB_2 molecules and, 311–312
 AB_4 molecules and, 317–319
 AB_3U molecules and, 323–324
 AB_2U_2 molecules and, 325
Valence electrons The s and p electrons in the outermost shell of an atom, **267**, 276–277
Valence shell The outermost occupied electron shell of an atom, **303**
 expanded, 287, 290
Valence shell electron pair repulsion (VSEPR) theory Assumes that valence electron pairs are arranged around the central element of a molecule or polyatomic ion so that there is maximum separation (and minimum repulsion) among regions of high electron density, **303**, 305–306
 AB_6 , AB_5U , and AB_4U_2 molecules and, 331
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 AB₃U molecules nd, 320–323
 AB₂U₂ molecules nd, 325–325
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van der Waals equation An equation of state that extends the ideal gas law to real gases by inclusion of two empirically determined parameters, which are different for different gases, **465**, 466
 van der Waals forces, 485–486
 van Vleck, J.H., 985
van't Hoff equation The relationship between ΔH^0 for a reaction and its equilibrium constants at two different temperatures, **734**
van't Hoff factor, *i* A number that indicates the extent of dissociation or ionization of a solute; equal to the actual colligative property divided by the colligative property calculated assuming no ionization or dissociation, **560**
Vapor A gas formed by boiling or evaporation of a liquid or sublimation of a solid; a term commonly used when some of the liquid or solid remains in contact with the gas, **427**, 549
 composition of, 551–552
Vapor pressure The partial pressure of a vapor in equilibrium with its parent liquid or solid, **452**, 453*t*, 490*t*, 490–492
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 of solids, sublimation and, 500
 of solution of nonvolatile solutes, 550
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 Velcro, 486
 Viscometer, Ostwald, 487*i*
Viscosity The tendency of a liquid to resist flow; the inverse of its fluidity, **487**
 Volatile liquids, 491
Volatility The ease with which a liquid vaporizes, 491, **525**
 Volta, Alessandro, 852
Voltage Potential difference between two electrodes; a measure of the chemical potential for a redox reaction to occur, 852, **886**
Voltaic cell An electrochemical cell in which spontaneous chemical reactions produce electricity; also called a galvanic cell, **843**, **852**–857
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Vulcanization The process in which sulfur is added to rubber and heated to 140°C, to cross-link the linear rubber polymer into a three-dimensional polymer, **1086**
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 Wave function, 350
 Wave(s), constructive and destructive interference of, **350**, 351*i*
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Wavelength (λ) The distance between two identical points of a wave, **190**–191, 191*i*
 Wavelength, de Broglie, 201
 definition of, 190
 of light, 192–193
 of water waves, 190–191, 191*i*
 Waxes, definition of, **1075**
Weak acid An acid that ionizes only slightly in dilute aqueous solution. *See also* **Acid(s)**, **weak**. **753**–759, 754*t*
Weak base A molecular substance that ionizes only slightly in water to produce an alkaline (base) solution, 753, **762**–763, 763*t*
Weak electrolyte A substance that conducts electricity poorly in dilute aqueous solution, 129–131
Weak field ligand A ligand that exerts a weak crystal or ligand field and generally forms high spin complexes with metals. A ligand that forms a weak dative bond, **989**
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Weight A measure of the gravitational attraction of the earth for a body, **18**
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 Wideroe, Rolf, 1017
 Wilson, C.T.R., 1006
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Work The application of a force through a distance; for physical changes or chemical reactions at constant external pressure, the work done on the system is $-P\Delta V$, 605
 and heat, 605, 605*i*
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 Zinc deficiency, 920–921
 Zinc sulfate, 152
 Zinc–copper cell, 853*i*, 853–854
 Zinc–SHE cell, 858–860, 859*i*
Zone refining A method of purifying a bar of metal by passing it through an induction heater; this causes impurities to move along in the melted portion, **900**, 901*i*