



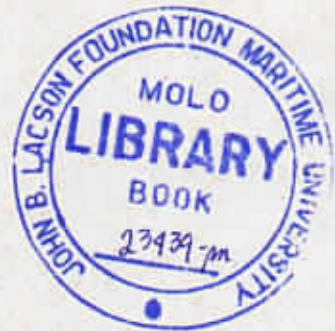
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Principles and Reactions:  
**Chemistry**   
for Engineering Students

William L. Masterton • Cecile N. Hurley • James F. Petersen • Dorothy Sack • Robert E. Gabler

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Principles and Reactions:

# Chemistry

## for Engineering Students

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**Notes:** Boldface terms are defined in the context used in the text; italic locators indicate figures; † indicates a table.

- A**  
**A. See** Mass number  
**Abbreviated electron configuration** Brief notation in which only those electrons beyond the preceding noble gas are shown. The abbreviated electron configuration of the Fe atom is [Ar]4s<sup>2</sup>3d<sup>6</sup>, 140, 140†  
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**Acetylsalicylic acid (ASA)**, 52–53, 52  
**Acid** An aqueous solution in which [H<sup>+</sup>] is greater than 10<sup>-7</sup> M 45–48  
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**Acid-base solutions, equilibria in**  
   acid-base indicators, 371–373, 384b  
   acid-base titration, 371–382, 384b–384c  
   buffers, 360–371, 384–384b  
**Acid-base titrations** Procedures used to determine the concentration of an acid or base. The volume of a solution of an acid (or base) of known molarity required to react with a known volume of base (or acid) is measured, 85, 371–374, 374  
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   strong acid-weak base, 379–380  
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**Acid equilibrium constant (K<sub>a</sub>)** The equilibrium constant for the ionization of a weak acid, 339–343, 351–352, 352†, 364, 372  
**Acidic ion** Ion that forms H<sup>+</sup> ions in water. The ammonium ion is acidic because of the reaction, NH<sub>4</sub><sup>+</sup>(aq) ⇌ H<sup>+</sup>(aq) + NH<sub>3</sub>(aq), 339  
**Acidic oxide**, 537

- Acidic solution** An aqueous solution with a pH less than 7, 80, 92, 111, 338, 353, 432, 441, 520–522  
**Acid indigestion**, 93  
**Acidosis**, 336  
**Acid rain**, 382–383  
**Acrylic resins**, 577†  
**Acrylonitrile**, 577†  
**Actinides** Elements 89 (Ac) through 102 (No) in the periodic table, 142  
**Actinium**, 142  
**Activated complex** An unstable high-energy species that must be formed before the reaction can occur, 291–292  
**Activation energy** The minimum energy that must be possessed by a pair of molecules if collision is to result in reaction, 290, 291–293, 292, 294, 295–296, 297, 298  
**Activity (A)** Rate of radioactive decay; number of atoms decaying per unit time, 473–475  
**Addition polymer** Polymer produced by a monomer, usually a derivative of ethylene, adding to itself; no other product is formed, 577–580  
**Addition reactions** Reactions in which a small molecule (e.g., H<sub>2</sub>) is directly inserted into a double or triple bond, 572  
**Adenosine triphosphate (ATP)**, 426–427, 426  
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**Alanine**, 589†, 592  
**Alanylglycine**, 592  
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**Alcohol dehydrogenase**, 523  
**Alcoholic beverages**, 560  
**Alcohols** Compounds containing an —OH group attached to a hydrocarbon chain. The simplest example is CH<sub>3</sub>OH, 37, 256†, 558–561, 559†, 560†  
**Aldehydes** Compounds containing the carbonyl group —CHO bonded to two hydrocarbons, 559†, 561–562, 562  
**Aleve**, 571  
**Alkali halides**, 242  
**Alkali metals** Metals in Group 1 of the periodic table, 33–34, 513  
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**Alkaline earth metals** Metals in Group 2 of the periodic table, 34, 513  
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   oxygen, reaction with, 514–516  
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**Alkaloids**, 358  
**Alkanes** Hydrocarbons containing only single carbon-carbon bonds. The simplest example is methane, CH<sub>4</sub>, 548–553, 548, 550†, 560†  
**Alkenes** Hydrocarbons containing one carbon-carbon double bond. The simplest alkene is C<sub>2</sub>H<sub>4</sub>, 553–555, 572, 573  
**Alkyl group** A hydrocarbon functional group based on an alkane, 550–551, 550†, 559  
**Alkynes** Hydrocarbons containing one carbon-carbon triple bond. Example: HC≡CH, 554, 555–556


**Allotrope** One of two or more forms of an element in the same physical state. Graphite and diamond are allotropes of carbon; O<sub>2</sub> and O<sub>3</sub> are allotropes of oxygen, 545

- Alloy**, 3  
**Almonds**, 562  
**Alpha particle** A helium nucleus; He<sup>2+</sup> ion, 467, 468, 469†  
**Alpha particle emission**, 467  
**Aluminium**, 60–61  
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   percent abundance, 4†  
   and specific heat, 190  
**Aluminum hydroxide**, 542  
**Aluminum salts**, 340  
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**Americium**, 470†  
**Amine** An amine can be considered to be a derivative of ammonia in which one or more hydrogen atoms have been replaced by hydrocarbon groups, 37, 81, 357–358, 357†, 559†, 568–566  
**α-amino acids** Compounds that have both an NH<sub>2</sub> group and a COOH group attached to the same carbon atom, 588–592, 589†  
**Ammonia**  
   acid-base titration, 379–380  
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**Ammonium ion**, 340†, 353, 355, 366, 366†, 380, 380  
**Ammonium nitrate**, 197, 410, 526  
**Amount**, 96. *See also* Mass; Mole  
**Ampere (A)** Rate of flow of electric current such that one coulomb passes a given point in one second, 453, 453†  
**Amphetamine**, 571  
**Amphiprotic species** Capable of acting as either a Bronsted-Lowry acid or base, 332, 333  
**Amplitude (W)** Height of a standing wave, 125, 133  
**Anesthetic**, 561  
**Aniline**, 557  
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- Anions** Ions with a negative charge. Examples include  $\text{Cl}^-$  and  $\text{OH}^-$ , 37–38  
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 and ionic solid dissolved in water, 56  
 and ionic solids, 235  
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- Anode** Electrode at which oxidation occurs and toward which anions move, 430, 435, 436–437, 452, 453
- Anode half-cell**, 436
- Antacids**, 93, 93t
- Anthracene**, 558
- Antifreeze**, 264, 561
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- Arginine**, 589t, 593
- Argon**, 34, 139, 184, 185, 223t
- Arlington National Cemetery**, 596
- Armbruster**, Peter, 470
- Aromatic hydrocarbons** Hydrocarbons containing one or more benzene rings, 556–558, 575a
- Arrhenius**, Svante, 80, 87, 331–332
- Arrhenius acid** Species that, upon addition to water, increases  $[\text{H}^+]$ , 80, 81
- Arrhenius base** Species that, upon addition to water, increases  $[\text{OH}^-]$ , 80, 81
- Arrhenius equation** Equation that expresses the temperature dependence of the rate constant:  $(E_a/R)(1/T_1 - 1/T_2)$ , 294–296, 294, 327, 356t
- Arsenic**, 20, 31–32, 545–546
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- Aspirin**, 52–53, 52, 342, 342, 357
- Assay**, 252
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- Atmosphere (atm)** Unit of pressure equal to 101.325 kPa; equivalent to the pressure exerted by a column of mercury 760 mm high, 97, 424
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- ATP (adenosine triphosphate)**, 426–427, 426
- Atom** Smallest particle of an element that retains the chemical properties of that element, 22–23  
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- Atomic bomb**, 480–481, 480
- Atomic mass** Average mass of an atom compared to that of another element, based upon the C-12 scale, 28, 50a–50b, 87
- Atomic mass units (amu)** The units used to express atomic masses; 1/12 of the mass of a carbon-12 atom, 28
- Atomic nucleus**, 25–26
- Atomic number (Z)** Number of protons in the nucleus of an atom, 26, 466
- Atomic orbital model**. See **Valence bond model**
- Atomic orbitals**, 138, 156, 178–184, 186b
- Atomic radius** One half of the distance of closest approach between two nuclei in the ordinary form of an element, 148–150, 148, 149, 239–240, 239
- Atomic spectrum** Diagram showing the wavelength at which light is emitted by excited electrons in an atom, 129–130, 130t, 154a
- Atomic theory** Dalton's theory of the atomic nature of matter, 22–23, 23, 24, 50–50a
- Atomic weights**, 28. See also **Atomic mass**
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- Average speed of gas molecules**  $u = \left(\frac{3RT}{MM}\right)^{1/2}$ , 115–117
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- Avogadro's number ( $N_A$ )**  $6.022 \times 10^{23}$ ; the number of units in a mole, 31–32, 52, 54, 65, 109, 115
- B**
- Baking powder**, 740
- Baking soda**, 52
- Ball-and-stick model**, 36, 161
- Balmer series**, 129, 132
- Bar** Unit of pressure =  $10^5 \text{ Pa} = 1.013 \text{ atm}$ , 97
- Barium hydroxide**, 81t, 336
- Barium ion**, 397
- Barium sulfate**, 390, 393
- Barometer**, 96, 96
- Bartlett**, Neil, 184
- Base** Compound that dissolves in water to give a solution in which  $[\text{OH}^-]$  is greater than  $10^{-7} \text{ M}$   
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 alternative definitions of, 356t  
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 ion product of water, 333  
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 weak bases and their equilibrium constants, 348–352
- Base equilibrium constant ( $K_b$ )** The equilibrium constant for the ionization of a weak base, 349, 351–352, 352t
- Basic anhydrides**, 515
- Basic ion** An anion that forms  $\text{OH}^-$  ions in water; the  $\text{CO}_3^{2-}$  ion is basic because of the reaction  $\text{CO}_3^{2-}(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{HCO}_3^-(\text{aq}) + \text{OH}^-(\text{aq})$ , 348
- Basic solution** An aqueous solution with a pH greater than 7 (at 25°C), 80, 84, 334, 338, 432, 441, 520, 522, 542
- Bauxite ore**, 509–510
- Becquerel**, Henri, 473
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- Bent molecule** Molecule containing three atoms in which the bond angle is less than 180°; examples include  $\text{H}_2\text{O}$  and  $\text{SO}_2$ , 166
- Benzaldehyde**, 562
- Benzedrine**, 571
- Benzene**  
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- Beta particles** High speed energy electrons emitted by the nucleus during radioactive decay or fission, 467, 468, 468, 469t
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- Blood sugar**, 585
- Body-centered cubic cell (BCC)** A cubic unit cell with an atom at each corner and one at the center, 238–239, 238, 239t
- Bohr**, Niels, 130
- Bohr model** Model of the hydrogen atom developed by Niels Bohr; it predicts that the electronic energy is  $-R_H/n^2$ , where  $R_H$  is the Rydberg constant and  $n$  is the principal quantum number, 130–132
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- Boiling point** Temperature at which the vapor pressure of a liquid equals the applied pressure, leading to the formation of vapor bubbles, 16, 221–222  
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- Boiling point elevation ( $\Delta T_b$ )** Increase in the boiling point caused by addition of a nonvolatile solute, 261–264
- Boltzmann**, Ludwig, 114
- Bombardment reactions**, 469–471, 470t
- Bomb calorimeter** Device used to measure heat flow, in which a reaction is carried out within a sealed metal container, 193–195, 194
- Bonaparte**, Napoleon, 20, 545–546
- Bond angle** The angle between two covalent bonds, 166, 169–170, 180, 548
- Bonded atoms**, 169
- Bond energy**. See **Bond enthalpy**
- Bond enthalpy** The enthalpy change (kJ/mol) when a particular type of bond is broken in the gas state, 207–209, 208t, 208
- Bond polarity**. See **Polarity**
- Boric acid**, 164, 356
- Boron**, 143–144, 179
- Boron trifluoride**, 163, 164, 167, 168, 531
- Boyle**, Robert, 338
- Boyle's law** Relation stating that at constant  $T$  and  $n$ , the pressure of a gas is inversely proportional to its volume, 99, 218

- Bragg, William H., 241  
 Bragg, William L., 241  
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   reactivity of, 528  
 Bromthymol blue, 372, 373, 373t, 374, 376, 377  
 Brønsted, Johannes, 332  
 Brønsted-Lowry acid A species that donates a proton in an acid-base reaction; in the reaction  $\text{HB}(aq) + \text{A}^-(aq) \rightleftharpoons \text{HA}(aq) + \text{B}^-(aq)$ , HB is a Brønsted-Lowry acid, 332, 336, 347, 351, 352t, 531, 590  
 Brønsted-Lowry acid-base model, 374, 379  
   ion product of water, 333  
   vs. the Lewis model, 355, 356t  
   overview of, 331-332  
   with weak acids, 339  
 Brønsted-Lowry base A species that accepts a proton in an acid-base reaction; in the reaction  $\text{HB}(aq) + \text{A}^-(aq) \rightleftharpoons \text{HA}(aq) + \text{B}^-(aq)$ ,  $\text{A}^-$  is a Brønsted-Lowry base, 332, 336, 351, 352t, 531, 590  
 Buffer A system whose pH changes only slightly when strong acid or base is added. A buffer ordinarily consists of a weak acid and its conjugate base, present in roughly equal amounts  
   applications of, 362  
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   effect of, 361  
   effect of added  $\text{H}^+$  or  $\text{OH}^-$ , 368-370  
   introduction to, 360-362  
   selection of, 364-368  
 Buffer capacity Amount of strong acid or base that can be added to a buffer without causing a drastic change in pH, 370-371  
 Buffer range, 370-371  
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 Butane, 549, 549, 550, 550t, 552, 560t  
 Butanol, 256t  
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 Calcium propionate, 563  
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 Calvin, Melvin, 165  
 Camphor, 264t  
 Canada, 482  
 Cancer treatment, 471, 471  
 Cannizzaro, Stanislao, 109  
 Carbohydrates Large biological molecules made up of carbon, hydrogen and oxygen, 583-587, 597a  
 Carbon. *See also* Organic chemistry  
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   in iron and steel production, 509-510  
   percent abundance, 4t  
   as a reducing agent, 509  
   valence electrons, 158  
 Carbon-12, 471, 475  
 Carbon-12 scale Atomic mass scale where the C-12 isotope is assigned a mass of exactly 12 amu, 28  
 Carbon-14, 475  
 Carbonated beverages, 257, 257, 259, 259  
 Carbonate ion, 353, 502  
 Carbonates, 390t, 400  
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   and sodium hydroxide, 64-65  
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   supercritical carbon dioxide, 243-244  
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   and high temperatures, 299  
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   reaction energy diagram, 292  
   spontaneous oxidation of, 425-426  
   transition-state model, 291-293  
 Carbon tetrachloride, 176, 176, 226  
 Carbonyl group The group  $\begin{array}{c} \diagup \\ \text{C} \\ \text{||} \\ \text{O} \end{array}$  found in aldehydes and ketones, 361  
 Carboxylic acids Organic compounds containing the  $\begin{array}{c} \text{O} \\ \text{||} \\ \text{C}-\text{OH} \end{array}$  group, 356-358, 559t, 562-565  
 Carotenoids, 153  
 Carothers, Wallace, 582  
 Carrier gas, 6  
 Carus, Titus Lucretius, 576  
 Catalase, 298  
 Catalysis, 296-298, 297, 305t  
 Catalyst A substance that increases the rate of a reaction without being consumed by it, 296-298  
 Catalytic converter, 297, 297  
 Cathode Electrode at which reduction occurs and toward which cations move, 430, 435, 436-437, 452, 453  
 Cathode half-cell, 436  
 Cathode ray, 23, 24  
 Cations Ions with a positive charge, such as  $\text{Na}^+$ , 37  
   colors of, 503  
   complexes with ammonia and hydroxide, 401t  
 Group I, 403-404  
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   of transition metals, equilibria between, 519-521  
   as weak acids, 339, 340  
   as weak acids or spectator ions, 353  
 Cellulose, 587, 587  
 Cell voltage A measurement of the current flow in an electrochemical cell, 439  
 Celsius, Anders, 8  
 Celsius ( $^{\circ}\text{C}$ ) Unit of temperature based on there being  $100^{\circ}$  between the freezing and boiling points of water, 8-9, 8  
 Centi Metric prefix indicating a multiple of  $10^{-3}$ , 7t  
 Central atom Atom at the center of a molecule, to which two or more atoms are bonded. C is the central atom in  $\text{CH}_4$ , 158, 488  
 Ceres (god), 48  
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 Chadwick, James, 473  
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 Chalcocite, 38, 511  
 Charge balance, 77  
 Charged particle, 470  
 Charles's and Gay-Lussac's law Relation stating that at constant  $P$  and  $n$ , the volume of a gas is directly proportional to its absolute temperature, 99, 99  
 Chelates Compounds that have a metal cation bonded at two or more points to nonmetal anions or molecules, 490, 490, 503-504  
 Chemical equation Expression that describes the nature and relative amounts of reactants and products in a reaction, 63-65. *See also* Equations  
 Chemical kinetics Study of reaction rates, 87, 274, 292. *See also* Reaction rate  
 Chemical properties Properties of a substance that are observed during a chemical reaction, 15-16, 16  
 Chemical reactivity, 526-529  
 Chemical warfare, 71  
 Chernobyl accident, 482  
 Chiral center Carbon atom bonded to four different groups, 569-571, 584, 588  
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- Chlorine trifluoride, 163  
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 Chromium(III) nitrate, 147  
 Chromium(III) oxide, 521  
 Chromium(III) salts, 520  
 Chromium-oxygen compounds, 24  
 Cinnamaldehyde, 562  
 Cinnabar, 4, 511  
 Cinnamon, 562  
**Cis isomer** Geometric isomer in which two like groups are relatively close to another (e.g., a, 495-497, 496, 497, 567-568)
- 
- Citric acid, 340, 357t  
 Clapeyron, B. P. E., 220  
 Clathrates, 71  
 Clausius, Rudolph, 114, 220, 409  
**Clausius-Clapeyron equation** An equation expressing the temperature dependence of vapor pressure:  $\ln(P_2/P_1) = \Delta H_{\text{vap}}/RT_1 - 1/T_2)/R$ , 220, 295, 327  
 Clausen, Walter, 72  
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 Cobalt, 520t  
 Cobalt-60, 471, 471  
 Cobalt chloride, 71  
 Cobalt(II) chloride, 147  
 Cobalt(II) oxide, 516  
**Coefficient rule** Rule which states that when the coefficients of a chemical equation are multiplied by a number  $n$ , the equilibrium constant is raised to the  $n$ th power, 311-312t  
 Coefficients, 64, 65, 67  
**Coffee-cup calorimeter** Calorimeter made of nested coffee cups in which essentially all of the heat given off by a reaction is absorbed by a known amount of water, 192-193, 192, 197  
 Coke, 509-510  
 Cold pack, 197  
 Coleridge, Samuel Taylor, 246  
 Collagen, 595  
**Colligative properties** Physical properties of a solution that primarily depend on the concentration rather than the kind of solute particle. Vapor pressure lowering is a colligative property; color is not.  
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 of electrolytes, 269-271, 273d  
 freezing point lowering, 262-264  
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 lithium-ion (Li-ion) batteries, 460-461  
 primary (nonrechargeable) voltaic cells, 458-459  
 sodium chloride, electrolysis of, 457  
 storage (rechargeable) voltaic cells, 459-460
- Common ion effect** The reduction in the solubility of a salt in a solution that contains either an anion or a cation common with that salt, 393-394  
 Complex anions, 492-493  
 Complex cations, 492  
 Complex formation, 386, 401-403, 402  
**Complex ion** An ion containing a central metal atom bonded to two or more ligands. The species  $\text{Ag}(\text{NH}_3)_2^+$  and  $\text{Zn}(\text{H}_2\text{O})_6^{2+}$  are complex ions.  
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 geometry of, 491t, 494-497, 505a  
 introduction to, 487-488  
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 naming, 492-493, 505a  
 precipitate formation, 394-398  
 solubility, 388-394  
**Compound** Substance containing more than one element, 3, 4-5, 23, 42-43, 50c, 411t  
**Concentration** A measure of the relative amounts of solute and solvent in a solution; may be expressed as molarity, mole fraction, etc., 54  
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**Concentration units**  
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 mole fraction, 249  
 for solutions, 246-254  
 and time, 276, 277  
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 Condensation, 217, 222, 264-265, 264  
**Condensation polymer** A polymer formed from monomer units by splitting out a small unit, most often a water molecule, 580-583  
**Condensation reactions** Reactions in which two molecules combine to produce a larger molecule and a small molecule (e.g.,  $\text{H}_2\text{O}$ ), 572  
 Condensed ring structures, 558  
**Condensed structural formula** Formula of a molecule which indicates the functional group present (e.g.,  $\text{CH}_3\text{COOH}$  for acetic acid), 36  
**Conductivity** The relative ease with which a sample transmits electricity. Because a much larger electrical current will flow through an aluminum rod at a given voltage than through a glass rod of the same shape, aluminum is a better electrical conductor than glass, 40, 40, 226, 233, 235, 236  
 Conine, 358  
**Conjugate acid** The acid formed by adding a proton to a base;  $\text{NH}_4^+$  is the conjugate acid of  $\text{NH}_3$ , 332, 352t  
**Conjugate base** The base formed by removing a proton from an acid;  $\text{NH}_2^-$  is the conjugate base of  $\text{NH}_3$ , 332, 339, 340t, 352t, 365  
 Conservation of mass, law of, 24  
 Constant composition, law of, 24  
 Contact process, 543  
 Continuous visible spectra, 129  
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**Conversion factor** A ratio, numerically equal to 1, by which a quantity can be converted from one set of units to another, 12-14  
 Conversions, 53-54, 54, 251-254  
 Coordinate covalent bonds, 488  
**Coordination compounds** Compounds in which there are complex ions. Examples include  $[\text{Cu}(\text{NH}_3)_4]\text{Cl}_2$  and  $\text{K}_4[\text{Fe}(\text{CN})_6]$ , 487, 488-489, 492-493, 498, 498, 505a  
**Coordination number** The number of bonds from the central metal to the ligands in a complex ion, 488, 491, 491t, 494-495, 494  
**Copper**  
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 and electrolysis, 511-512  
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 Copper(II) chloride, 494  
 Copper(II) salt, 488  
 Copper(II) sulfate, 147  
 Copper(I) sulfide, 511-512  
 Copper nails, 52  
 Copper sulfate, 6, 71, 127, 226, 247, 444, 444  
 Copper tetramine, 489, 492  
**Core electrons** Electrons in an inner, complete level, 150, 157  
 Cosby, Bill, 409  
**Coulomb (C)** A unit of quantity of electricity;  $9.648 \times 10^4 \text{ C} = 1 \text{ mol } e^-$ , 453, 453t  
 Coulomb's law of electrostatic attraction, 130  
**Coupled reactions** Two reactions that add to give a third, 425-427, 429d  
**Covalent bond** A chemical link between two atoms produced by sharing electrons in the region between the atoms, 35, 36, 36  
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 compared to intermolecular forces, 232  
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 molecular geometry, 166-174  
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 polarity of molecules, 174-178  
 valence bond model, 178-179  
 Crick, Francis, 595  
 Critical mass, 481  
**Critical pressure** The pressure at the critical temperature; the highest vapor pressure that a liquid can have, 222-223  
**Critical temperature** The highest temperature at which a substance can exhibit liquid-vapor equilibrium. Above that temperature, liquid cannot exist, 222-223, 222, 223t  
 Crosslinking, 427, 428  
 Crowfoot, 547  
 Crustacyanin, 153, 153  
 Crutzen, Paul, 303  
 Cryolite, 509  
 Crystal field energy, 505a-505b  
**Crystal field model** Electrostatic model of the bonding in complex ions. The only effect of the ligands is to change the relative energies of the d orbitals of the central metal atom, 498  
**Crystal field splitting energy** The difference in energy between the two sets of d orbitals in a complex ion, 500-502, 500  
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 Cucumber, 266, 266

- Curie, Irene. See Joliot-Curie, Irène  
 Curie, Marie, 241, 467, 473  
 Curie, Pierre, 473  
**Curies** (unit) (Ci) Units of radiation corresponding to the radioactive decay of  $3.700 \times 10^{10}$  atoms/s, 474  
 Curiosity (Mars rover), 63, 63  
 Curium, 470t  
 Cyalume light, 293  
 Cyanide, 494  
 Cyanide process, 512–513, 512  
**Cycloalkanes** Saturated hydrocarbons containing closed rings. General formula  $C_nH_{2n}$ , 553, 553  
 Cyclohexane, 264t, 553  
 Cyclopentane, 553  
 Cysteine, 589t  
 Cystic fibrosis, 452
- D**  
 Dalton, John, 22–23, 23, 24, 109, 111, 258  
**Dalton's law** A relation stating that the total pressure of a gas mixture is the sum of the partial pressures of its components, 111  
 Davy, Humphry, 458  
 De Broglie, Louis, 132  
 Debye, Peter, 271  
 Decaffeinated coffee, 243  
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 Decomposition rate, 277, 278, 278, 280, 285, 285t, 297, 298  
 Dehydrating agents, 544  
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 Denatured alcohol, 560  
**Density** The ratio of the mass of a substance to its volume, 16–18, 18, 103–105, 105, 225, 226, 234  
 Deoxyribonucleic acid (DNA), 595–596, 595  
**Deposition** The phase transition from the vapor phase to the solid phase, without passing through the liquid phase, 225  
 Deuterium, 484  
 Dexamethasone, 571  
**Diamagnetic** A term indicating that a substance does not contain unpaired electrons and so is not attracted into a magnetic field, 144  
 Diamine, 582  
 Diamminediacquacopper(II), 492  
 Diamminesilver (I) ion, 494  
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 and compression, 325–326, 325t, 325  
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 and temperature, 326–328, 326  
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**Dinitrogen trioxide**, 535  
**Dipole** Species in which there is a separation of charge (i.e., a positive pole at one point and a negative pole at a different point), 174–176  
**Dipole forces** Attractive forces between polar molecules, 228–229, 228  
**Dipole moment**, 175  
 Diprotic acids, 346, 380–382, 381  
**Disaccharides** The carbohydrates formed when two monosaccharides undergo a condensation reaction, 584  
**Dispersion force** An attractive force between molecules that arises because of the presence of temporary dipoles, 227, 227, 550  
**Disproportionation** A reaction in which a species undergoes oxidation and reduction simultaneously, 519, 532, 532  
 Distillation, 6, 7  
 DNA fingerprinting, 595–596, 595  
 Dogs, 161  
 D orbitals, 498–499, 499, 500, 501  
**Double bond** Two shared electron pairs between two bonded atoms, 158  
 Double helix model, 595–596, 596  
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 Dry cells, 458–459  
 Dry cleaning industry, 244  
 Dry ice. See Carbon dioxide  
 Dubnium, 470t  
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- E**  
 $E^\circ$ . See Standard cell voltage  
 $E^\circ_{\text{red}}$ . See Standard reduction voltage  
 $E^\circ_{\text{ox}}$ . See Standard oxidation voltage  
 Eckberg, Anders, 49  
*E. coli*, 472  
 EDTA (Ethylenediaminetetraacetate) ion, 504, 504  
**Effective nuclear charge** Positive charge felt by the outermost electrons in an atom; approximately equal to the atomic number minus the number of electrons in inner, complete levels, 150  
**Efflorescence** Loss of water by a hydrate, 71  
**Effusion** Movement of gas molecules through a pinhole or capillary, 117–119, 119  
 Einstein, Albert, 127  
 Elastomers, 427–428  
**Electrical neutrality** The principle that, in any compound, the total positive charge must equal the total negative charge, 41, 436–437, 452, 517  
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**Electrochemistry**  
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 standard cell voltage and standard free energy change, 443–446, 464c  
 standard voltages, 439–446, 464a–464c  
 voltaic cells, 435–439, 464a  
**Electrodes** Anodes or cathodes in an electrochemical cell, 430, 452  
**Electrolysis** Passage of a direct electric current through a liquid containing ions, producing chemical changes at the electrodes.  
 and chloride ores, 507, 508  
 and copper, 511–512  
 to decompose water, 407  
 definition of, 5, 452  
 and Faraday, 458  
 and fluorine and chlorine, 530  
 and oxides, 509  
 of potassium iodide, 456  
 of sodium chloride, 457  
 of water, 108  
 of water solution, 456t  
 Electrolyte, 40, 81, 269–271  
**Electrolytic cell** A cell in which the flow of electrical energy from an external source causes a redox reaction to occur, 430, 452–456, 457, 464d–464e  
**Electrolytic copper**, 512  
 Electromagnetic spectrum, 126, 126  
 Electron cloud, 133, 227  
**Electron configuration** An expression giving the population of electrons in each sublevel. The electron configuration of the Li atom is  $1s^2 2s^1$ , 124, 138–145, 141  
 Electron-deficient molecules, 163–164  
 Electron density, 155–156, 156  
**Electronegativity** A property of an atom that increases with its tendency to attract electrons to a bond, 152, 152t  
 Electronic level capacities, 137, 137t  
 Electron-pair bond, 165, 179  
 Electron-pair geometry, 169  
**Electron-pair repulsion** The principle used to predict molecular geometry. Electron pairs around a central atom tend to orient themselves to be as far apart as possible, 166  
 Electron pairs, in Lewis acid-base model, 355–356  
**Electrons** Negatively charged components of an atom, found outside the nucleus.  
 atomic orbitals, 138  
 atomic spectra, 129–130  
 electron arrangements in monatomic ions, 145–148  
 electron configuration in atoms, 138–143  
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 photon energies, 127–129  
 properties of, 25t  
 quantum mechanical model, 132–133  
 quantum numbers, 133–137  
 in voltaic cells, 435  
**Electron-sea model** A model of metallic bonding in which cations act as fixed points in a mobile "sea" of electrons, 236  
**Electron spin** The property of an electron described by the quantum number  $m_s$ , which can be  $+1/2$  or  $-1/2$ , 135, 135  
 Electroplating, 455, 456  
**Element** A substance whose atoms are all chemically the same, containing a definite number of protons, 3  
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 chemical reactivity, 526–529  
 definition of, 2–4  
 occurrence and preparation, 529–530  
 with percentage abundances, 4t  
 and the periodic table, 50b  
 and physical state at room temperature, 37  
 standard molecular entropies, 411t  
 and their preparation, 526–530  
 Elementary oxygen, 164  
**Elementary steps** The individual steps that constitute a reaction mechanism, 299  
*Elements of Chemistry* (Lavoisier), 15  
**Elimination reactions** Reactions in which a reactant loses an atom or groups of atoms to form a double bond, 372  
 Emerson, Ralph Waldo, 22  
 Empty space, 240  
 Enantiomers Optical isomers, 569–571  
**Endothermic** A process in which heat is absorbed by a system;  $\Delta H$  is positive for an endothermic reaction, 189, 190, 196, 196, 197, 208, 257, 326–328, 407–408  
**End point** The point during a titration at which the indicator changes color, 371, 373t  
**Energy** A property of a system which can be altered only by exchanging heat or work with the surroundings, 127, 127, 187, 209–212, 210t, 214t  
 Energy balance, 211, 213–214

- Energy change ( $\Delta E$ ), 211–213, 461, 476–480  
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 Energy output, 213–214  
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**Enthalpy ( $H$ )** A property of a system that reflects its capacity to exchange heat ( $q$ ) with the surroundings; defined so that  $\Delta H = q$  for a constant-pressure process, 195–196, 211–212, 413  
**Enthalpy change ( $\Delta H$ )** The difference in enthalpy between products and reactants.  
 and energy change, 211–213  
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 Hess's law, 200–201, 200, 206  
 introduction to, 195–197  
 for phase changes, 200t  
 preference for using enthalpies of formation to calculate, 209  
 relation with enthalpy of formation, 206  
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**Enthalpy of formation ( $\Delta H_f^\circ$ )** When one mole of a species is formed from the elements, 202  
 calculation of, 202–207  
 example of, 202  
 exothermic reactions, 202  
 relation with enthalpy change, 206  
 standard, 202, 203t, 206  
**Entropy ( $S$ )** A property of a system related to its degree of order; highly ordered systems have low entropy  
 of ammonia, 409–410, 409  
 in elastomeric materials, 428  
 overview of, 409–410  
 second law of thermodynamics, 413  
 spontaneity, effect on, 413  
 standard entropy change ( $\Delta S^\circ$ ), 412–413  
 standard molar entropies, 410–411  
**Entropy change ( $\Delta S$ )** The difference in entropy between products and reactants, 409  
 Environmental Protection Agency (EPA), 485, 546  
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**Equations**  
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 mass relations from, 65–67  
 net ionic equation, 76–78, 83  
 nuclear equations, 465  
 thermochemical equation, 196–202, 215b–215c  
 Van't Hoff equation, 327  
**Equilibrium** A state of dynamic balance in which rates of forward and reverse reactions are equal; the system does not change with time.  
 changes in conditions, effect of, 323–328  
 compression or expansion, 325–326  
 gaseous species, adding or removing, 323–325  
 liquid-vapor, 217–223, 217  
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 between a solid and its liquid, 223  
 between a solid and its vapor, 223  
 and spontaneous reactions, 407  
 and sublimation, 225  
 temperature, change in, 326–328  
 vapor pressure, 222  
**Equilibrium constant ( $K$ )** A number characteristic of an equilibrium system at a particular temperature. For the system  $A(g) + 2B(aq) \rightleftharpoons 2C(g)$  the expression for  $K$  is  $(P_C)^2 / (P_A)[B]^2$ .  
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 changing the chemical equation, 310–311  
 for complex ions. See Formation constant ( $K_f$ )  
 and free energy change, 424–425, 429c–429d  
 Haber process, 328  
 and hemoglobin, 503  
 for heterogeneous equilibria, 313–315, 314t  
 in the ionization of water, 333  
 as a measure of the strength of an acid, 347  
 $N_2O_4$ - $NO_2$  equilibrium system, 307, 309–310  
 of the oxoacids of the halogens, 538t  
 relation to standard cell voltage, 448t  
 for some weak polyprotic acids, 346t  
 and standard cell voltage, 446–448, 446c  
 of weak acids, 339–343, 359b–359c  
 for weak acids and their conjugate bases, 340t  
 of weak bases, 348–352, 359c–359d  
 Equilibrium constant expression, 310–315, 330a–330b  
 Equilibrium curve, 395  
 Equilibrium partial pressures, 320–323  
**Equivalence point** The point during a titration when reaction is complete; equivalent quantities of the two reactants have been used, 84–85, 371, 374, 380–381  
 Essential metal ions, 523t  
**Esters** Organic compounds containing the  $-C(=O)-O-$  functional group, 559t,  

$$\begin{array}{c} \text{O} \\ \parallel \\ \text{C}-\text{O}- \\ | \\ \text{O} \end{array}$$
 562–565, 564t  
 Ethane, 223t, 548, 550t  
 Ethanol, 191t, 553, 560, 560t. See also Ethyl alcohol  
 Ethene, 554. See also Ethylene  
**Ethers** Organic compounds containing the  $-O-$  functional group, 558–561, 559t, 560t  
 Ethyl alcohol, 37, 61, 223t, 226, 255, 256t, 262, 560. See also Ethanol  
 Ethyl butyrate, 564t  
 Ethylene, 158, 174, 181, 182–183, 183, 554, 554, 577t. See also Ethene  
 Ethylenediamine, 490, 490, 497, 497  
 Ethylenediaminetetraacetate (EDTA) ion, 504, 504  
 Ethylene glycol, 255, 255, 264, 561, 581  
 Ethyl ether, as liquid, 223t  
 Ethyl formate, 564, 564t  
 Ethyl group, 550t  
 Ethyl methyl ether, 560t  
 Europium oxide, 341  
 Evaporation, 217, 219, 264–265, 264  
**Excited state** An electronic state that has a higher energy than the ground state, 131  
**Exothermic** Describes a process in which heat is evolved by a system;  $H$  is negative for an exothermic reaction, 189, 190, 196, 196, 197, 202, 208, 407, 414  
**Expanded octets** More than four electron pairs about a central atom, 164–166, 167, 172  
**Experimental yield** The amount of product actually obtained in a reaction, 70–71  
 Exponential notation, 11  
**Extensive properties** Properties of a substance which depend upon the amount of sample; volume is an extensive property, 15–16, 16  
 Eyring, Henry, 292  
**F**  
**Face-centered cubic cell (FCC)** A cubic unit cell with atoms at each corner and one at the center of each face, 238, 238, 239t  
 Fahrenheit, Daniel, 8  
 Fahrenheit scale, 8–9, 8  
 Faraday, Michael, 71, 458, 556  
**Faraday constant** The constant that gives the number of coulombs equivalent to one mole of electrons; 96480 C/mol  $e^-$ , 446  
 Fats, 574, 574  
 Fermentation, 15t, 360  
 Fermium-258, 287  
 Fertilizer, 66–67, 67, 545  
**Filtration** A process for separating a solid-liquid mixture by passing it through a barrier with fine pores, such as filter paper, 6  
 Final and initial state problems, 100–102  
 Fireworks, 125, 125  
**First law of thermodynamics** The statement that the change in energy,  $\Delta E$ , of a system is the sum of the heat flow into the system,  $q$ , and the work done on the system,  $w$ , 209–213, 215d  
**First-order reaction** A reaction whose rate depends upon reactant concentration raised to the first power, 283–287, 284, 288t, 305c–305d  
 First quantum number ( $n$ ), 134  
**Fission** The splitting of a heavy nucleus by a neutron into two lighter nuclei, accompanied by the release of energy, 480–483, 480  
**Fission process**, 480–481  
**Five percent rule** The empirical rule that the approximation  $a = a - x$  if  $x \leq 0.05a$ , 345  
 Fixed nitrogen, 328  
 Flame test, 404, 404  
 Flerov, G. N., 470  
 Flotation, 511, 511  
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 reactivity of, 526–527, 528  
 and xenon, 184  
 Fluorite, 238  
 Food portions, energy values in, 213t  
 Food preservation, 472, 472  
 Forensic toxicology, 545–546  
**Formal charge** The charge that an atom would have if the bonding electrons in a molecule were equally shared, 162–163, 186–186a  
 Formaldehyde, 561, 562  
**Formation constant ( $K_f$ )** Equilibrium constant for the formation of a complex ion from the corresponding cation and ligands, 385–388, 386t, 405  
 Formic acid, 340t  
 Fourth quantum number ( $m_l$ ), 135  
 Franklin, Rosalind, 595  
 Frasch, Herman, 529  
**Frasch process** The process used to extract native sulfur from underground deposits, 529, 529  
**Free energy ( $G$ )** A thermodynamic quantity, defined as the difference between the enthalpy and the product of the absolute temperature and entropy of a system, 413–415, 414  
**Free energy change ( $\Delta G$ )** The difference in free energy between products and reactants, 414, 424–427, 429c–429d  
**Free energy of formation  $\Delta G_f^\circ$**  for the formation of a species from the elements, 413–415, 461  
 Free radicals, 163, 485  
 Freezing curves, 262  
**Freezing point** The temperature at which the solid and liquid phases of a substance are at equilibrium, 223, 225  
 Freezing point constants, 264t  
**Freezing point lowering** The decrease in the freezing point of a liquid caused by adding a solute, 262–264, 268, 270t  
 Freon, 303  
**Frequency ( $\nu$ )** The number of complete wave cycles per unit time, 125–127, 125  
 Frost, Robert, 187

- Fructose, 586t  
Fruit juices, 340  
Fuel cells, 461-463, 467  
Fuel rods, 481  
**Functional group** A small group of atoms in an organic molecule that gives the molecule its characteristic chemical properties.  
alcohols and ethers, 558-561  
aldehydes and ketones, 561-562  
amines, 565-566  
carboxylic acids and esters, 562-565  
common, 559t  
**Fusion** A reaction between small atomic nuclei to form a larger one, releasing energy in the process, 480, 483-484, 486b
- G**  
G. See Free energy  
Gadolinium oxide, 141  
Galactose, 586t  
**Gamma radiation** High-energy photons emitted by radioactive nuclei, 467, 468, 468, 469t, 471, 471  
**Gas** The physical phase of matter without a fixed shape or volume, 2, 3  
calculation of  $P$ ,  $V$ ,  $n$ , or  $T$ , 102-103  
comparison of solids, liquids, and gases, 216-217  
final and initial state problems, 100-102  
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standard molecular entropies, 411  
stoichiometry of gaseous reactions, 105-110, 123b-123c  
volume, amount, and temperature, 96  
Gas chromatography (GC), 6  
**Gas constant ( $R$ )** The constant that appears in the ideal gas law;  $R = 0.0821 \text{ L} \cdot \text{atm/mol} \cdot \text{K} = 8.31 \text{ J/mol} \cdot \text{K}$ , 99-100, 100t  
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**Gaseous chemical equilibrium**  
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pressure, effect of, 326t  
**Gaseous effusion**, 480  
**Gaseous species, adding or removing**, 323-325  
**Gas law.** See Avogadro's number; Boyle's law; Charles's and Gay-Lussac's law; Ideal gas law  
**Gas-liquid chromatography (GLC)**, 6  
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Gasoline, 552  
Gaviscon, 93t  
Gay-Lussac, Joseph, 108  
GC (Gas chromatography), 6  
Gelasil, 93t  
Generation III+ reactors, 483  
**Geometric isomerism** A type of isomerism that arises when two species have the same molecular formulas but different geometric structures, 494, 495-497, 567-569
- Ghiorso, Albert, 470  
Giauque, William, 165  
Gibbs, J. Willard, 413, 415  
Gibbs free energy, 413. See also Free energy  
**Gibbs-Helmholtz equation** The relation  $\Delta G = \Delta H - T\Delta S$ , 414-415, 418-420  
Gillespie, R. J., 167  
Glass electrode, 452, 452  
Glass transition temperature, 427  
GLC (Gas-liquid chromatography), 6  
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Glutamic acid, 589t  
Glutamine, 589t  
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in Rutherford experiment, 25, 26  
zero-order reaction, 287  
"Golden Fleece," 512  
Goran, Morris, 329  
Graham, Thomas, 117  
**Graham's law** The rate of effusion of a gas is inversely proportional to the square root of its molar mass, 117-119  
Grain alcohol, 560. See also Ethyl alcohol  
Gram, 52-54, 73-73a  
Granite, 6  
Graphite, 233-234, 233  
Gray arsenic, 545  
Greek prefixes, 44-45, 45t  
Gregor, William, 48  
Grilled cheese sandwiches, 68  
**Ground state** The lowest allowed energy state of a species, 131, 138  
**Group, functional.** See Functional group  
**Group 1**, 507, 513, 515. See also Alkali metals  
**Group 2**, 507, 513, 514, 515. See also Alkaline earth metals  
**Group I** Cation group in qualitative analysis, 403-404  
**Group II** Cation group in qualitative analysis, 403-404, 403  
**Group III** Cation group in qualitative analysis, 404, 404  
**Group IV** Cation group in qualitative analysis, 404  
**Groups** Vertical columns of the periodic table, 33-34, 140, 140t
- H**  
H. See Enthalpy  
"H-2 blockers," 93, 93  
Haber, Clara, 329  
Haber, Fritz, 328-329  
**Haber process** An industrial process used to make ammonia from the elements, 328-329, 329t, 530-531  
Hahn, Otto, 480  
**Half-cell** Half of an electrochemical cell, at which oxidation or reduction occurs, 436  
**Half-equations** Equations written to describe half-reactions of oxidation or reduction, 87, 431-435, 432  
**Half-life** The time required to convert half of the original amount of reactant to product, 285-287, 290  
Half-neutralization, 377  
Half-reactions, 88, 431, 511  
Halfway point, 377  
Halide anions, 530  
Hall, Charles, 3-4, 509  
**Halogens** Elements of Group 17, 34, 164, 227t, 528, 530, 538t  
Hatchett, Charles, 49  
HDL (High-density) cholesterol, 573-574  
Head-to-head, tail-to-tail polymer, 579  
Head-to-tail polymer, 579  
Heartburn, 93  
**Heat** A form of energy that flows between two samples because of their difference in temperature, 5-6, 187, 209-211, 210t  
**Heat capacity** The amount of heat required to raise the temperature one degree Celsius, 190  
**Heat content.** See Enthalpy  
**Heat flow ( $q$ )** The amount of heat flowing into a system (+) or out of it (-)  
direction and sign of, 189  
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**Heat of formation.** See Enthalpy of formation  
**Heat of fusion  $\Delta H_{\text{fus}}$**  for the conversion of one mole of a solid to a liquid at constant  $T$  and  $P$ , 199  
**Heat of vaporization  $\Delta H_{\text{vap}}$**  for the conversion of one mole of a liquid to a gas at constant  $T$  and  $P$ , 199, 220  
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Heme, 503, 503  
Hemoglobin, 503, 523  
Hemophilia, 594  
Henderson-Hasselbalch equation, 362  
Henry, William, 258  
**Henry's law** At low to moderate pressures, gas solubility is directly proportional to pressure, 258, 258, 259  
Heptane, 550t, 553  
Heptanol, 256t  
Hérault, Paul, 3-4, 509  
Herschel, William, 48  
**Hertz (Hz)** A unit of frequency; one cycle per second, 125  
Hess, Germain, 200  
**Hess's law** The heat flow in a reaction that is the sum of two other reactions is equal to the sum of the heat flows in those two reactions, 200-201, 200, 206, 425  
Heterogeneous catalysis, 297  
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Hexaaquaaluminum(III) ion, 340t  
Hexaaquairon(III) ion, 340t  
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Hexamminecobalt(III) chloride, 388, 388  
Hexane, 61, 255, 550t  
Hexanol, 256t  
High-density (HDL) cholesterol, 573-574  
Highly toxic elements, 35, 35  
**High-spin complexes** Any complex that, for a particular metal cation, has the largest possible number of unpaired electrons, 500, 501  
High-temperature fuel cells, 462  
Hindenburg explosion, 105  
Histidine, 589t  
Hitler, Adolf, 329  
Hodgkin, Dorothy Crowfoot, 241  
Hodgkin, Thomas, 241  
Hoffmann, Roald, 95, 274  
**Homogeneous** Uniform in composition, 5-6, 6, 297-298

- Homogeneous catalysis, 297-298  
 Homogeneous mixtures, 5-6, 6  
 Honey, 586  
 Horace, 1  
 Household products, 537, 545  
 Household solutions, 80  
 Hubble Space Telescope, 48  
 Human body, energy balance in, 213-214  
 Hund, Friedrich, 144  
**Hund's rule** Ordinarily, electrons will not pair in an orbital until all orbitals of equal energy contain one electron, 144, 498  
**Hybridization** Mixing of two or more orbitals or structures, 178-184, 186b  
**Hybrid orbital** An orbital made from a mixture of individual atomic orbitals. An  $sp^3$  orbital is formed by mixing an  $s$  with two  $p$  orbitals, 179-181, 179, 180t  
**Hydrates** Compounds containing bound water such as  $BaCl_2 \cdot H_2O$ , 71-72  
**Hydration** Reaction with water, 572  
 Hydrazine, 45, 63-64, 65, 531  
**Hydride** A compound of hydrogen, specifically one containing  $H^-$  ions, 460  
 Hydride ion-water reaction, 351  
 Hydroiodic acid, 81t  
 Hydrobromic acid, 81t  
**Hydrocarbon** An organic compound containing only carbon and hydrogen atoms, 227c, 255, 411, 548, 553  
**Hydrochloric acid**  
 common ion effect, 394  
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 rate expression, 302  
 use of in air ships, 105  
 valence electrons, 158  
 and water displacement, 111  
 Hydrogenation, 572  
 Hydrogen atoms, 130-133, 154a  
 Hydrogen bomb, 484  
**Hydrogen bond** An attractive force between molecules found when a hydrogen atom is bonded to N, O, or F, 229-232, 229t, 231, 255  
 Hydrogen carbonate ion, 340t, 366t, 370, 370  
 Hydrogen chloride, 197, 197  
 as an acid, 45-46  
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 Hydrogen fuel, 461  
 Hydrogen fuel cells, 462  
 Hydrogen iodide, 287, 324  
 Hydrogen peroxide, 45, 60, 277-278, 278, 298, 298, 515, 532-533  
 Hydrogen phosphate ion, 340t  
 Hydrogen sulfide, 403, 531-532  
 Hydrogen sulfite ion, 340t  
**Hydronium ion** The  $H_3O^+$  ion characteristic of acidic water solutions, 332, 374, 379  
 Hydroperoxides, 561  
 Hydroxide, 93, 368-370, 374, 401t  
 Hydroxides, 390t, 404, 515  
 Hydroxyapatite, 522  
 Hyperbaric chamber, 259  
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 Hypochlorous acid, 340t, 527-528  
**I**  
 Ibuprofen, 342, 357  
 Ice, 217, 217t, 231, 231  
 Ice beer, 262  
 Ideal gases, 120t  
**Ideal gas law** A relation between pressure, volume, temperature, and amount for any gas at moderate pressures:  $PV = nRT$ , 98-100, 98  
 calculations, 100-105  
 and enthalpy, 212  
 and gas mixtures, 110-114  
 and law of combining volumes, 108  
 and real gases, 120-121  
 stoichiometry of gaseous reactions, 105-110  
 and vapor, 217  
**Ideal geometry** The geometry a molecule would have if the effect of unshared pairs were neglected, 167  
 Indium, 371-372  
 Induced dipole, 227  
 Induced radioactivity, 473  
 Industrial ethanol, 560  
 Inert gases, 34  
**Infrared (IR) radiation** Light having a wavelength greater than about 700 nm, 127  
 Initial rate, 279  
 Insoluble carbonate, 93  
 Instantaneous rate, 277  
 Instruments, for measurement, 8-9  
 Inulin, 241  
**Intensive properties** Properties of a substance which are independent of the amount of sample; density is an intensive property, 15-16, 16  
 Intermediates, elimination of, 300-302  
**Intermolecular forces** The forces between molecules, 226  
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 dispersion force, 227  
 hydrogen bonds, 229-232  
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 rate expression, 302  
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 sublimation of, 314  
 Iodine chloride, 228, 228  
 Ion concentrations, 451-452  
 Ionic atmosphere, 271, 271  
**Ionic bonds** The electrostatic forces of attraction between oppositely charged ions in ionic compounds, 39  
**Ionic compound** Any compound made up of cations and anions, 39  
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 and hydrates, 71  
 names and formulas of, 50c-50d  
 names of, 43-44  
 and polyatomic ions, 42  
 at room temperature, 40  
 simplest formula for, 60  
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 solubility of, 75-76  
 structure and properties of, 237t  
 Ionic crystals, 242-243, 242  
**Ionic radius** The radius assigned to a monatomic ion, 149, 150-151  
**Ionic solids** Any compound made up of cations and anions. (Also sometimes referred to as *ionic compounds*), 232, 232, 235, 245c  
**Ionization energy** The energy that must be absorbed to remove an electron from a species, 151-152, 151  
 Ion pair, 271  
**Ion product constant (Q)** The product of the concentration of dissociated ions of a salt (raised to the power of their coefficients) at a particular point in time, 395  
**Ion product constant of water ( $K_w$ )** The product  $[H^+][OH^-] = 1.0 \times 10^{-14}$  at 25°C, 333  
**Ions** Charged species, 37-40, 39, 43, 50b-50c, 146, 389-390, 405a. *See also* Anions; Cations  
**Iron**  
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 Iron(III) chloride, 147  
 Iron(III) oxide, 509, 510, 520  
 Iron(II) sulfate, 147  
 Iron oxide, 421, 509-510  
 Iron production, 509-510, 509  
 Isobutyl formate, 564t  
**Isoelectric point** The pH at which an amino acid does not migrate in an electric field, 591  
 Isoelectric, 146  
 Isoleucine, 589t  
 Isomerism in organic compounds, 566-571, 575b-575c  
**Isomers** Any species with the same formula as another species but having different properties. Structural and geometric isomers are possible, 162, 495-497

- Isooctane, 553  
 Isopentyl acetate, 564t  
 Isopropyl group, 550t  
**Isotope** An atom having the same number of protons as another atom but with different numbers of neutrons, 27–28, 50a  
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 Joliot-Curie, Irène, 241, 470, 473  
**Joule (J)** The base SI unit of energy, a joule is equal to the kinetic energy of a two-kilogram mass moving at a speed of one meter per second, 127, 189, 453, 453t, 478  
 Jung, Carl, 360
- K**  
 K. See Equilibrium constant  
 $K_a$ . See Acid equilibrium constant  
 $K_b$ . See Base equilibrium constant  
**K-electron capture** The natural radioactive process in which an inner electron ( $n = 1$ ) enters the nucleus, converting a proton to a neutron, 468, 469t  
**Kelvin (K)** The scale obtained by taking the lowest attainable temperature to be 0 K; the size of degree is the same as °C, 9, 96  
 Kelvin, Lord, 9  
**Ketones** Compounds containing the carbonyl group  $-C=O$  bonded to two hydrocarbons, 559t, 561–562  
 K. See Formation constant  
**Kilo** The prefix indicating a multiple of 1000, 7t  
 Kilograms, 478  
 Kilojoules, 127, 189, 478  
 Kilowatt-hour (kWh), 453  
 Kinetic energy, 115, 132  
**Kinetic theory** A model of molecular motion used to explain many of the properties of gases  
 average kinetic energy of translational motion,  $E_{tr}$ , 115  
 average speed,  $u$ , 115–117  
 distribution of molecular speeds, 119–120  
 effusion of gases, 117–119  
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 Krypton, 139, 184, 185  
 $K_{sp}$ . See Solubility product constant
- L**  
 Labradoodle, 161  
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 Lactic acid, 340t, 357t, 363–364, 364, 366t, 571  
 Lactose, 586t  
**Lanthanides** Elements 57 (La) through 70 (Yb) in the periodic table, 141  
 Lanthanum, 481  
 Laser fusion, 484  
 Lavoisier, Antoine, 15  
 Law of combining volumes, 108  
**Law of conservation of energy** Energy can neither be created nor destroyed; it can only be converted from one form to another, 209  
 Law of conservation of mass, 24  
 Law of constant composition, 24  
 Law of multiple proportions, 24, 24  
 Lawrence Livermore National Laboratory, 470  
 Lead, 4t, 545  
 Lead azide, 526  
 Lead(II) chloride, 390  
 Leading elements, 88  
 Lead(IV) oxide, 459  
 Lead poisoning, 504  
 Lead shot, 20  
 Lead storage battery, 459–460, 459  
 Le Châtelier, Henri, 323  
**Le Châtelier's principle** When a system at equilibrium is disturbed it responds in such a way as to partially counteract that change, 323, 325, 326, 363, 393  
 Leclanché cell, 458–459  
 Length, 8, 13t  
 Length of edge, 239, 239  
 Leucine, 589t  
 Lewis, Gilbert Newton, 156, 165, 408  
**Lewis acid** A species that accepts an electron pair in an acid-base reaction, 355–356  
**Lewis acid-base model**, 355–356, 356t  
**Lewis base** A species that donates an electron pair in an acid-base reaction, 355–356, 490, 531  
**Lewis structure** An electronic structure of a molecule or ion in which electrons are shown by dashes or dots (electron pairs), 156–166, 385, 535, 535  
 of atoms commonly forming covalent bonds, 157t  
 definition of, 157  
 of ethylenediamine molecule, 490  
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 of oxoacids and oxoanions, 538  
 resonance forms, 160–162  
 writing, 158–160  
 Libby, Willard, 165, 475  
 Lichens, 503  
 Life processes, kinetics of, 292  
**Ligands** Molecules or anions bonded to the central metal in a complex ion, 488, 490, 499, 499, 503  
 Light, 125–129, 154a  
 Light, speed of ( $c$ ), 476–480  
 Light absorption, 501  
 Light water reactors, 481–482  
 Limestone, 510, 534, 534. See also Calcium carbonate  
**Limiting reactant** The least abundant reactant based on the equation for a reaction; dictates the maximum amount of product that can be formed, 67–70  
**Linear functions**, 219–220  
**Linear molecule** A triatomic molecule in which the bond angle is 180°; examples include  $BeF_2$  and  $CO_2$ , 166  
 Linear polyethylene, 578, 578  
 Line emission spectra, 129  
 Liquid propane, 552  
 Liquid scintillation counter, 473  
**Liquid** The physical phase of matter that has a fixed volume but is not rigid in shape, 3  
 boiling point, 221–222  
 comparison of solids, liquids, and gases, 216–217  
 and critical temperature, 222–223, 223t  
 critical temperature and pressure, 222–223  
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 Lithium chlorate ( $LiClO_3$ ), 75  
 Lithium chloride, 242, 242  
 Lithium hydroxide, 81t, 336  
 Lithium-ion ( $Li$ -ion) batteries, 460–461  
 Livingston, James D., 487  
 Lobsters, 153  
 Lockyer, Norman, 49
- London forces, 227  
 Low-density (LDL) cholesterol, 573–574  
 Lowry, Thomas, 332  
**Low-spin complexes** Any complex that, for a particular metal ion, has the smallest possible number of unpaired electrons, 500, 500, 501  
 Lucite, 577t  
**Luster** The characteristic shiny appearance of a metal surface, 236  
 Lye. See Sodium hydroxide  
 Lysine, 589t, 593
- M**  
 Maalox, 93t  
 Manganese(II) chloride, 147  
 Magic numbers, 466  
 Magnesium, 70–71  
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 thermite reaction, 204  
 Magnesium iodide, 70–71  
 Magnesium ion, 396–397  
 Magnesium oxide, 202  
 Magnesium sulfate, 270–271, 270t  
 Magnus, Albertus, 20  
**Main-group elements** Elements in one of the groups numbered 1 to 2 or 13 to 18 of the periodic table, 33  
 Malic acid, 357t  
**Malleability** The ability to be shaped, as by pounding with a hammer; characteristic of metals, 236  
 Maltase, 298  
 Maltose, 298, 585–586, 586t  
 Manganese, 4t, 236, 519, 520t  
 Manganese dioxide, 458, 532, 532  
 Manometer, 96, 97, 122  
 Maple syrup, 272  
 Marcell, Jane, 458  
 Mars rover Curiosity, 63, 63  
 Mass, 8, 13t, 16, 17, 31–32, 54  
 Mass, change in ( $\Delta m$ ), 476–480  
**Mass defect** The difference between the mass of a nucleus and the sum of the masses of the neutrons and protons of which it is composed, 479  
**Mass-energy relations**, 476–480, 486b  
**Mass number (A)** An integer equal to the sum of the number of protons and neutrons in an atomic nucleus, 27–28  
**Mass percent** 100 times the ratio of the mass of a component to the total mass of a sample, 249–250, 251  
**Mass relations**  
 from equations, 65–67  
 experimental yield and percent yield, 70–71  
 limiting reactant and theoretical yield, 67–70  
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**Mass spectrometry**, 7, 28–29, 29  
 Masterton, William L., 272  
 Matter, 1–7, 3, 15–20, 21a  
 Maxwell, James, 114, 119, 415  
**Maxwell distribution** A relation describing the way in which molecular speeds or energies are shared among gas molecules, 119  
 Mayer, Maria, 467  
**Measurements**  
 conversion of units, 12–14  
 instruments and units, 8–9  
 introduction to, 7  
 uncertainties in, 9–12, 10  
**Medicine**, 20, 471  
 Mega, 7t

- Meitner, Lise**, 480
- Melting point** The temperature at which the solid and liquid phases of a substance are in equilibrium with each other, 16, 223, 225–226, 226, 228, 233, 235–236
- Membrane**, 265–266
- Mendeleev, Dmitri**, 34, 184
- Mendelevium**, 142
- Mercury**, 3, 4t, 4, 9, 18, 96–97, 96, 236, 520t
- Mercury (god)**, 48, 48
- Mercury cell**, 459
- Mercury(II) oxide**, 15–16, 459
- Mercury sulfide (HgS)**, 75
- Metabolic energy**, 213–214
- Metal alloys**, 246
- Metal cations**, 339, 523t
- Metal ions**, 505a–505b
- Metallic iron**, 58–59
- Metalloids** Elements such as Si or B that have properties intermediate between those of metals and nonmetals, 34, 34
- Metallurgy** The science and processes of extracting metals from their ores, 506
- chloride ores, 507–508
  - native metals, 512–513
  - oxide ores, 509–510
  - sulfide ores, 511–512
- Metals** Substances having the characteristics luster, malleability, and high electrical conductivity, 34–35
- alkali and alkaline earth metals, reactions of, 513–516, 524a
  - and cations, 37
  - crystal structures, 238–241
  - diagram of, 232
  - metallic solids, 232, 236–237, 245c
  - metallurgy, 506–513, 524–524a
  - in nutrition, 522–523
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  - structure and properties of, 237t
  - transition metals, 516–522, 524a
- Methane**, 4, 168, 169
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  - as a binary compound, 45
  - bond angle, 548
  - deviation from ideal gas behavior, 121–122, 121
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  - hybrid orbital, 180
  - molecular formula for, 36
  - nomenclature, 550t
  - as permanent gas, 223t
  - reaction with oxygen, 211, 211
  - structural formula for, 36, 36
- Methane hydrate**, 71, 72, 72
- Methanol**, 153, 559. *See also* Methyl alcohol
- Methionine**, 589t
- Methylacetylene**, 555, 555
- Methyl alcohol**, 162–163, 255, 256c. *See also* Methanol
- Methylamine**, 81, 82, 565
- Methyl butyrate**, 564t
- Methyl group**, 550t
- Methyl methacrylate**, 577t
- Methyl red**, 372, 373, 373t, 374, 376, 377, 379, 380, 380
- Metric system** A measuring system where all units of a particular type (e.g., volume) are related to one another by powers of ten, 7, 7t
- Metric ton**, 8
- Micro**, 7t
- Microstates**, 409
- Milk of magnesia**, 515
- Milli** The prefix on a metric unit indicating a multiple of  $10^{-3}$ , 7t
- Millimeters of mercury (mm Hg)** A unit of pressure: 1 atm = 760 mm Hg, 97
- Milton, John**, 430
- Mirror images**, 569
- Mixture** Two or more substances combined so that each substance retains its chemical identity, 3, 5–6
- Models**, for reaction rates, 289–293
- Mode of decay**, 467–469
- Moissan, Henri**, 530
- Molal boiling point constant**, 263
- Molal freezing point constant**, 263
- Molality (m)** A concentration unit defined as the number of moles of solute per kilogram of solvent, 250–253, 252, 263
- Molar heat capacity**, 190
- Molarity (M)** A concentration unit defined to be the number of moles of solute per liter of solution, 54–58, 247–248, 251–253, 252, 424
- Molar mass** The mass in grams of one mole of a substance, 52, 54
- boiling point, effect on, 227t
  - colligative properties, determination from, 267–269
  - and dispersion forces, 227
  - and effusion, 117, 119
  - and gases, 96, 103–105
  - and molecular speed, 116
  - molecular speed, relation to, 116
  - and standard molecular entropies, 411
- Molar volume**, 100, 121–122
- Mole** A collection of  $6.022 \times 10^{23}$  items. The mass in grams of one mole of a substance is numerically equal to its formula mass, 51–58, 54, 73–73a, 100–103
- Mole fraction (X)** A concentration unit defined as the number of moles of a component divided by the total number of moles, 112–114, 123c–123d, 249, 251
- Mole ratio**, 59, 108–109
- Molecular collisions**, 290
- Molecular compounds**, 50c–50d, 60
- Molecular formula** A formula in which the number of atoms of each type in a molecule is indicated as a subscript after the symbol of the atom, 36, 62–63
- Molecular geometry** The shape of a molecule, describing the relative positions of atoms, 166–174, 168, 170t, 172, 186a
- Molecular hydrates**, 71–72
- Molecular liquids**, 226
- Molecular model**, 114, 114
- Molecular orbitals**, 164
- Molecular speeds**, 116, 119–120
- Molecular structure**, of rubbery materials, 427–428
- Molecular substance** A substance composed of discrete molecules such as  $H_2$  or  $CH_4$ , 36
- dipole forces, 228–229
  - dispersion force, 227
  - effect of molar mass on boiling points, 227t
  - hydrogen bonds, 229–232
  - liquid, 226–232
  - in solids, liquids, and gases, 217
  - structure and properties of, 237t
- Molecule** An aggregate of atoms that is the fundamental building block in all gases and many solids and liquids; held together by covalent bonds between the atoms, 35–37, 50b–50c, 174–178, 186b, 216–217, 348
- Mole-mass conversions**, 66, 73–73a
- Molina, Mario**, 303
- Monatomic anions**, 43
- Monatomic cations**, 43
- Monatomic ions**, 39, 145–148, 154c
- Monoatomic ion**, 88, 146
- Monomers** Small molecules that join with other monomers to form a polymer, 576
- Monosaccharides** Carbohydrates that cannot be broken down into a simple sugar, 583
- Monounsaturated fats**, 574, 574
- Morphine**, 358
- Moss**, 503
- Multiple bond** A double or triple bond, 171, 181–182
- Multiple proportions**, law of, 24, 24
- Muscular activity**, 214
- Mylanta**, 93t
- N**
- n*. *See* Mole
- $N_A$ . *See* Avogadro's number
- Naming**, complex ions and coordination compounds, 492–493
- Nano** The prefix on a metric unit indicating a multiple of  $10^{-9}$ , 7t
- Naphthalene**, 4, 264c, 558
- Naproxen**, 571
- Native metals**, 512–513
- Natural gas pipelines**, 71–72, 352
- Natural logarithm**, 219–220
- Natural radioactivity**, 467
- Neon**, 34, 34, 146, 184
- Neptune (god)**, 49
- Neptunium**, 470, 470t
- Neerst, Walther**, 449
- Nernst equation** An equation relating cell voltage  $E$  to the standard voltage  $E^\circ$  and the ionic concentrations and/or pressures of reactants and products at 25°C:  $E = E^\circ - (0.0257/n) \ln Q$ , 449–451
- Net ionic equation** A chemical equation for a reaction involving ions in which only those species that actually react are included, 76–78, 83
- Network covalent** Having a structure in which all the atoms are linked by a network of covalent bonds, 232–234, 232, 237t, 245c
- Neutral complexes**, 492
- Neutralization** A reaction between a strong acid and base to form a neutral solution, 82, 374, 399
- Neutral solution** A water solution with a pH of 7 (at 25°C), 333, 334
- Neutral species**, 88
- Neutron activation analysis**, 471–472
- Neutron** A particle in an atomic nucleus with zero charge and a mass of approximately 1 amu, 25–26, 25t, 469, 473
- Neutron bombardment**, 470, 470t
- Neutron-to-proton ratio (n/p<sup>+</sup>)**, 466, 466
- Newman, John Henry Cardinal**, 51
- Newton, Isaac**, 5, 129, 465
- Newton's law of motion**, 130
- Nickel**, 4t, 444, 444, 501, 518, 527
- Nickel-based batteries**, 460
- Nickel-cadmium (Nicaid) batteries**, 460
- Nickel chloride**, 76, 76
- Nickel hydroxide**, 76
- Nickel(II) oxide**, 517
- Nickel(II) salt**, 437
- Nickel(II) sulfate**, 147
- Nickel-metal hydride batteries**, 460
- Nickel nitrate**, 236
- Nitric acid**
- and acid rain, 382
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  - vs. nitrous acid, 539
  - overview of, 542–543
  - and oxidation, 518–519
  - as oxoacids, 46
  - reaction with proteins, 543
  - as a strong acid, 81t, 82
- Nitric oxide**, 45, 163–164, 536
- Nitrogen**
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  - in fertilizer, 66–67, 67
  - hydrogen bonds, 229–230
  - occurrence and preparation, 529
  - oxoanions of, 44t
  - percent abundance, 4t
  - as permanent gas, 223t
  - properties of, 526c
  - reactivity of, 526
  - as a reducing agent, 531
  - single bonds, 158
- Nitrogen dioxide**
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- Nitrogen oxides, 535
- Nitronium ion, 382
- Nitrous acid, 339, 340t, 539
- Nitrous oxide, 45, 297, 536
- Nobelium, 142
- Nobel Peace Prize, 178
- Nobel Prize in chemistry, 87, 142, 178, 241, 303, 329, 473, 498, 530, 571
- Nobel Prize in medicine, 595
- Nobel Prize in physics, 130, 467, 473
- Noble gases Elements in group 18 at the far right of the periodic table, 34, 41, 146, 146, 184–185, 227t
- Noble-gas structures, 41, 156
- Nonelectrolytes, 40, 260–269
- Nonmetal oxides, 535–537, 535t
- Nonmetals Elements in the upper right part of the periodic table that do not show metallic properties, 34–35  
and anions, 37–38  
elements and their preparation, 526–530  
hydrogen compounds of, 530–534, 530t  
introduction to, 525  
oxoacids and oxoanions, 537–545, 546a–546c  
oxoacids of, 538t  
oxygen compounds of, 534–537  
and the periodic table, 526  
properties of, 526t
- Nonpolar bond A covalent bond in which the electrons are equally shared by two atoms, so there are no positive and negative ends, 174
- Nonpolar molecule A molecule in which there is no separation of charge and hence no positive and negative poles, 174–178, 228t
- Nonspontaneous reactions, 407, 414, 425
- Nonstoichiometric nickel(II) oxide, 517
- Nonstoichiometric oxides, 517
- Nonuniform mixtures. *See* Heterogeneous mixture
- Normal boiling point The temperature at which the vapor pressure equals 1 atm, 221
- Novocaine hydrochloride, 358
- Noyori, Ryoji, 571
- Nuclear accidents, 482
- Nuclear binding energy, 478–480
- Nuclear equations Symbolic representations of processes that show how the structure of an atomic nucleus is altered, 465
- Nuclear fission. *See* Fission
- Nuclear fusion. *See* Fusion
- Nuclear masses on the C scale, 477t
- Nuclear radiation, 468
- Nuclear reactions  
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radioactivity, 467–472, 486–486a
- Nuclear reactants, 481–483, 482
- Nuclear stability, 465–467, 479–480, 480, 486
- Nuclear symbol A symbol giving the atomic number and mass number of a nucleus. Example:  $^{12}_6\text{C}$ , 27, 50a
- Nucleon Either protons or neutrons, 466
- Nucleotides, 595
- Nucleus The small, dense, positively charged region at the center of the atom, 25–26
- Nutrition, essential metals in, 522–523. *See also* Carbohydrates; Proteins; Vitamins
- Nyholm, R. S., 167
- Nylon, 582–583, 583
- O**
- Octahedral complexes, 499–501
- Octahedron A figure with eight sides and six vertices, 168, 495, 495, 496, 497, 500, 503
- Octane, 226, 550t
- Octane number, 552–553
- Octet rule Bonded atoms (except H) tend to have a share in eight valence electrons, 156–166, 186
- Octyl acetate, 564t
- Odd electron, 163
- Oil, 255. *See also* Petroleum
- Omeprazole, 93
- 1-Propanol, 560t
- "On the Equilibrium of Heterogeneous Substances" (Gibbs), 415
- "On the Influence of Carbon Dioxide in the Air on the Temperature of the Ground" (Arrhenius), 87
- Opium poppy, 358
- Oppenheimer, J. Robert, 480
- Optical isomers Isomers which rotate the plane of plane-polarized light, 569–571, 569
- Orbital Region of space in which there is a high probability of finding an electron within an atom, 124, 133, 135
- Orbital diagrams Sketches showing electron populations of atomic orbitals; electron spins are indicated by up and down arrows, 124, 143–145, 144, 154b–154c
- Order of reaction An exponent to which the concentration of a reactant must be raised to give the observed dependence of rate upon concentration, 278–282
- Ores Natural mineral deposits from which metal can be extracted profitably  
chloride, 507–508  
gold content of, 512  
oxide, 509–510  
principal, 506, 507  
sulfide, 511–512, 511
- Organic acids, 356–358, 357t
- Organic bases, 356–358
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- Organic material, age of, 475–476, 476
- Organic polymers  
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synthetic condensation polymers, 580–583, 597a
- Organic reactions, 571–573, 575c
- Orientation of polar molecules, 175
- Ortega y Gasset, José, 307
- Osmosis A process by which a solvent moves through a semipermeable membrane from a region where its vapor pressure is high to one where it is low, 264, 265, 266
- Osmotic pressure The pressure that must be applied to a solution to prevent osmosis, 264–267, 265, 268, 272
- Osteoporosis, 522
- Ostwald, Wilhelm, 87, 542
- Oxalate anion, 490, 490
- Oxalic acid, 346, 346t, 357t
- Oxidation A half-reaction in which there is an increase in oxidation number, 89–90, 431–433, 517t, 518
- Oxidation number A number that is assigned to an element in a molecule or ion to reflect, qualitatively, its state of oxidation, 88–92, 90, 431, 432
- Oxidation-reduction reactions. *See* Redox reaction
- Oxide ores, 509–510
- Oxides, molecular structure of, 535–536, 546a–546b
- Oxidizing agent A species that accepts electrons in a redox reaction, 90–91, 431, 440–442, 464a–464b, 512, 521–522, 527–529, 540
- Oxoacids Acids containing oxygen, such as HNO<sub>3</sub> or H<sub>2</sub>SO<sub>4</sub>, 46, 347–348  
acid strength, 538–540  
equilibrium constants for, 538t  
introduction to, 537–538  
Lewis structures of, 538  
nitric acid, 542–543  
of nonmetals, 538t  
oxidation and strength reduction, 540–541  
phosphoric acid, 545  
sulfuric acid, 543–544
- Oxoanions Anions containing oxygen, such as NO<sub>3</sub><sup>-</sup> or SO<sub>4</sub><sup>2-</sup>, 42, 43, 44t, 521–522, 537–538, 538
- Oxyacetylene torch, 556
- Oxygen  
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- Oxyhemoglobin, 303
- Ozone, 126–127, 302–303, 303
- Ozone hole, 303, 303
- P**
- P.* *See* Pressure
- Paired electrons, 144
- Palladium, 17, 297
- Paramagnetic Showing magnetic properties caused by the presence of unpaired electrons, 144, 499
- Partial pressure The part of the total pressure in a gas mixture that can be attributed to a particular component. The partial pressure of a component may be found by multiplying the total pressure by the mole fraction, 110–114, 123c–123d, 306–310, 308, 315, 318
- Particles, 54
- Particle scattering experiment, 25, 26
- Particle volume, 121–122
- Partner-exchange reactions, 76
- Parts per billion (ppb) For liquids and solids, the number of grams of solute per billion grams of sample, 249–250
- Parts per million (ppm) For liquids and solids, the number of grams of solute per million grams of sample, 249–250
- Pascal (Pa) An SI unit of pressure; the pressure exerted by the force of 1 newton on an area of 1 square meter, 97
- Pascal, Blaise, 406
- Pasteur, Louis, 571



- Pauli, Wolfgang, 135
- Pauli exclusion principle** A principle which states that no two electrons in the atom can have four identical quantum numbers, 135-137
- Pauling, Linus, 152, 178
- p*-Dichlorobenzene, 264t
- PEM (Proton-exchange membrane), 461-462
- Penicillin, 241
- Pentaamminechlorochromium(III), 492
- Pentaamminechlorocobalt(III) Chloride, 388, 388
- Pentane, 255, 550t, 551
- Pentanol, 256t
- Pentyl propionate, 564t
- Peptide linkage** The  $\begin{array}{c} \text{---C---N---} \\ | \quad | \\ \text{O} \quad \text{H} \end{array}$  group found in polypeptides, including proteins, 592
- Percent composition** Mass percents of the elements in a compound, 58-59
- Percent ionization** For a weak acid HB, % ionization =  $100 \times \frac{[\text{H}^+]}{[\text{HB}]_0}$ , 342, 343
- Percent yield** A quantity equal to  $100 \times \frac{\text{actual yield}}{\text{theoretical yield}}$ , 70-71, 70
- Perchlorate ion, 540
- Perchloric acid, 81t
- Perchloroethylene (PERC), 244
- Periodic function** A physical or chemical property of elements that varies periodically with atomic number, 148
- Periodic table** An arrangement of the elements in rows and columns according to atomic numbers such that elements with similar chemical properties fall in the same column, 30, 33-35, 33, 50b
- atomic orbitals, 138
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- Periods** Horizontal rows of elements in the periodic table, 33-34
- Permanent gas, 222-223, 223t
- Permanganate ion, 431, 522
- Peroxide** A compound containing the peroxide ion,  $\text{O}_2^{2-}$ , 514
- PET (Positron emission tomography), 471
- Petroleum, 255, 552-553
- Petroleum distillation, 552
- pH** Defined as  $-\log_{10} [\text{H}^+]$
- measurement of, 338
- overview of, 333-336
- relationship with  $[\text{H}^+]$ , 334, 334
- of some common materials, 334t
- of strong acids and strong bases, 336-338
- Phase diagram** A graph of pressure vs. temperature showing the conditions for equilibrium between phases, 223-226, 243, 245a-245b
- Phenanthrene, 558
- Phenol, 557
- Phenolphthalein, 85; 371-373, 372, 373t, 374, 376, 376, 377, 379, 380, 514
- Phenylalanine, 589t
- Phillips, 93t
- pH meter, 338, 338, 452, 452
- Phosphates, 390t
- Phosphine, 45
- Phosphoric acid, 340t, 346t, 537, 537, 545
- Phosphorus, 4t, 67, 164, 180, 526t, 536, 537
- Phosphorus-30, 470
- Phosphorus pentachloride, 165; 180
- Phosphorus pentafluoride, 168; 168
- Photochemistry, 165
- Photon energies, 127-129, 154a
- Photons** Any individual particle of radiant energy, 127-129
- pH paper, 338
- Physical properties** Properties such as melting point or density which can be determined without changing the chemical identity of a substance, 16, 16 /
- Piazza, Giuseppe, 48-49
- $\pi$  bond** ( $\pi$ ) A bond in which electrons are concentrated in orbitals located off the internuclear axis; in a double bond there is one  $\pi$  bond, in a triple bond there are two, 182-184, 186b
- Pico, 7t
- Pig iron, 509, 510
- Piper, 8
- pK<sub>a</sub>** Defined as  $-\log_{10} K_a$ , where  $K_a$  is the ionization constant of a weak acid, 341
- pK<sub>b</sub>** Defined as  $-\log_{10} K_b$ , where  $K_b$  is the ionization constant of a weak base, 349
- Planck, Max, 127
- Planck's constant, 127
- Platinum, 297, 297, 489t
- Platinum electrode, 437, 437
- Platinum(II), 489
- Platinum-rhodium catalyst, 542
- Flexiglas, 577t
- Pluto (god), 49
- Plutonium, 470t
- pOH** Defined as  $\text{pOH} = -\log_{10} [\text{OH}^-]$ , 333-336, 359a-359b
- Poison gas, 329, 528
- Polar bond** A chemical bond that has positive and negative ends; characteristic of all bonds between unlike atoms, 174
- Polarimeter, 569
- Polarity, 174, 176, 186b, 229
- Polar molecule** A molecule in which there is a separation of charge and hence positive and negative poles, 174-178, 228, 228t
- Polonium, 473
- Polyacrylonitrile (PAN), 577t
- Polyamide** A compound formed when a diamine reacts with a dicarboxylic acid, 582-583
- Polyatomic ions, 39, 41t, 42-43, 42, 56-57, 88
- Polyester** A large molecule made up of ester units, 581
- Polyethylene, 577-579, 577t
- Poly(ethylene terephthalate) (PET), 581
- Polymers** Huge molecules made up of many small units linked together chemically. *See also*
- Organic polymers
- carbohydrates, 583-587, 597a
- introduction to, 576
- proteins, 587-595, 597a
- synthetic addition polymers, 577-580, 577t, 597-597a
- synthetic condensation polymers, 580-583, 597a
- Polypeptide** A compound containing two or more  $\alpha$ -amino acid residues, 592-593
- Polypropylene, 577t
- Polyprotic acid** An acid containing more than one ionizable H atom. Examples include  $\text{H}_2\text{SO}_4$  and  $\text{H}_3\text{PO}_4$ , 346-347, 346t, 359c
- Polyaccharides** Carbohydrates made up of sugar molecules bonded together, 584
- Polystyrene, 577t
- Polyunsaturated fats, 574, 574
- Polyvinyl chloride (PVC), 457, 577t, 579-580
- Poodle, 161
- Pope, Alexander, 124
- P orbitals, 138, 138
- Positive ion bombardment, 470t
- Positron** Identical to an electron except that it has a charge of +1 rather than -1, 468
- Positron emission, 468, 469t
- Positron emission tomography (PET), 471
- Post-transition metals** Lower members of periodic groups 13, 14, and 15, such as Pb and Bi, 33, 42, 44
- Potassium, 4t, 34, 67, 139
- Potassium carbonate, 352
- Potassium chromate, 56, 252, 394-395
- Potassium dichromate, 42, 57-58, 147
- Potassium ferricyanide, 493
- Potassium fluoride, 530
- Potassium hexacyanoferrate(III), 493
- Potassium hydroxide, 81t, 336
- Potassium iodide solution, 456
- Potassium nitrate, 42
- Potassium permanganate, 42, 127, 127, 278, 522
- Potassium superoxide, 515
- Pounds per square inch (psi), 96
- Povidone-iodine, 528-529
- Powell, H. M., 166
- Precipitate** A solid that forms when two solutions are mixed, 76, 76
- Precipitate formation**, 394-398, 405a-405b
- Precipitates**, dissolving, 399-403; 402, 405b-405c
- Precipitation reaction** Formation of an insoluble solid when two electrolyte solutions are mixed
- net ionic equations, 76-78
- solubility of ionic compounds, 75-76
- stoichiometry, 78-80
- Prefixes, Greek, 44-45, 45t
- Prefixes, metric, 7t
- Pressure (P)** Force per unit area, 223
- and boiling point, 221-222
- effect of on gaseous equilibria, 326t
- and gases, 96-98
- in gas law calculations, 100-103, 104
- and gas laws, 211-212
- and Haber process, 329t
- in ideal gas law, 99, 99
- and kinetic theory of gases, 114-115
- and melting point, 225, 226
- reaction spontaneity, effect on, 421-424, 429c
- and real gases, 121
- solubility, effect on, 257-259, 259
- vapor pressure, 218-219
- Prevacid, 93
- Friestly, Joseph, 5
- Prilosec, 93
- Primary (nonrechargeable) voltaic cells**, 458-459
- Primary structure** For a protein, it is the linear sequence of amino acids in the polypeptide chain, 593-594
- Principal energy level** The energy level designated by the quantum number,  $n$ , 134
- Principal ores, 507
- Probability, 408
- Product** A substance formed as a result of a reaction; appears on the right side of an equation, 37, 63, 65, 68, 198, 204, 209
- Proline, 589t
- Propane, 223, 223t, 548, 550, 550t, 560t
- Propane gas, 552
- Propanol, 256t
- Propene, 554
- Propylamine, 230
- Propylene, 60, 577t
- Propyl group, 550t
- Proteins** Large molecules made up of several amino acids, 587
- acid-base properties of amino acids, 589-592
- $\alpha$ -amino acids, 588-589
- polypeptides, 592-593
- primary structure, 593-594
- secondary and tertiary structure, 594-595
- Proton** The nucleus of the hydrogen atom, the  $\text{H}^+$  ion, 25-26, 25t
- Proton-exchange membrane (PEM), 461-462
- Proton pump inhibitors, 93, 93
- Prune, 266, 266
- Pure substances, 2, 3
- PVC (Polyvinyl chloride), 457, 577t, 579-580
- Pyrite, 382
- Q**
- q. *See* Heat flow
- Q. *See* Reaction quotient

- Quadratic formula** The formula used to obtain the two roots of the quadratic equation  $ax^2 + bx + c = 0$ . The formula is  $x = (-b \pm \sqrt{b^2 - 4ac})/2a$ , 322
- Qualitative analysis** The determination of the nature of the species present in a sample; most often applied to cations, 403-404
- Quantum mechanical model**, 132-133
- Quantum mechanics**, 130, 132-133
- Quantum numbers** Numbers used to describe energy levels available to electrons in atoms; there are four such numbers
- first ( $n$ ), 133-134, 136f, 137, 138
  - fourth ( $m_l$ ), 134, 135, 136, 136f
  - permissible values, 136f
  - second ( $l$ ), 133-135, 136f, 137
  - third ( $m_s$ ), 133-134, 135, 136f
- Quartz**, 234, 234
- Quinic acid**, 357f
- R**
- R*. See Gas constant
- Racemic mixture** Mixture containing equal numbers of two enantiomers of a substance, 570
- Radiation exposure**, 485, 485f, 485
- Radioactive decay**, 285, 469f, 473-476, 486a-486b
- Radioactive waste, disposal of**, 482-483
- Radioactivity** The ability possessed by some natural and synthetic isotopes to undergo nuclear transformation to other isotopes
- applications, 471-472
  - biological effects of, 485
  - bombardment reactions, 469-471
  - mode of decay, 467-469
- Radium**, 473
- Radon**, 185
- Radon-222**, 485, 485
- Rade**, 485
- Ramsay, William**, 184
- Randall, Merle**, 165
- Randomness factor**, 408-409, 408
- Random polymer**, 579
- Raoult, François**, 260
- Raoult's law** A relation between the vapor pressure ( $P$ ) of a component of a solution and that of the pure component ( $P^*$ ) at the same temperature;  $P_i = X_i P_i^*$ , where  $X$  is the mole fraction, 260-261, 260
- Rate constant** The proportionality constant in the rate equation for a reaction, 278, 280, 284, 291f
- Rate-determining step** The slowest step in a multi-step mechanism, 299-300
- Rate expression** A mathematical relationship describing the dependence of reaction rate upon the concentration(s) of reactant(s), 278, 283, 300-302
- Rayleigh, Lord**, 184
- Reactant** The starting material in a reaction; appears on the left side of an equation, 37
- bond enthalpy, 209
  - in chemical equations, 63, 65, 68
  - collisions between, 278
  - excess of, 68
  - kinetic energy of, 290
  - order of reaction with more than one, 280-282
  - order of reaction with single, 278-280
  - in rules of thermochemistry, 198
  - and theoretical yield, 67-70
  - in thermite reactions, 204
- Reactant concentration**
- first-order reactions, 283-287
  - and reaction rate, 277-282
  - second-order reaction, 287-289
  - and time, 283-289
  - zero-order reaction, 287-289
- Reacting species** A species that takes part in a reaction. When hydrochloric acid reacts with NaOH, the reacting species is the  $H^+$  ion, 83, 83, 85, 381, 459
- Reaction**
- direction of, 318-320, 330b-330c
  - extent of, 320-323, 330c-330d
  - spontaneity of, 406-428
- Reaction energy diagram**, 292
- Reaction mechanism** A sequence of steps that occurs during the course of a reaction, 298, 305f
- elementary steps, 299
  - intermediates, elimination of, 300-302
  - rate expression, deduced from proposed mechanism, 300
  - reaction plot for, 300
  - slow steps, 299-300
- Reaction order**, 289
- Reaction plot**, 300
- Reaction quotient ( $Q$ )** An expression with the same form as  $K$  but involving concentrations and pressures at a particular point in time rather than equilibrium partial pressures or concentrations, 318-320, 421-422, 449
- Reaction rate** The ratio of the change in concentration of a species divided by the time interval over which the change occurs.
- activation energy, 290-291
  - activation energy diagrams, 291-292
  - Arrhenius equation, 294
  - catalysis, 296-298, 305f
  - collision model, 290-291
  - and concentration, 277-282, 278, 305a
  - definition of, 274-277, 305-305a
  - enzymes, 298
  - first-order reactions, 284, 305c-305d
  - measurement of, 277, 277
  - models for, 289-293
  - order of, 305b-305c
  - order of with a single reactant, 278-280
  - order of with more than one reactant, 280-282
  - rate expression and rate constant, 278
  - reactant concentration and time, 283-289
  - reaction mechanism, 298-302, 305f
  - second-order reaction, 305d-305e
  - and temperature, 293-296, 293, 305e-305f
  - and time, 305b-305e
  - transition-state model, 291-292
  - two-point equation relating  $k$  and  $T$ , 295-296
  - zero-order reaction, 305d-305e
- Real gases**, 120-122, 120f, 123d
- Reciprocal rule** The equilibrium constant for a reaction is the reciprocal of that for the same reaction in the reverse direction, 311, 312f, 314, 374, 376
- Red cabbage**, 371
- Redox reaction** A reaction involving oxidation and reduction
- balancing half-equations, 431-433
  - balancing redox equations, 433-435
  - and copper, 511
  - definition of, 431
  - in electrochemistry, 431-435
  - half-reactions, 88
  - introduction to, 87-88, 87
  - oxidation number, 88-92
  - spontaneity of, 443-446
  - stoichiometric calculations, 91-92
  - terminology and concepts, 431
  - zinc-copper(II) voltaic cell, 435, 436
- Redox titration**, 92
- Reducing agent** A species that furnishes electrons to another in a redox reaction, 91, 431, 440-442, 464a-464b, 509, 531, 540
- Reduction** A half-reaction in which a species decreases in oxidation number, 88, 89, 431, 431-433, 520f
- Relative masses**, 28
- Reims**, 485
- Resonance** A model used to rationalize the properties of a species for which a single Lewis structure is inadequate; resonance forms differ only in the distribution of electrons, 160-162
- Resonance forms**, 160-162, 186-186a
- Resonance hybrids**, 160
- Reverse osmosis**, 243, 265
- Rhodium**, 297, 297
- Roasting** A metallurgical process in which a sulfide ore is heated in air, forming either the free metal or the metal oxide, 511
- Rock candy**, 20
- Roloids**, 93f
- Roman numerals**, 44
- Rose, Heinrich**, 49
- Rowland, F. Sherwood**, 303
- Rubber bands**, 428
- Rubber elasticity**, 427-428
- Rubidium**, 481
- Rubidium-90**, 481
- Rule of multiple equilibria** A rule which states that a reaction can be expressed as the sum of two or more reactions,  $K$  for the overall reaction is the product of the equilibrium constants of the individual reactions, 311, 312f
- Rust**, 413
- Rutherford, Ernest**, 23, 23, 25, 26
- Rutherfordium**, 470f
- S**
- S*. See Entropy
- Saccharin**, 586f
- Salt** An ionic solid containing any cation other than  $H^+$  and any anion other than  $OH^-$  or  $O^{2-}$ , 352-355, 354
- Salt bridge** A U-tube containing a salt solution; used to bridge the gap between two halves of a voltaic cell, 436, 437-439
- Salt solutions, acid-base properties of**, 352-355, 359d
- Samarium**, 481
- Sand**, 234
- Sap**, 272
- Saturated fats**, 574, 574
- Saturated hydrocarbons** Alkanes; hydrocarbons in which all the carbon-carbon bonds are single, 548-553
- Saturated solution** A solution in equilibrium with undissolved solute, 19
- Scandium**, 38, 39, 139
- Schrödinger, Erwin**, 133
- SCUBA divers**, 259, 259
- Seaborg, Glenn**, 142, 165, 470
- Seaborgium**, 470f
- Seawater**, 6
- Secondary structure** The three-dimensional form of segments of a protein- $\alpha$ -helix, 594-595
- Second law of thermodynamics** A basic law of nature, one form of which states that all spontaneous processes occur with an increase in entropy, 413
- Second-order reaction** A reaction whose rate depends on the second power of reactant concentration, 287-289, 288f, 291f, 305d-305e
- Second quantum number ( $l$ )**, 134-135
- Selective precipitation** Separation of ions in solution by adding a reagent which, at a given concentration, precipitates one of the ions, leaving the other(s) in solution, 396-398, 403, 405b
- Selene (god)**, 49
- Selenium**, 35, 539, 545-546
- Semiconductors**, 517
- Semipermeable membrane**, 265-266
- Sequester**, 504
- Serine**, 589f
- Sharpless, K. Barry**, 571
- Shield, John**, 525
- Shroud of Turin**, 476, 476
- SI (International System of Units)**, 9
- Sickle cell anemia**, 594
- Side of cell (s)**, 239, 239
- Sidgwick, N. V.**, 166
- Sigma bond ( $\sigma$ )** A chemical bond in which electron density on the internuclear axis is high, as with all single bonds. In a multiple bond, one and only one of the electron pairs forms a sigma bond, 182-184, 186b

- Significant figures** Meaningful digits in a measured quantity, 9–12, 21a–21b
- Silicate lattices**, 235
- Silicon**, 2, 4t, 35, 234
- Silicon dioxide**, 509
- Silver**, 4t, 34, 236, 388
- Silver chloride**, 395, 398, 399, 402, 416, 416, 452
- Silver (I) oxide**, 516
- Silver nitrate**, 402
- Silver phosphate**, 399
- Simple cubic cell (SC)** A unit cell in which there are atoms at each corner of a cube, 238, 238, 239t
- Simple organic compounds**, 61
- Simplest formula** A formula of a compound which gives the simplest atom ratio of the elements present. The simplest formula for hydrogen peroxide is HO, 60–63, 60
- Single bond** A pair of electrons shared between two bonded atoms, 15f
- Single proton emission computer tomography (SPECT scans)**, 471
- Slag**, 510
- Smog**, 535–536, 535
- Smoke detectors**, 472, 472
- Soap**, 563
- Soda water**, 6
- Sodium**, 5, 5
  - applications of, 563
  - and cations, 37
  - in ionic compounds, 41
  - and nutrition, 522–523
  - percent abundance, 4t
  - reaction with water, 34
- Sodium acetate**, 377, 377
- Sodium carbonate**, 64–65, 76–77, 77, 533
- Sodium chloride**, 5, 5
  - acid-base titration, 374, 376
  - crystal structures, 238
  - and cystic fibrosis, 452
  - dissolving precipitates, 402
  - electrolysis of, 457, 457, 507, 508
  - freezing point lowering, 270t
  - ionic crystals, 242
  - mass percent, 250
  - molecular formula for, 39
  - molecular structure of, 39
  - neither acidic nor basic, 352, 352
  - vs. sodium hydride, 514
  - sodium metal, 507–508
  - vapor pressure lowering, 269, 269
- Sodium cyanide**, 512
- Sodium fluoride**, 348
- Sodium hydride**, 514, 514
- Sodium hydrogen carbonate**, 559
- Sodium hydroxide**
  - acid-base titration, 374, 374, 376–377, 377
  - complex formation, 401
  - and electrolysis, 457
  - freezing point lowering, 270
  - ionization of, 336
  - molarity, 34
  - pellets, 65
  - precipitation of nickel hydroxide, 76, 76
  - precipitate formation, 194
  - precipitation of iron(III) hydroxide, 78
  - reaction with hydrochloric acid, 533
  - as a strong base, 81, 81t, 82
  - titration of diprotic acids, 380–381
  - titration with hydrogen chloride, 85
  - titration of with vinegar, 84
- Sodium iodide**, 298
- Sodium ion**, 396–397
- Sodium lactate**, 363–364
- Sodium nitrate**, 256–257
- Sodium peroxide**, 515
- Solid** The physical phase of matter that has a fixed shape and volume, 2
  - in classification of matter, 3
  - comparison of solids, liquids, and gases, 216–217
  - crystal structures, 238–243
  - intermolecular forces, 217
  - ionic solids, 232, 235
  - mass and volume of, 17
  - melting point, 225–226, 226
  - metallic solids, 232, 236–237
  - network covalent, 232–234
  - weighing, 8
- Solid deuterium oxide**, 27
- Solid oxide fuel cell (SOFC)**, 462–463
- Solubility** The amount of a solute that can be dissolved in a given mass of solvent at a specified temperature
  - of alcohols, 256t
  - complex ion, 388–394, 405–405a
  - of hydrocarbons, 255, 255
  - of ionic compounds, 75–76, 75, 256
  - of ionic solids, 235
  - metals, 236
  - of molecular substances, 226
  - of network covalent solids, 233
  - overview of, 18–20
  - of oxygen, 257
  - pressure, effect of, 257–259, 259
  - principles of, 255–259
  - solute-solvent interactions, 255–256
  - of sucrose, 19
  - temperature, effect of, 256–257
  - of vitamins, 255
- Solubility chart**, 75
- Solubility product constant ( $K_{sp}$ )** The equilibrium constant for the reaction by which a slightly soluble ionic solid dissolves in water
  - at 25°C, 390t
  - and the common ion effect, 393–394
  - and the equilibrium concentrations of ions, 389–390
  - expression of, 388–389
  - and precipitate formation, 395–396
  - and sulfide minerals, 392
  - and water solubility, 390–393
- Solute** The solution component present in smaller amount than the solvent, 246
- Solute-solvent interactions**, 255–256
- Solution** A homogeneous mixture containing a solvent and one or more solutes
  - in classification of matter, 3
  - colligative properties of electrolytes, 269–271
  - colligative properties of nonelectrolytes, 260–269
  - concentration units, 246–254
  - definition of, 5
  - moles in, 54–58, 73a
  - solubility, principles of, 255–259
- Solution stoichiometry**, 78
- Solvent** A substance, usually a liquid, which is the major component of a solution, 246
  - s orbitals, 138
  - Sørensen, Søren, 333–334
  - Soybeans, 503
  - Space filling model, 36
  - Specific gravity, 252
- Specific heat** The amount of heat required to raise the temperature of one gram of a substance by 1°C, 190, 190, 191t
- Specific heat capacity**, 190
- Specific ion electrode**, 452
- Spectator ions** Ions that, although present, takes no part in reactions, 77, 82, 85, 353, 381
- Spectrochemical series**, 503, 503
- Spectrum**, 129. *See also* Atomic spectrum
- Sphygmomanometer**, 122
- Splitting energy**. *See* Crystal field splitting energy
- Spontaneous change**, 408
- Spontaneous processes** Processes that can occur by themselves without input of work from outside;  $\Delta G < 0$  for a spontaneous process at constant  $T$  and  $P$ 
  - additivity of free energy changes, 425–427, 429d
  - coupled reactions, 425–427, 429d
  - effect of enthalpy and entropy on, 413
  - energy factor, 407–408
  - entropy, 409–413
  - free energy ( $G$ ), 413–413, 414
  - free energy change and the equilibrium constant, 424–425
  - introduction to, 406
  - precipitation of silver chloride, 416, 416
  - pressure and composition, 423–424
  - randomness factor, 408–409
  - redox reactions, 443–446
  - spontaneous processes, 407–409
  - and standard entropy change, 413
  - standard free energy change ( $\Delta G^\circ$ ), 415–419
  - and temperature, 420–421, 420t
  - temperature, pressure, and concentration, effect of, 419–424, 429b–429c
- Square planar** The geometry of a species in which four groups are located at the corners of a square, surrounding the central atom, 494, 494, 495
- Square pyramids** Pyramids that have a square as their base, 168
- Stability constant**. *See* Formation constant ( $K_f$ )
- Stained glass**, 545, 545
- Stainless steel**, 190
- Standard cell voltage ( $E^\circ$ )** The voltage of a cell in which all species are in their standard states (1 atm for gases, 1 M for ions in solution), 439, 446–448, 448t, 464b–464c
- Standard conditions**, 415–416
- Standard enthalpy**, 202
- Standard enthalpy change ( $\Delta H^\circ$ )** The enthalpy change at 1 atm, 1M, at a specified temperature, usually 25°C, 202, 327, 416
- Standard entropy change ( $\Delta S^\circ$ )** The entropy change at 1 atm, 1 M, at a specified temperature, usually 25°C, 410–411, 412, 413
- Standard free energy change ( $\Delta G^\circ$ )**  $\Delta G$  when reactants and products are in their standard states, 415–416, 446
  - calculation of at other temperatures, 418–419
  - and the equilibrium constant, 424–425
  - free energies of formation, 417–418
  - relation to standard cell voltage, 448t
- Standard free energy of formation ( $\Delta G_f^\circ$ )** Defined as the free energy change per mole when a compound is formed from the elements in their stable states at 1 atm, 417–418
- Standard molar entropy ( $S^\circ$ )** Entropy of a substance in its standard state (per mole), 410–411, 411t
- Standard oxidation voltage ( $\Delta E_{ox}^\circ$ )** The voltage associated with an oxidation half-reaction when all gases are at 1 atm and all aqueous solutes are at 1 M, 439–440, 442–443
- Standard potential** Identical with the standard reduction voltage, 440, 441t
- Standard reduction voltage ( $\Delta E_{red}^\circ$ )** The voltage associated with a reduction half-reaction when all gases are at 1 atm and all aqueous solutions are at 1 M, 439–440, 442–443
- Standard solution**, 84
- Standard temperature and pressure (STP)** Conditions of 0°C, 1 atm, 100
- Standard voltages**, 439
  - calculation of, 442–443
  - oxidizing and reducing agents, strength of, 440–442
  - spontaneity of redox reactions, 443–446
- Starch**, 586–587, 587
- State** A condition of a system at fixed temperature, pressure, and chemical composition, 188
- State properties** Properties of a system whose values are fixed when its temperature, pressure, and composition are specified, 188, 196, 206, 211, 409, 413–414
- Steam**, molecule density, 216, 217t
- Stearic acid**, 563
- Steel production**, 509–510, 509

- Steric factor, 291, 294  
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 Stoichiometry Relationships between amounts (grams, moles) of reactants and products  
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- Storage (rechargeable) voltaic cells, 459-460  
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 Strong acid A species that is completely ionized to  $H^+$  ions in dilute water solution, 81t  
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 strong base, reactions with, 82, 83t  
 weak base, reactions with, 82, 83t  
 zinc, reactions with, 89
- Strong base A species that is completely ionized to  $OH^-$  ions in dilute water solution, 81t  
 acid-base titration, 374, 374-379, 377, 381t  
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- Strong electrolytes, 81  
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 Strontium-90, 481  
 Strontium chromate, 288-289, 388, 388, 394-395, 394, 423-424, 423, 515  
 Strontium hydroxide, 81t, 336  
 Structural formula A formula showing the arrangement of bonded atoms in a molecule, 36, 548  
 Structural isomers Two or more species having the same molecular formula but different structural formulas. Examples:  $C_2H_5OH$  and  $CH_3-O-CH_3$ , 549-550
- Styrene, 577t  
 Styrene polymer, 428  
 Subatomic particles, 25t  
 Sublevel energies, 138-140  
 Sublevels Subdivisions of an energy level, designated as an s, p, d, or f sublevel, 134-135, 135t, 137-142, 137t, 139  
 Sublimation The phase transition from the solid phase to the vapor phase, without passing through the liquid phase, 225, 225t
- Subscripts, 59, 64  
 Substances, 15-20, 19, 21c-21e  
 Substitution reactions Reactions in which a group of atoms or molecule is replaced by a different atom or group, 573  
 Successive approximations A technique used to solve quadratic or higher-order equations. A first, approximate answer is refined to obtain a more nearly exact solution, 345
- Sucralose, 586t  
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 Sulfur trioxide, 536-537, 543  
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 Supercritical carbon dioxide, 243-244  
 Supercritical fluid, 223  
 Superoxide A compound containing the  $O_2^-$  ion, 514, 515  
 Superphosphate of lime, 545  
 Supersaturated solution A solution containing more solute than allowed at equilibrium; unstable to addition of solute, 19, 20  
 Surface tension, 217, 217  
 Surpass, 93t  
 Surroundings Everything outside the system being studied, 188  
 Symbol A one- or two-letter abbreviation for the name of an element, 2  
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 Synthetic addition polymers, 577-580, 597-597a  
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 System The sample of matter under observation, 188, 188
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 Terephthalic acid, 581  
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 Termolecular, 299  
 Terra (god), 48  
 Tertiary structure A three-dimensional conformation of a protein showing the folding of the secondary structure, 594-595
- Tetraamminecopper(II) chloride, 493  
 Tetraamminezinc(II) ion, 494  
 Tetraaquacopper(II), 492  
 Tetraaquazinc(II) ion, 340t  
 Tetrachlorocuprate(II), 493  
 Tetraethyllead, 553  
 Tetrafluoroethylene, 577t  
 Tetrahedron A figure of four triangular faces with eight edges and four vertices, 168, 494, 494, 536  
 Tetrahydroxozincate(II), 492  
 Theoretical yield The amount of product obtained from the complete conversion of the limiting reactant, 67-70  
 Thermal conductivity The ability to conduct heat, 236  
 Thermite reaction, 204, 204  
 Thermochemical equation A chemical equation in which the value of  $\Delta H$  is specified, 196-202, 215b-215c  
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 Thermodynamics The study of heat and work effects in physical and chemical changes, 406, 415, 546b-546c  
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 Thermodynamics and the Free Energy of Chemical Substances (Lewis/Randall), 165  
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 The Thinker (Rodin), 504, 504  
 Third law of thermodynamics A natural law that states that the entropy of a perfectly ordered, pure crystalline solid is 0 at 0 K, 410  
 Third quantum number ( $m_l$ ), 135  
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 Tincture of iodine, 528  
 Titanic, 5  
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 Titration A process in which one reagent is added to another with which it reacts; an indicator is used to determine the point at which equivalent quantities of the two reagents have been added, 84-86, 84, 85  
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 Toluene, 414, 557  
 Tomb of the Unknown Soldier, 596  
 Top Care, 93t  
 Torr, 97  
 Torricelli, Evangelista, 96  
 Toxic elements, 35, 35  
 Trans isomer A geometric isomer in which two identical groups are as far apart as possible (e.g., a, b), 495-497, 496, 497,



567-569

Transition metal cations, 56-57, 56, 146-148, 455, 498-499, 523t

**Transition metals** Metals in the central groups (3–12) of the 4th, 5th, and 6th periods of the periodic table, 33, 42, 141

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**Transplants**, 244

**Transuranium elements**, 470, 470t

**Trichloroacetic acid**, 563

**Triglycerides**, 574

**Trigonal bipyramid** A solid with five vertices; may be regarded as two pyramids fused through a base that is an equilateral triangle, 168

**Trigonal planar** The geometry of an AX<sub>3</sub> molecule where A is at the center of the equilateral triangle formed by three X atoms, 167

**Trigonal pyramid** The geometry of an AX<sub>3</sub>E molecule in which atom A lies directly above the center of an equilateral triangle formed by three X atoms, 169

**Trimethylamine**, 230

**Triple bond** Three electron pairs shared between two bonded atoms, 158

**Triple point** The temperature and pressure at which the solid, liquid, and vapor phase of a substance can coexist in equilibrium, 224, 225

**Triprotic acids**, 346

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**Tris(ethylenediamine)iron(III) phosphate**, 493

**Troposphere**, 302

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**Tungsten**, 236

**2-methylpropane**, 549, 549, 550–551

**Tyrosine**, 589t

## U

**UAVs (Unmanned autonomous vehicles)**, 461

**Ultraviolet (UV) radiation** Light with a wavelength less than 400 nm but greater than 10 nm, 126–127, 302–303

**Uniform mixtures**. See **Homogeneous mixtures**

**Unimolecular**, 299

**Unit cell** The smallest unit of a crystal that, repeated again and again, generates the whole crystal, 238–239

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**Units of measurement**, 8–9

**Unmanned autonomous vehicles (UAVs)**, 461

**Unpaired electrons**, 144, 164

**Unreactive gases**. See **Noble gases**

**Unsaturated hydrocarbons**, 553–556

**Unsaturated solution** A solution that contains less solute than the equilibrium (saturated) value, 19

**Unshared electron pair** A pair of electrons that “belongs” to a single atom and is not involved in bonding. Also called a *lone pair*, 157, 171, 172, 173

**Unstable isotopes**, 467

**Uranium**, 26, 27, 118–119, 142, 287, 473

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**Uranus (planet)**, 48

**Urey, Harold**, 165

**Uso-294**, 470

## V

**V**

**V**. See **Volume**

**Valence and the Structure of Atoms and Molecules (Lewis)**, 165

**Valence bond model** Model of the electronic structure of molecules in which electrons are assigned to orbitals, pure or hybridized, of individual atoms, 178, 498

**Valence electrons** Electrons in the outermost principal energy level. For a main-group element, the number of valence electrons is given by the last digit of the group number, 156, 157, 162–163, 498

**Valine**, 589t

**Vanadium oxide**, 543

**Vanilla beans**, 562

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**Van't Hoff factor**, 269

**Vapor**, 217

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**Vapor pressure** The pressure exerted by a vapor when it is in equilibrium with a liquid, 111–112, 218–222, 218, 220, 221, 225, 260–261

**Vapor pressure lowering**, 260–261, 262–263, 262, 269

**Vinegar**, 84, 340, 563

**Vinyl chloride**, 577t, 579–580

**Vitamin B-12**, 241

**Vitamin C**, 62–63

**Vitamins**, 255, 256

**Volt (V)** A unit of electric potential: 1 V = 1 J/C, 440, 453t

**Voltage**, 448–452, 464c–464d

**Voltaic (galvanic) cell** A device in which a spontaneous reaction produces electrical energy, 430, 435–439, 464a

**Volume (V)**

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and vapor pressure, 218

**Volume ratio**, 108–109

**Von Hofer, Ludwig**, 48

**VSEPR model** Valence Shell Electron Pair Repulsion model, used to predict molecular geometry; states that electron pairs around a central atom tend to be as far apart as possible, 156, 166–167, 167, 169–171, 173, 180, 494, 548

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## W

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**Water solubility**, 390–393

**Watras, Stanley**, 485

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**Watt (W)**, 453t

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**Wavelength ( $\lambda$ )** A characteristic property of a wave related to its color and equal to the length of a full wave, 125–127, 125, 127t, 127

**Weak acid** An acid that is only partially dissociated to H<sup>+</sup> ions in water

acid-base titration, 374, 376–379, 377, 381t

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ionization of, 342

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and their equilibrium constants, 339–343, 359b–359c

**Weak base** A base that is only partially dissociated to form OH<sup>-</sup> ions in water

acid-base titration, 374, 379–380, 380, 381t

Arrhenius and, 87

definition of, 81

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OH<sup>-</sup> in a water solution of, 349–350

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**WHO (World Health Organization)**, 546

**Wilkins, Maurice**, 595

**Wine, fermentation of**, 15t, 560

**Women**, 241, 467, 470, 473

**Wood alcohol**. See **Methyl alcohol**

**Work (*w*)** Any form of energy except heat exchanged between system and surroundings; includes expansion work and electrical work, 209–210, 210t, 211

**Work effect**, 211

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**World War II**, 480

## X

**X**

**X**. See **Mole fraction**

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**Yttrium oxide**, 141

**Yucca Mountain, Nevada**, 482–483

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**Zero-order reaction** A reaction whose rate is independent of reactant concentration, 287-289, 288t, 305d-305e

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Zinc-hydrogen-ion voltaic cell, 439

Zinc hydroxide, 399, 401, 492

Zinc(II) cation, 488

Zinc-manganese dry cell, 458, 458

Zinc salts, 339

**Zwitterion** Form of an amino acid in which there is a separation of charge between the nitrogen atom of the  $\text{NH}_2$  group (+) and one of the oxygen atoms of the  $\text{COOH}$  group (-), 590-591