

# INDEX / GLOSSARY

Page references with “f” indicate figures; those with “t” indicate tables. Glossary terms are printed in blue.

- abiogenic methane, 95  
absolute zero of temperature, 417  
**absorption spectrum** A plot of the percentage of radiation transmitted by a substance over a range of incident radiation energies (or wavelengths), 51, 74–77, 105, 158, 555  
abundances of elements, 977  
acceptor level, 1081  
**acetals** Functional groups with the structure  $\text{RHC}(\text{OR}')_2$ , or compounds whose molecules have that functional group, 853, 930, 961  
acetylene, 790  
**achiral** Molecules or objects that are superimposable on their mirror images and therefore not chiral, 330–333, 348  
**acid** A species that is a proton donor or electron-pair acceptor, or a substance that is the source of the species, 193, 194f, 204, 953, 954  
characteristics, 528–532  
strong, 194  
weak, 194  
**acid anhydrides** Functional group with two acyl groups bonded to the same O atom,  $\text{RC}(=\text{O})\text{OC}(=\text{O})\text{R}'$ , or compounds whose molecules have that functional group, 921, 960  
acid-base  
adduct, 197, 541  
character, 539  
distribution, 554–559  
equilibria, 523–524, 545–553, 583  
indicator, 573  
pH, 554–557  
properties, 559–575  
reactions, 193–193–196  
speciation, 557–558, 581–582  
titrations, 573–578  
**acid-base neutralization** Reaction due to transfer of protons, with formation of water, 195, 204  
acidic condition, 656  
**acidic solution** An aqueous solution in which  $[\text{H}^3\text{O}^+] > [\text{OH}^-]$ . At 25 °C,  $\text{pH} < 7$ , 533, 583  
acidification  
ocean, 591–595, 614  
soils and water, 975  
**acid ionization constant ( $K_a$ )** The equilibrium constant for ionization of a weak acid in aqueous solution, 523–527, 535–536, 538t, 583  
acidity, 552  
acidosis, 582  
acids  
and bases, 193–200, 528  
in an aqueous solution, 193–194  
actinides, 1035  
**activation energy ( $E_a$ )** The minimum combined kinetic energy that a pair of colliding particles must have in excess of the average for their collision to result in reaction, 741–744, 808  
of reaction, 742  
active site, 764  
**activity (A)** (nuclear chemistry) Number of disintegrations observed per unit time, measured in becquerel (Bq), 1159  
**activity (a)** The effective concentration of a solute species, 473, 498, 592  
activity-based equilibrium constants, 498  
acylation, 834  
acyl chlorides, 948–951  
**acyl halides** Functional group with acyl group bonded to a halogen atom,  $\text{RC}(=\text{O})\text{X}$ , or compounds whose molecules have that functional group, 921, 948, 960  
addition of  
alcohols, 933–934  
Grignard reagents, 934–936  
**addition reactions** Reactions between molecules of two substances to form molecules of a new substance with no atoms “left over,” 782, 840  
of  $\text{H}_2$  to alkenes: hydration, 813  
of  $\text{H}_2$  to alkenes: hydrogenation, 802, 805, 816  
of  $\text{H}_2\text{O}$  to alkynes: hydration, 819  
of  $\text{HX}$  to alkynes: hydrohalogenation, 818  
of  $\text{X}_2$  to alkenes: halogenation, 814  
polymers from ethylene derivatives, 804t  
to unsymmetrical alkenes and carbocation stability, 809  
adenosine-5-diphosphate (ADP), 244, 621, 764  
adenosine-5-triphosphate (ATP), 244, 621, 764  
adhesion, 1182  
adrenaline, 527  
aerogels, 1087  
**aerosols** Fine droplets of liquid or dust suspended in a gas, such as the atmosphere, 99–100f, 119, 478  
age-related macular degeneration (AMD), 3–6  
agglutinate, 1114  
**albedo** The fraction of sunlight incident on the earth that is reflected, 100, 415  
**alcohol** Functional group with the structure  $\text{R-OH}$ , or compounds whose molecules have that functional group, 77, 856–866  
addition, 933–936  
models, 930  
naming, 856–860  
reactivity, 851  
spectroscopic evidence, 860–866  
reactivity, 881–893  
structure, 881–893  
**aldehydes** Functional group with the structure  $\text{RC}(=\text{O})\text{H}$ , with a carbonyl group bonded to one hydrogen atom, or compounds whose molecules have that functional group, 886, 911–915  
naming, 917–918  
reactivity, 916–917, 924–938  
structure, 916–917, 924–938  
aldohexose, 1099  
aldopentose, 1099  
aldoses, 1099  
alkali metals, 987–991, 995  
alkaline earth elements, 991–995  
alkalosis, 582  
**alkanes** Substances whose molecules contain skeleton frameworks with C–C single bonds, 110–114, 119–120  
conformations, 317–322, 348  
cyclic, 115  
nomenclature of, 113  
**alkene** The C=C double bond functional group, or compounds whose molecules have that functional group, 77, 773–776, 788–796  
spectroscopy, 793–796  
reactivity, 796–815  
structure, 796–815  
alkenes, stereoisomers of, 323  
alkyl halides, 856–866  
naming, 856–860  
reactivity, 851, 866–881  
spectroscopic evidence, 860–866  
structure, 866–881  
alkylation, 834, 897, 899  
alkynes, 114, 773–773, 788–796  
electronic structure, 816  
spectroscopy, 793–796  
reactivity, 816–820  
structure, 816–820  
**alkylating agents** Substances whose molecules are able to transfer an alkyl group to a molecule of another substance, 897  
**alkyl group** A functional group or side chain, that, like alkanes, consists only of single-bonded carbon atoms and hydrogen atoms. An example is a methyl group, 114  
**allotropes** Different forms in which an element can exist, 445  
alloying, 659  
**alloys** Mixtures of a metal with one or more other elements that retain metallic characteristics, 1078–1079  
**alpha ( $\alpha$ ) radiation** Radioactive decay involving loss of an alpha particle ( $^4\text{He}^{2+}$  ions) which is readily absorbed, 1148  
alternative delocalized electron representations of a benzene molecule, 823  
aluminum, 995–1001  
aluminosilicates, 1004

- amides** Functional group with the structure  $RC(=O)NR_2$ , or compounds whose molecules have that functional group, 895, 921, 949, 957, 958, 960
- amines, 856–866, 936, 958  
 addition, 936–937  
 naming, 856–860  
 reactivity, 851, 893–899  
 spectroscopic evidence, 860–866  
 structure, 893–899
- amino acid** Compounds whose molecules have both carboxylic acid and amine functional groups, 559–563, 1115–1125  
 acid–base properties, 559–563  
 proteins, found in, 561t  
 amino sugars, 1113  
 ammonia synthesis apparatus, 489  
 nitrogen in the air, 487  
 amount fraction, 424, 466
- amount of substance ( $n$ )** A fundamental quantity in the SI system, of which the unit of measurement is a mole, 35, 43
- amounts table, 138  
 amphibole, 1004  
 amphiprotic, 531
- amphoteric** (or *amphiprotic*) Species that can behave as acids or bases, depending on their environment, 531, 583  
 hydroxides, 199  
 amylopectin, 1112  
 amylose, 109–110, 1112  
 angular momentum quantum number, 277
- anion** A particle with negative charge because it has more electrons than protons, 56, 59–60, 82, 980
- anode** The electrode at which oxidation occurs, 630, 660
- anomeric centre** The hemiacetal carbon atom in molecules of a pyranose or furanose sugar, 1106
- anomers, 1106
- antibonding molecular orbital** A molecular orbital in which the distribution of density of electrons that “occupy” it results in an effect of repulsion between atoms and weakening of the bond between them, 400
- anticancer drug, cisplatin, 1031–1035  
 anticodon, 1134  
 anti conformer, 317  
 antigenic determinants, 1114  
 antisense strand. *See* template strand  
 antisymmetric Stretching, 76f  
 anthropomorphism, 629  
 apoenzyme, 1123  
 aqua regia, 1010
- aquated ions** Solute ions surrounded by water molecules, 179
- aquation** The process of surrounding molecules or ions in aqueous solution by water molecules, 158, 179, 198, 982  
 of cations, 982  
 of Metal Ions, 198
- aqueous solutions** Solutions with water as the solvent, 178, 204, 523–527, 539–541, 545–555, 651–652  
 acidity, 982  
 Ionization of molecular solutes, 185–186  
 aragonite, 592  
 argon in air, 1022  
 Armstrong, Lance, 17–20
- aromatic compounds** Compounds with cyclical conjugated molecules significantly more stable than a model compound whose molecules have a localized electronic structure, 773–776, 788–796, 820, 840  
 reactivity, 820–839  
 spectroscopy, 820–839  
 structure, 820–839
- aromatic  
 heterocycles and ions, 826  
 aromaticity, 822–825
- Arrhenius equation** A mathematical expression that relates reaction rate to the activation energy, collision frequency, molecular orientation, and temperature, 744–745–747, 765
- arsenic  
 inorganic, 159  
 organic, 159  
 speciation, 157–159  
 water, 1013
- arsenobetaine, 159  
 artificial leaves, 619–624  
 arylamines, 894  
*aspergillus niger*, 720  
 atmosphere, 100, 102, 414–415  
 characteristics, 528–532  
 CO<sub>2</sub>, 109f, 774f  
 Earth, 413  
 greenhouse gases in, 96–106  
 lifetime, 104f  
 Mars, 413
- atom economy** The principle that, as far as possible, all of the atoms in the starting materials should be in the desired products, 126–128, 132, 147–149
- atom efficiency** The percentage of atoms of each element in the reactants that end up in the desired product, 126–128, 147–149, 150
- atomic composition, 30  
 atomic mass, 31–33
- atomic mass units (u)** One-twelfth of the mass of a <sup>12</sup>C atom, 31–33
- atomic nuclei, 1153–1158
- atomic number (Z)** The number of protons in the nucleus of every atom of an element, 29
- atomic orbital, 276, 386–388, 403–404  
 atomic properties, 259  
 atomic radii, 262f  
 atomic radius, 1039  
 atomic spectroscopy, 256  
 atomic structure, 28–29
- atomic weight** The average relative atomic mass of a representative sample of atoms of an element, weighted by the relative abundances of its isotopes, 33–35, 43, 63  
 conventional atomic weights, 41  
 standard atomic weights, 40
- atoms** Tiny particles characteristic of each element, 25–25, 28–29, 35, 43, 58, 125  
 excited, 268–269, 272  
 localised regions, 388–396  
 modelling, 253–254, 295–297  
 nuclear charge, 289–291  
 atom size, 261–263, 292  
 atom structure process, 296f
- aufbau principle** Imaginary building of atoms of successive elements by assigning each successive electron to the orbital that results in the lowest–energy atom, 285, 297
- average rate of reaction, 723  
 Avogadro, Amadeo, 417
- Avogadro constant ( $N_A$ )** The number of specified particles in 1 mol of a substance, 35, 43  
 hypothesis, 417
- bacterial oxidation of minerals, 975  
 baking soda, 990
- balanced chemical equation** A chemical equation in which the total charge on the species that react is equal to that on the species that are formed, and atoms are conserved, 131–134, 149
- Balmer, Johann, 269  
 balmer series, 271  
 band of stability in nuclei, 1154–1155
- band theory** A theory of bonding in metals, 1077
- barium sulfate slurries in intestinal X–rays, 600
- barometer** A device used to measure atmospheric pressure, 416
- Bartlett, Neil, 1023
- base** A species that is a proton acceptor or electron–pair donor, or a substance that is the source of the species., 194f, 195, 204  
 characteristics, 528–532  
 strong, 195  
 weak, 195
- base ionization constant ( $K_b$ )** The equilibrium constant for ionization of a weak base in water, 536, 538t, 583, 894
- bases in aqueous solution, 195  
 basic oxygen furnace, 1043
- basic solution** An aqueous solution in which  $[OH^-] > [H^3O^+]$ . At 25 °C, pH > 7, 533, 583
- basicity, 894  
 Bassler, Bonnie Lynn, 914–915
- batteries** Portable voltaic cells, 634–635  
 bauxite, 998  
 Bayer process, 998  
 Becquerel, Antoine Henri, 1147  
 beetle, pine, 773–774  
 Bent, Henry, 358  
 benzene, 791, 822  
 bonding, 788  
 model of bonding in molecules, 396, 407  
 molecule, bonding, 371  
 stability, 821
- beryllium compounds, 993–994
- beta ( $\beta$ ) radiation** Electrons ( $\beta$  particles) emitted during radioactive decay of some elements, 1148
- bidentate, 334, 1046  
 bimolecular, 752

- binding energy per mol of nucleons, 1157
- bioactive compounds, 9
- bioassays** (biological assay) Experiments to study the effects of a substance on living matter, 8
- bioavailability** A measure of the extent to which a species is available to an organism—for example, from an administered drug or from the soil, 159, 488, 523, 558, 854
- biochemical, 581–582
- bio-leaching, 1044
- bio-extraction, 1044
- biofilms** Collections of micro-organisms in which cells cling to each other on a surface, 914
- biofuels** Fuel derived from plants or algae, 110, 119
- biogas** Gas formed by the breakdown of organic matter in low-oxygen environments, 95, 110
- biogenic methane, 95
- biomass, 110
- biomaterials, 1089–1090
- biomimetics** The use of natural biological systems to assist in the design of new materials or reactions, 303, 348
- biomimicry** (biomimetics) The use of natural biological systems to assist in the design of new materials or reactions, 303, 348
- biopolymers, 108–110
- black carbon, 100
- blast furnace, 1042
- Bohr model of electrons in atoms, 270
- Bohr, Niels, 270
- boiling point** Temperature at which the vapour pressure of a liquid is the same as the pressure of the atmosphere on the liquid surface, 163, 203, 259
- normal boiling point, 163
- Bonaparte, Napoleon, 256
- Boltzmann, Ludwig, 674
- Boltzmann's constant, 674–675
- bond angle, 307
- bond energy (*D*)** Enthalpy change for breaking a particular bond in the molecules of 1 mol of substance, with the reactants and products in the gas phase, 241–243, 246
- bonding
- in coordination complexes, 1062–1069
  - in metals, 1076–1079
  - in molecules, 357
  - in semiconductors, 1080–1082
- bonding molecular orbital** A molecular orbital in which the distribution of density of electrons that “occupy” it results in an effect of pulling atoms together, 357–407
- bond length, 307–308t
- bond order** A measure of the strength of bonding between two atoms in a molecule or ion, dependent on the number of electrons in the bond, and the types of orbital they “occupy”, 371–408
- bond polarity** A measure of the charge separation across a polar bond, 165–167, 168f, 169f
- bond rotation, 322–323
- boranes, 999
- borax, 999
- boron, 995–1001
- neutron capture therapy (BNCT), 1171
  - production, 1088
- Bosh, Carl, 489
- Boyle, Robert, 417
- Boyle's law, 417
- brittleness, 55
- Broglie, Louis Victor de, 274
- bromination, 829
- bromine, 1018
- Brønsted-Lowry model** In proton-transfer reactions, a base takes  $H^+$  ions from an acid, 527–532
- Brouwer, Darren, 446
- Buckminsterfullerene, 839
- buffer capacity** A measure of the ability of a buffer solution to minimize pH change on addition of acids or bases, 571–572, 584
- buffer solution** A solution that minimizes the change of pH when some strong acid or base is added, because it contains relatively large amounts of both a weak acid and its conjugate base, 564–573, 583
- burning, 27
- butane, 110
- $^{13}C$  NMR. *See also* nuclear magnetic resonance (NMR) spectroscopy, 313
- alkenes and alkynes, 794
  - c-terminal, 1118
  - caffeine, 12–13
  - Cahn-Ingold-Prelog rules, 800
  - calcification, 593
  - calcite, 1076
  - calcium, 992, 994
    - carbonate, 592  - calculating pH change of buffer solutions, 570
  - calculation of enthalpy change of a reaction
    - Values, 239–240
  - calmodulin (CaM), 1096
  - calorimeter, 231f–232
  - calorimetry** Experimental measurement of the enthalpy change accompanying a chemical reaction, 231–232, 245
  - Cameron lakes, 457–458
  - carbocation, 759, 809
  - carbohydrates** Polyhydroxylated aldehydes and ketones, commonly called sugars, 243, 852, 933–934, 1097–1115
  - carbon-13/ carbon-12 isotope ratio in forensic analysis, 19, 30
    - Mars atmosphere, 117
  - carbon-13 NMR. *See*  $^{13}C$  NMR
  - carbon-14 dating techniques, 1162
  - carbon-14/carbon-12 ration on  $CO_2$ , 1146
  - Carbonate buffers in biochemical systems, 581
  - carbonate speciation
    - in aqueous solution, 592
    - in surface ocean water, 593
  - carbonated soft drinks, 462
  - carbon atoms, 309–310
- carbon compounds, 89–122, 776–787
- capture, 107
  - fossil, 102f
  - specific, 92–93
  - storing, recycling, 106–110
  - structure and reactivity, 776
  - unsaturated, 114
- carbon dioxide, 107, 442, 418, 457
- atmosphere, 96, 103–110, 591
  - clathrate cages, 91
  - feedstock and solvent, 107
  - phase diagram, 443
  - supercritical, 445
- carbon framework of molecules, 309–317
- carbon sequestration** Geoengineering technique to trap carbon dioxide or other forms of carbon, 108
- carbon steel, 1043
- carbonic anhydrase, 763
- carbonyl compounds, 78t, 916–924, 958
- naming, 917–922
  - reactivity, 916–917
  - spectroscopy, 922–924
  - structure, 916–917
- carbonyl functional groups (C=O)** The most important and widely occurring class of functional groups in both organic and biological chemistry, 76, 916, 961
- carboxylic acid, 5
- carboxylic acid derivatives** Compounds whose molecules have a functional group formally derived from a carboxylic acid group, with the structure  $RC(=O)X$ , where a group  $-X$  replaces the  $-OH$  of a carboxylic acid group, 911–915, 961
- naming, 920–921
  - reactivity, 916–917, 938–960
  - structure, 916–917, 938–960
- carboxylic acid** Functional group having the structure  $RC(=O)OH$ , or compounds whose molecules have that functional group, 911–915, 961
- carvone, 304, 330
- cast iron, 1043
- catalysts** Species that accelerate chemical reactions and are regenerated after performing their function, 114, 719, 726, 747–748, 750, 768
- catalytic steam-re-formation, 986
- cathode** The electrode at which reduction occurs, 630, 660
- cation** A particle with positive charge because it has more protons than electrons, 56, 58, 59, 82
- charged density, 978–984
- cell electromotive force. *See* cell emf
- cell emf ( $E_{cell}$ )** The applied potential required to stop electron flow in a voltaic cell, 635–645, 660
- cellobiose, 1110
- cellulose, 109–110, 1111
- starch, 1097, 1111
- cements, 1087
- central dogma, 1139
- ceramics** Solid inorganic compounds that combine metal and non-metal atoms, 1084–1089

- CFCs (chlorofluorocarbons)  
in atmosphere, 104
- chain reaction, 1166
- chair conformer, 325
- characteristic reaction, 801, 816, 867–869, 888–889, 896–897
- charge, monatomic ions of elements, 264–265
- charge density** The charge/radius ratio of ions, a factor that influences the polarization of electrons on adjacent species, 978–979, 1024
- covalent–ionic bond character, 979
- charge-to-radius ratio** (charge density) The charge/radius ratio of ions, a factor that influences the polarization of electrons on adjacent species, 979, 1024
- of cations. *See* charge density
- Charles, Jacques, 417, 984
- Charles's law, 417
- chelate effect** Complex ions with polydentate ligands are more stable than complexes that have the same number and type of donor atoms in monodentate ligands, 1054–1055
- chelating ligands** Ligands that form more than one coordinate covalent bond with the central metal ion in a complex, 1047
- chelates** Complex ions with polydentate ligands, 329–330, 1047
- chemical accounting, 131–134
- chemical analysis, 144–146
- chemical biology** The application of chemical knowledge and techniques to study and manipulate biological systems, 911
- chemical change** (See chemical reactions)  
A process in which one or more new species form as a result of redistribution of atoms, ions, or electrons, 27–28, 131, 218–219, 218–219
- basic, 125–155
- specific, 129–131, 649–650
- chemical communication, 911–915, 960
- chemical compounds** Pure substances whose molecules or ions are composed of atoms of different elements in fixed proportions, 25–26, 43
- chemical energy, 221f
- chemical equation** A symbolic representation of a chemical reaction, 27, 131–134
- chemical equilibrium, 134, 487–491, 667–670
- chemical formula** A representation of the composition of a compound, 26, 43
- chemical kinetics, 134
- chemical message, 775
- chemical potential** A relative measure of how far a reaction mixture is from chemical equilibrium, 134–135, 149
- chemical properties** The characteristic behaviour of a substance in reactions with other substances, 27–28, 43
- chemical reaction** (chemical change) A process in which one or more new species form as a result of redistribution of atoms, ions, or electrons, 27–28
- basic, 125–155, 149, 213–250
- categories, 188–200
- energy, 218f
- reaction rate, 721–725, 727, 740–750
- specific, 130–131, 149, 188–200
- chemical reactivity, 1, 1145–1147
- chemical shift** ( $\delta$ ) Specifies the position of peaks in an NMR spectrum of a compound, and gives information about the electronic environment of the atoms, 310–311, 314, 348
- NMR, 309
- chemical species** Any particles (atoms, ions, molecules) that have characteristic chemical behaviour, 58, 82, 130, 149, 158
- chemical thermodynamics, 671
- chemistries of nitrogen and phosphorus, 1007
- chemistry
- drugs, sports, 17–20
- ethics, 19
- chemotherapy** The use in medicine of substances that are selectively toxic to malignant cells or to a disease-causing virus or bacterium, 3–5
- chiral** Adjective describing a molecule or object that is “handed,” or not superimposable on its mirror image, 305, 330–333, 343, 348
- environments, 345–347
- chirality** The property of molecules or ions that are chiral, 117, 330–334, 1059
- chitin, 1113
- chlorination, aromatic compounds, 832
- chlorine compounds, 1017, 1020–1021
- chloroethane molecule, 69f, 70f
- chlorofluorocarbons, 104
- chlorophyll II, 621
- cholesterol, 325
- chromatography** The science of separation of compounds in mixtures, 2
- Ciamician, Giacomo, 622
- cis-trans isomerism** Isomerism due to the existence of different molecules with the same number of atoms of each type, and the same connectivity, but different spatial arrangement of the atoms because of the inability to interconvert without breaking of bonds, 322–324, 326, 783, 797–799, 1032–1034, 1058–1061
- cisplatin, 324, 1031–1035
- citrate synthase, 1124–1125
- citric acid cycle, 1124
- classifying
- functional groups by level, 779
- reactions by change in level of functional groups, 781
- reactions by type of overall transformation, 782
- substances, 186
- clathrate** Substance in which guest molecules are inside a cage of host molecules, 90, 91–92, 119
- clays, 1087
- climate change, 97–107, 720
- clouds, 100
- clostridium perfringens, 1129
- Cockroft, J.D., 1164
- coding strand, 1133
- codon, 1134
- co-enzyme, 1123
- co-factor, 1123
- cold pack, 461
- collagen, 1090
- colliding molecules, 744–745
- colligative properties, 468–478
- solutions of electrolytes, 472
- collisional de-excitation, 103
- collision theory of reaction rates** A way of rationalizing observations about rates of reactions based on a model that assumes that molecules, atoms, or ions of reactants are in rapid and random motion, frequently colliding with each other, 740–750, 768
- colloidal dispersions** An intermediate state between a solution and a suspension, 478–481, 482
- colloids** (colloidal dispersions) An intermediate state between a solution and a suspension, 478, 480–481
- combustion, 27
- common ion effect** The presence of common ions reduces the extent of ionization of a weak acid or the solubility of a slightly soluble salt, 548–549, 586, 600–601, 616
- common oxidizing and reduction agents, 192t
- complexation** Reaction in which a bond is formed by sharing of a non-bonding pair of electrons on one of the reactants, 196–200, 204, 541, 557–558, 591, 610–614, 1051–1056
- complexes, 610, 1033, 1045–1048, 1051–1056
- complex ion** Ion that is a product of a complexation reaction, 159, 196, 204, 1046
- speciation, 1052–1054
- complexity leading, 599–600
- compounds, 25–26
- concentrated, 200
- concentration, 200–203
- aqueous solutions, 200
- cell emf, 643–644
- definitions, 545
- ions, 608–609
- species, 554–559
- concerted reactions, 784
- condensation** Change of phase of a material from vapour to liquid, 958
- condensed formulas** Formulas showing particular groupings of atoms in molecules, 71
- condensed structure, 113–114
- conduction band, 1080
- configuration** (stereochemistry)  
Three-dimensional spatial orientation of atoms and bonds in a molecule, 306–307, 337–340, 348
- conformations** Different arrangements of atoms in molecules that result from rotation around a single bond, 317–322, 327
- conformers** Relatively stable (energy minima) conformations of molecules of a substance, 317–321, 348

- composition, 67–71
- conjugate acid–base pair** Two species whose compositions differ by an H<sup>+</sup> ion, 530–531, 537–538, 583
- connectivity** The sequence by which atoms are joined to each other in molecules, 64, 71–81, 362
- conservation of energy, 221–222
- constitutional isomers** (structural isomers) Two substances with the same formula but different connectivity of the atoms, 71, 112f, 310, 323, 348
- in complexes, 1057
- controlling pH, 564–573
- conventional atomic weight, 41
- conversion
- acyl chlorides, 948–951
  - amids, 957
  - ethers, 889, 953, 954
  - solid to liquid, 439–440
  - solid to vapour, 441
- coordinate covalent bond, 1046
- coordination
- chemistry, 1046
  - complex, 329–330, 1045, 1046, 1056, 1057–1069
  - complex, bonding, 1153
  - complex formation constant, 1051
  - complex, isomerism, 1056
  - complex, pH-dependence of speciation, 1053
  - complex stability, 1050
  - complex, structure and shape, 1056
  - compounds, 610, 1044–1050
  - geometry, 1046
  - number, 1046
- coordination geometry** The distribution in space of ligands around the metal atom or ion in a complex, 1046, 1048
- coordination number** The number of donor atoms to which a metal ion is bonded in a complex, 1046, 1048, 1050, 1056, 1060
- core electrons** The “inner” electrons whose configuration corresponds with that of the previous noble gas in the periodic table, 287
- copper extraction from ores, 1043–1044
- corrosion** The deterioration of metals as the result of oxidation in the presence of air and water, 654
- inhibitors, 659
  - iron, 654–659, 660
- corundum, 1001
- Coulson, Charles A., 359
- covalent bond** A force of attraction between adjacent atoms in molecules and in covalent network substances, 64, 66–67, 82, 359–360
- formation, 66f, 385f
- covalent-ionic bond character, and charge density, 979–980
- covalent molecular, 981
- hydrides, 985
- covalent networks solids**, 50, 54
- covalent network substance** Hard, high-melting substance modelled as a three-dimensional network of atoms, each atom covalently bound to a number of others, 53–54, 82
- covalent radius** Half the experimentally determined distance between the nuclei of atoms of the same element bonded to each other in a molecule, 261
- cracking, 114
- Crick, Francis, 1129
- critical point** The unique conditions of pressure and temperature at which the interface between liquid and vapour disappears, forming one phase, 443–445, 448
- critical pressure ( $p_c$ )** The pressure at the critical point of a substance, 444
- critical temperature ( $T_c$ )** The temperature at the critical point of a substance, 444
- pressures for common compounds, 444t, 1088
  - ssuperconductors, 1088
- Crookes, William, 488
- crystal-field theory** A model to account for the colours and magnetic properties of transition metal complexes, 1038, 1062–1069
- coordination complexes, 1065–1067
- crystalline solids, 439–441
- Curie, Marie Skłodowska, 1015
- Curie, Pierre, 1015
- Curiosity Rover, 116
- Curl, Robert, 838
- cyanide, 554
- and seed germination, 11
- cyclic alkanes, 115, 322
- cyclic molecules, 325–329
- cyclobutane, 325
- cyclodextrins, 851–855
- cyclohexane, molecular structure of, 325–329
- axial and equatorial bonds, 326
  - ring-flip, 327
- cycloalkanes, *cis-trans* stereoisomers of, 322
- cyclopentane, molecular structure of, 325
- cyclopropane, 325
- DNA, 1033, 1126, 1128–1131, 1132–1140
- double helix, 1129
  - replication, 1132
- d*-orbital energy splitting, 1063–1065
- d*-to-*d* transition, 1065
- Dalton's law of partial pressures** The total pressure of a mixture of gases is the sum of the partial pressures of each, 423–424, 447
- Dalton, unit of atomic mass, 32
- Davy, Humphry, Sir, 988
- Davison, C.J., 274
- d*-block elements** Elements that differ in the number of electrons in *d* orbitals, 1035–1041
- definitions, 36
  - degenerate orbitals, 285–286
  - dehydration of alcohols, 890
- delocalized electrons** (in metals) Electrons not constrained to a bond between two atoms, 62, 370–376
- density ( $\rho$ )** Mass of a sample divided by its volume, 1040
- density of gases, 422–423
- deoxy sugars, 1113
- deoxyribonucleic acid (DNA), 1126, 1128–1131, 1132–1140
- dependence of reaction rates on temperature, 741–743
- deprotonated species, 555
- detergents** Surfactants used for cleaning, 481, 482
- determining the order of a reaction
- method of initial rates, 729–732, 735–737
- deuterium, 30
- dextrorotatory, 335
- diagonal relationship, 990
- diamagnetic** Substances slightly repelled by a magnet and that have no unpaired electrons, 280
- diastereomers** A pair of stereoisomeric molecules that are not mirror images of each other, 340–344, 349
- diborane, 999
- different conformers, 317
- differential aeration, 657
- diffraction patterns, 274f
- diffusion** The mixing of molecules of two or more gases due to their rapid molecular motions, 429–431, 447
- dilute, 200
- dimer, 1001
- diodes, 1081–1083
- dipole-induced dipole, 434t
- dipole** Molecule that experiences a force aligning it with an electrostatic field, 165, 166f, 169t
- dipole-dipole force** Attractions between charges of opposite sign on different polar molecules, 167–171, 204, 434t
- dipole moment** Quantitative measure of the tendency of a molecule to be oriented in an electric field, due to its polarity, 101, 165, 168f, 204
- diprotic acid, 530
- disaccharide, 1099, 1110–1111
- dispersion, 174
- dispersion forces** Intermolecular forces of attraction in non-polar substances, also operating in polar substances, 90, 174, 175f, 204, 434t
- disproportionation reaction, 1021
- dissociation** Separation of an ionic compound into its ions as it dissolves, 179–180, 204
- dissolving, 178
- molecular substances, 182–184
  - solutions in water, 182
- distillation, 110, 111f
- distribution of molecular energies, 437
- Dolphin, David, 1–6
- donor level, 1081
- dopant, 1080
- double bond** Covalent bond pictured as formed by sharing of four electrons between the bonded atoms, 66, 82, 361, 391–392
- double helix, 1129
- downs cell, 988
- drugs, chemistry, in sports, 17–20
- ductility of metals, 63

- dynamic chemical equilibrium** A condition in which reactions go in opposite directions at the same rate, so that amounts and properties remain constant, 136–137, 149, 493, 487–488  
dynamic equilibrium, 163, 459
- E1 reaction mechanism** Unimolecular mechanism for elimination reaction to form alkenes, 879, 899
- E2 reaction mechanism** Bimolecular mechanism for elimination reaction to form alkenes, 879, 899
- Earth  
atmosphere, 100  
radiation balance, 97–103  
eclipsed conformations, 319  
*E.coli*, 1032
- E-factor** Ratio of the mass of waste materials to the mass a desired product, 147–148, 150
- effective concentration, 473
- effective nuclear charge ( $Z^*$ )** The nuclear charge experienced by any one valence electron, which is less than the actual nuclear charge because of shielding, 289–291, 297, 979
- effusion** The movement of gas through a tiny opening in a container into another container in which the pressure is very low, 429–431, 447
- effusion of gases, 429–431  
Einstein, Albert, 273, 685, 1156  
elastomer, 1006  
electrical conductivity, 55, 179f  
electrical force of attraction, 54  
electricity, 630–634  
electrochemical  
cell conventions, 630, 634–636
- electrochemistry** A field of study about the interaction between electricity and chemistry, 619, 630, 660
- electrolysis** A non-spontaneous process brought about by application of an electrical potential, 630, 649–654, 660  
of aqueous sodium chloride solution, 990  
of molten NaCl, 988  
of water hydrogen from, 215
- electrolysis cell** An arrangement in which the application of an electrical potential forces a non-spontaneous oxidation-reduction reaction to occur, 630
- electrolytes** Compounds whose aqueous solutions conduct electricity because of the presence of ions, 180, 186, 472–473  
strong, 179, 186  
non, 179, 187  
weak, 179, 186
- electrolytic  
cell, 630  
refining copper, 1044
- electron affinity ( $E_{ea}$ )** The enthalpy change accompanying removal of 1 mol of electrons from 1 mol of negative ions of atoms of an element, 267–268, 294–295  
elements, 267
- electron capture** Nuclear process in which an inner shell electron is captured, 1152
- electron cloud, 174  
electron competition for electrons, 635–637
- electron configuration** The distribution of electrons among the possible orbitals, 284–288t, 289, 297, 401–402, 1037  
periodicity, 286–287  
transition elements, 1037  
electron-deficient, 999
- electron delocalization model** A way of modelling of molecules or ions such that electrons are distributed over a number of bonds, rather than localized between two atoms, 371–372, 396–397, 408
- electron density** A measure of the probability of finding the electron at any point in the electron cloud of an atom, ion, or molecule, 281, 297, 388
- electron pair transfer, 541–542  
electromagnetic radiation, 52  
electromagnetic spectrum, 76f  
electronegativities of elements, 266
- electronegativity ( $\chi$ )** The ability of an atom to attract bonding electrons in a molecule, 166, 204, 266  
electronic structures, 816–820, 822–823, 866–867, 881–883, 893–899, 917–918, 939–946
- electron impact ionization mass spectrometry (EI)** A variation of mass spectrometry, 67
- electrons** Subatomic particles that have negative electrical, charges, 28–29, 43, 58, 253–257  
ions, 268–275  
orbitals 285–287, 297  
electrons in atoms, experimental evidence, 268–275  
quantum mechanical model, 276  
wave-particle duality, 273
- electron spin** A property of electrons that results in them generating a small magnetic field, 279–281, 297
- electron transfer, 190–191, 619–665  
electrophile, 803
- electrophilic aromatic substitution** Substitution reaction where an electrophile replaces an H atom on an aromatic ring, 828–839, 840  
electrophoresis, 1116,  
electroplating, 649, 653  
electrostatic potential map, 170, 542, 789
- elemental substances** The observable form in which elements exist under specified conditions, 24, 259, 295, 1014–1015, 1017
- elementary steps** Single molecular events such as the formation or rupture of a chemical bond or the displacement of atoms as a result of a molecular collision  
reaction mechanisms, 751–754, 768
- elements** Characterized by atoms having the same atomic number, 24–25, 29–33, 43  
atom size, 261  
atomic weights of, 33–35  
boiling points, 259
- electron affinity, 267, 294  
electronegativities, 266, 294  
identified by atomic  
ion size, 265, 294  
melting points, 259, 440t  
metallic and non-metallic, 260  
monatomic ions, charge, 264  
number 29  
periodic table, 38–40  
periodic variation of properties of the elements, rationalization, 257–268  
properties, 257–268  
reactivity as oxidizing agents and reducing agents, 261
- elimination reactions** Reactant molecules split into two or more molecules of products, 782, 840, 878–879
- emulsions** Colloidal dispersions of one liquid in another liquid, 478
- enantiomeric pair, 1059
- enantiomers** Pairs of stereoisomers whose molecules are non-identical mirror images, 330–331, 336–337, 340–344, 349, 349
- enantioselective synthesis, 346
- endogenous substances** Substances naturally produced in an organism through the transformation of other substances in diet, 18, 43
- endothermic** Process in which the products have more energy than the reactants, 218–219f, 229f, 245
- energy** The capacity to do work, 2–6, 213–251  
artificial, 616–619, 622–623  
changes, 807–808  
conservation, 221–222  
density of fuels, 214  
flow, 222–226  
food, 243–245  
forms, 219–226  
interconversion, 219–221, 244f  
kinetic, 221  
light, 2–6  
measurement, 222–223  
potential, 221  
redistribution, 218–219  
solar, 620–622  
states, 3  
storage, 219, 220f, 221  
transfer, 221–224, 225t  
transformation, 219–226
- enol, 819  
Enright, Gary, 446
- enthalpy ( $H$ )** A property of a system whose change during a constant pressure process is equal to the amount of heat transferred between the system and the surroundings, 226–229f, 234f, 245
- enthalpy change ( $\Delta H$ )** The amount of heat transferred between system and surroundings during a process that occurs at constant pressure if no work other than that due to expansion occurs, 161, 225, 226–227–229
- enthalpy change of aqution ( $\Delta_{aq}H$ )** Enthalpy change due to aqution of ions, 461, 982

- enthalpy change of fusion, 440f
- enthalpy change of reaction ( $\Delta_r H$ )** The difference between the sum of the enthalpies of the products and the sum of the enthalpies of the reactants, 228–243, 245, 671–672
- enthalpy change of solution, 461–462, 482
- enthalpy change of sublimation ( $\Delta_{\text{sub}} H$ )** The enthalpy change of a substance when it changes phase from solid to vapour, 441
- enthalpy change of vaporization, 161–162
- entropy ( $S$ )** A measure of the lack of order resulting from dispersal of energy and matter, 182, 672–681, 709
- entropy change of reaction ( $\Delta_r S$ )** The difference between the sum of the entropies of the product species and the sum of the reactant species of a reaction, 679–685
- enzymes** Naturally occurring substances that catalyze particular reactions, 719, 747, 761–765, 1122–1125
- epinephrine, 527
- epitestosterone, 18–20
- equation *See* chemical equation
- equilibrium, 487, 671–672
- concentrations, 505–506, 511–512, 546–547
- equilibrium constant ( $K$ )** Value of the reaction quotient ( $Q$ ) when a reaction mixture comes to equilibrium, 496, 498, 503–505, 510, 514, 516, 532, 648–649, 698–703
- activity based, 498
- dependence on reaction equation, 507
- equilibrium reaction, 495f
- equilibrium vapour pressure** Pressure of vapour above a liquid in a sealed vessel at which liquid and vapour are in equilibrium, 162–164, 177, 203, 704–706
- equivalence point, 573
- escherichia coli*, 1031
- essential amino acids, 1117
- esters** Functional group having the structure  $\text{R}-\text{C}(=\text{O})\text{OR}'$ , or compounds whose molecules have that functional group, 77f, 921, 952, 960
- conversion, 889, 953, 954
- hydrolysis, 953
- ethene, 790
- ethylene, 790
- ethyne, 790
- ethane, 110
- evaporation. *See* vaporization
- evidence for aromaticity
- $^1\text{H}$  NMR Spectroscopy, 824
- evidence for aromaticity:  $^{13}\text{C}$  NMR Spectroscopy, 825
- Exact Masses of Isotopes of Several Elements, 68t
- excited state** Any electron configuration such that an atom has more energy than the ground state, 268, 284, 297
- of oxygen, 3–6
- of gases, 12
- exogenous substances** Substances administered to an organism from outside the organism, 18, 43
- exothermic** A process occurring in a system that releases energy as heat to the surroundings, 218–219f, 229f, 244f, 245
- extraction** Isolation of a compound or a group of compounds from a mixture, using physical and chemical methods techniques, 9
- extremophiles, 975
- extrinsic semiconductors, 1080
- E, Z system of nomenclature** A set of sequence rules for specifying the *cis-trans* geometry of a molecules' double bonds, 800, 840
- fac-mer isomerism** A form of isomerism in octahedral complexes with the formula  $\text{MX}_3\text{Y}_3$ , 1058
- Faraday, Michael, 820
- f-block elements** Elements whose ground-state atoms have partially filled *f* orbitals, 1035
- feedback cycles
- negative, 100
- positive, 100
- Fermi, Enrico, 1165
- Fermi level** Chemical potential of electrons in a solid (metal, semiconductor, or insulator), 1077
- fibroin, 1121
- fibrous proteins, 1120
- fingerprint region, 77
- fire, 89
- first ionization energy ( $IE_1$ )** The minimum energy required to eject an electron from an atom in its ground state elements, 263
- first law of thermodynamics** The total energy of the universe is constant, 221
- first-order reactions. 728, 732–739, 758, 874–876
- Fisher, Emil, 1100
- Fisher projections, 1100–1102
- fixation, 125, 488, 489
- fixation of nitrogen, 125, 515
- fixed nitrogen, 125, 488, 489
- fixing of carbon atoms from  $\text{CO}_2$  gas, 620, 624
- flatulence, 719
- Flematti, Gavin, 1, 6–12
- flotation, 1043
- fluorescence, 1017
- fluorine, 1017, 1019–1020
- fluorspar, 1017
- foam, 478
- food
- energy, 243–245
- irradiation, 1173
- production, 125
- form of  $K$ , 497–498
- form of  $Q$ , 497–498
- formal charge** The charge an atom in a molecule or ion if the bonding electrons were shared equally by the atoms that are directly bound to each other, 374
- formation constant ( $\beta$ )** (stability constant) The overall equilibrium constant for formation of a complex ion from an aquated metal ion and the ligands, 1051–1052
- formation constant ( $K_f$ )** The equilibrium constant for any step in the formation of a complex ion, 611, 616
- formulas of covalent network solids, 54
- formulas of ionic compounds, 59–60
- fossil fuels, 106
- fractional crystallization, 470
- fragment ions** Ions formed in mass spectrometry by the breaking of bonds in the molecular ion, 73, 82
- Franklin, Rosalind, 305
- Frash, Herman, 1014
- free energy ( $G$ )** (Gibbs free energy) Defined as  $G = H - TS$ , 692
- free energy change of reaction ( $\Delta_r G$ )** The difference between the sum of  $n_i G$  of the products and the sum of  $n_i G$  of the reactants, where  $n_i$  is the number of moles of each species in a balanced equation; a measure of the amount of useful work that can be obtained from a reaction, 686–687, 696–697, 710
- free radicals** Atoms, ions, or molecules with one or more unpaired electrons, 370f, 784
- free radical chain reaction, 803, 840
- freezing point depression, 470–474
- frequency ( $\nu$ )** The number of wave peaks that pass by a fixed point per unit time, 75–76f
- Friedel-Crafts acylation reaction, 834
- fuel cell, 216
- fuels, energy density, 214
- fullerenes, 836–839
- functional group isomers** Constitutional isomers (different connectivity) with different functional groups, 311, 348
- functional groups** Commonly occurring groups of atoms with particular connectivity patterns, in molecular compounds, 75–77, 78t–81t, 82, 776–783, 805, 820, 840
- Level 1*, with 1 bond between a C atom and more electronegative heteroatoms, 780t
- Level 2*, with 2 bonds between a C atom and more electronegative heteroatoms, 780t
- Level 3*, with 3 bonds between a C atom and more electronegative heteroatoms, 780t
- Level 4*, with 4 bonds between a C atom and more electronegative heteroatoms, 781
- levels of, 779
- furanose, 1105
- fusion, molar enthalpy change, 226
- galvanic cell, 630
- galvanizing, 653
- gamma ( $\gamma$ ) radiation** Emission of high energy electromagnetic radiation, 1148
- Gamow, George, 254
- gauge, 1041
- gas, 20
- amount, 417–418
- density, 422–423
- effusion, 429–431
- ideal equation, 417–423, 428–429, 447
- kinetic energies of gas molecules, 426
- mixtures, 423–425

- gas (*continued*)  
 molecular speeds, 426  
 noble, 1022–1024  
 pressure, 416–417  
 properties, 416–417  
 real, 431–433  
 relationships among  $n$ ,  $V$ ,  $p$  and  $T$   
 solubility, 457, 591–618  
 similarities and differences, 418–419  
 temperature, 417–418  
 gases, 413–433  
 volume, 417–418  
 geological CO<sub>2</sub>, 107f
- gas-chromatography** A technique for separation of compounds in a mixture by differences in their abilities to be removed from a solid phase into a passing gas stream, 18
- gas constant ( $R$ )** The proportionality constant in the ideal gas equation, 96f, 419
- gas-phase reaction mixture, changing volume, 512–513
- gauche conformer, 317
- gavione, 6–12
- gecko, 303
- Geiger-Müller counter, 1159, 1160f
- Geim, Andre, 836
- gel, 478, 479
- Germer, L.H., 274
- Gibbs free energy ( $G$ )** (free energy) Defined as  $G = H - TS$ , 500, 686–697, 710
- Gibbs, Willard J., 686
- Gillepsie, Ron, 376
- glass, 1085–1087
- global warming potential** Measure of the ability of a “greenhouse gas” to cause changes to the earth’s climate, relative to the same mass of CO<sub>2</sub>(g), over a defined period of time, 103–105, 119
- globular proteins, 1120
- glucose, 109–110
- glycoside, 1108–1110
- glycogen, 109, 1112
- glycoproteins, 1113
- glycosidases, 1112
- Graf Zeppelin, 984
- Graham, Thomas, 429, 479
- Graham’s law, 430
- graphene, 836–839
- gravimetric analysis, 145
- Green Chemistry Institute, 128
- green solutions, 445
- greenhouse gases, 97–107, 418, 720  
 carbon dioxide, 773
- Grignard reagents** Organomagnesium halides, 879–881, 900, 934–936, 955, 960
- groups, 780
- groups of the periodic table,  
 group 1, 987–991  
 group 2, 991–995  
 group 13, 995–1001  
 group 14, 1002–1006  
 group 15, 1006–1014  
 group 16, 1014–1017  
 group 17, 1017–1021  
 group 18, 1021–1024  
 main group, 976–978
- ground state, 3
- ground-state configuration** The distribution of electrons among the possible orbitals that results in the most stable atom or molecule, 284, 297
- <sup>1</sup>H (NMR), 313  
 spectroscopy of alkenes and alkynes, 795
- Haber-Bosch Process, 125–126, 488, 489f, 515–516
- Haber, Fritz, 488
- Hahn, Otto, 1166
- half-cell, 631
- half-cell reduction potential ( $E_{\text{half-cell}}$ )** A quantitative measure of the ability of a half-cell to attract electrons compared with that of the standard hydrogen electrode, 631, 636–638
- half-equations, 192
- half-life ( $t_{1/2}$ )** The time required for the concentration of a reactant to decrease to one-half its initial value, 5, 737–738, 768, 1158–1159
- Hall, Charles Martin, 998
- halocarbons, 104
- halogen, 79t, 1017–1022
- halogenation, 805, 818–819
- hard acids and bases, 1034
- hard-hard, 1034
- hard-soft acid-base (HSAB) theory, 1034
- hardness, 55
- heat ( $q$ )** Energy flowing from one object to another, 222–223, 245
- heat and work accompanying chemical reactions, 225
- heat capacity of water, 177
- heavy water, 984
- Heisenberg, Werner, 255
- $\alpha$ -helix, 1120
- hemiacetal** Functional group having the structure RHC(OH)OR’, 853, 925  
 formation, 1104–1106
- hemiketal** Functional group having the structure R<sub>2</sub>C(OH)OR, 925, 930
- hemoglobin, 1048–1050
- Henderson-Hasselbalch equation, 565
- Henry’s law** The solubility of a gas in a liquid is directly proportional to the partial pressure of the gas in contact with the solution, 462–464, 482
- heredity, nucleic acids, 1131
- Heroult, Paul, 998
- Hess’s law** If a reaction can be written as the sum of two or more steps, its enthalpy change of reaction is the sum of the enthalpy changes of reaction of the steps, 233–237, 245
- heteroatoms** Atoms other than carbon atoms in molecules of an organic compound, 779, 826
- heterocyclic compounds** Cyclic compounds with atoms of two or more elements in their rings; usually C and heteroatoms such as O, N, P, or S, 826, 840
- heterogeneous catalysis** When the catalyst is in a different phase (solid, liquid, gas, solution) from that of the reactants, 749–750
- heterogeneous mixture** A mixture in which matter is not uniformly dispersed, 22, 43
- hexokinase, 764
- hexoses, 1123
- heterolytic, 784
- heteronuclear diatomic molecules**  
 Molecules containing two atoms of different elements, 406
- heterotrophs, 92
- highest occupied molecular orbital (HOMO)**  
 The highest-energy molecular orbital that is “occupied” by electrons, 407, 408
- high electron density, 388–395
- high melting point, 55
- high-resolution mass spectrometry** An instrumental technique in which the accurately measured mass/charge ratio of ions of molecules is used to determine a molecular formula, 67–71, 82
- high-resolution mass spectrum, 306
- high-spin configuration** Configuration of a complex with weak-field ligands, having the maximum number of unpaired electrons, 1067
- Hindenburg, 215, 984
- HOCl(aq) as bactericide, 555
- Hodgkin, Dorothy Crowfoot, 1041–1042
- Hoffmann, Roald, 685
- Hofstadter, Douglas, 1096
- holoenzyme, 1123
- homogeneous catalysis** A catalytic process in which all reactants and the catalyst are in the same phase (solid, liquid, gas, solution), 747–748
- homogeneous mixture** A mixture with uniform composition throughout, with components not visible, 22, 43
- homogenic, 784
- homolytic, 784
- homonuclear diatomic molecules**  
 Molecules composed of only two atoms of the same element, 399, 404–406
- host-guest complex** A structural arrangement between a large molecule or cluster of molecules that has a suitable shape and a site to bind through non-covalent interactions to another molecule, 81, 90, 853–855
- Hückel’s  $4n + 2$  rule for aromaticity, 822
- Hückel’s rule** Rule to predict the aromaticity of cyclic, conjugated compounds by counting the number of electrons, 822–825, 840
- human activity, 94–95
- Hund’s rule, 386, 399
- hybridization, 386–387, 797
- hybrid orbitals** Orbitals in a molecule or polyatomic ion that are imagined to form by redistribution of the densities of the electrons in the atomic orbitals of the bonding atoms, 386, 408
- hydrated ions. *See* aquated ions
- hydrated protons, 187–188f
- hydration. *See also* aquation, 813, 819
- hydrocarbons** Substance whose molecules have only carbon and hydrogen atoms, 78t, 93, 115t, 119, 172f  
 classification of, 115

- saturated, 114–116  
 unsaturated, 114–116
- hydrochloric acid, 1020
- hydrogen, 213–218  
 compounds, 364–365, 1008–1010  
 economy, 216–217  
 electrode, 633  
 energy, 216  
 from electrolysis of water, 215  
 gas, 418  
 group, 987  
 making, 985–987  
 properties, 984–985  
 reactions, 984–985  
 sources, 215  
 storage, 216
- hydrogenation, 802
- hydrogen bonding** A particularly strong form of intermolecular dipole-dipole interactions between H atoms on one molecule and O, N, or F atoms on nearby molecules, 171–174, 176, 183, 185, 204, 434t, 1129f
- hydrogen chloride, 1020
- hydrohalogenation, 805, 814, 818
- hydrolases, 1123
- hydrolysis of esters, 953
- hydrometallurgy** Metallurgy that uses aqueous solution chemistry, 1041, 1043–1044
- hydronium ion** A transient species represented simply as  $\text{H}_3\text{O}^+$ , 187, 204, 533–534
- hydrophilic** Physical property of being attracted to water, usually through hydrogen bonding, 853
- hydrophilic colloids** Colloids with strong attractions between the particle surfaces and water molecules, 480–480, 482
- hydropasticity, 1087
- hydrophobic colloids** Colloids in which only weak attractive forces exist between the water and the surfaces of the colloidal particles, 480, 482
- hydroxyl radical in atmosphere, 96
- hypergolic fuel, 1028
- hypertonicity, 477
- hypochlorous acid, 1021
- hypotonic, 477
- ideal gas equation** A mathematical equation that allows approximate calculation of any one of  $n$ ,  $p$ ,  $V$ , or  $T$  if the other three are known, 419–421, 428–429, 447
- ice, 89, 100
- ideal solutions** Solutions that obey Raoult's law, 468, 482
- ignition rate, 730–731
- imagination, 357
- imine functional group** Functional group with the structure  $\text{RN}=\text{CR}_2$ , or substances whose molecules have this functional group, 936, 960
- immiscible, 183
- induced dipole, 434t
- inductively coupled plasma (ICP) spectrometer** An instrument used to analyze for elements, based on their emission of radiation of characteristic wavelengths when excited, 415–416
- inert** Unreactive under specified conditions; in transition metal chemistry, complexes that undergo very slow substitution of ligand species, 669, 1055
- inert electrodes, 633
- infrared absorptions, 82
- infrared absorption spectrum** Absorption spectrum that results when the incident light is in the infrared region, 75
- infrared radiation  
 absorption by greenhouse gases, 101
- infrared (IR) spectroscopy, 74–81, 777, 793–795, 826  
 alkenes and alkynes, 793  
 aromatic compounds, 826
- infrared spectrum, 306
- infrared “windows,” 103–105
- initiation, 803, 1166
- in-plane, bending, 76f
- instantaneous dipole** Atom or molecule with momentary unsymmetrical distribution of its electron cloud, 174
- instantaneous dipole-induced dipole forces** Attractions between instantaneous dipoles and momentarily induced dipoles in neighbouring molecules, 174, 204
- integrated rate equation** An alternative form of a rate equation that shows the (changing) concentration of a reactant at a specified time, 732–739, 768  
 first-order reactions, 732  
 second-order reactions, 733, 736f
- instantaneous rate of reaction, 723
- insulators, 1078
- intensive property, 200
- Intergovernmental Panel on Climate Change, 104, 414
- interhalogens, 1029
- intermediate, 760
- intermetallic compounds, 1079
- intermolecular forces** Forces of attraction between molecules, 64, 82, 165–175, 177f, 203, 433–437
- internal energy ( $U$ )** The sum of the kinetic energy and potential energy of the collection of atoms, ions, and molecules in the system, 224–225, 245
- internal circuit, 631
- International Union of Pure and Applied Chemistry (IUPAC), 36, 40–43
- interstitial, 1079
- intramolecular forces** Bonds between atoms within molecules (rather than between molecules), 64, 82, 165
- intramolecular level** An aspect of the molecular level of operation in chemistry where we consider the distribution of electrons within molecules, 358, 408, 1105
- intrinsic semiconductors, 1080
- inversion of configuration, 757
- invertases, 1111
- invert sugars, 1111
- iodine, 1018
- ion concentration, 607–608
- ion-dipole force** Attraction between either a cation or an anion and the oppositely charged end of a polar molecule, 178, 179, 204, 434t
- ionic, 980
- ionic compound** Generally solid compound that conducts electricity only when molten, and which is modelled as a lattice of anions and cations, 54, 60–61, 81  
 solubilities, 180
- ionic-covalent character of bonds, 980–981
- ionic hydrides, 985
- ionic lattice** A regular three-dimensional array of ions that comprises an ionic compound, 82
- ionic radius** An estimate of the radius of an ion in its crystalline compounds, 265
- ionic salts, 595–605  
 solutions in water, 178–182
- ionic substance, 50, 54–61
- ionization** Formation of ions from a molecular substance when it dissolves in water, as a result of bond breaking, 186, 292, 529f
- ionization constant for water ( $K_w$ )** The equilibrium constant for self-ionization of water, 532, 538t, 583
- ionization energies, 263–264
- ionization isomerism** Isomers of complexes due to interchange of a coordinated ligand and an uncoordinated counterion, 1057
- Ionization of Molecular Solutes, 185
- ion pairs, 592
- ions** Charged particles in which the number of protons is different from the number of electrons, 56–59  
 mobility in water, 983  
 monatomic, 58–59  
 polyatomic, 59  
 solution, mobility, 983
- ion-selective electrodes** Electrodes used to measure ion concentrations in solution, based on the Nernst equation, 645–646
- ion size of elements, 265, 294
- iron corrosion, 654–659, 660
- iron extraction from ores, 1042–1043
- irradiation, food, 1173
- isodensity surface** A contour surface of equal electron density, 282, 297
- isoelectric pH** The pH at which more of an amino acid is in the form of zwitterions than at any other pH, 560–561, 583
- isoelectronic ions, 265
- isoelectric point (pI)** The pH at which an amino acid is balanced between anionic and cationic forms and exists primarily as the neutral, dipolar, zwitterion, 1116
- isoelectronic species** Molecules and ions with the same number of valence electrons and the same number and connectivity of atoms, but have atoms of different elements, 367
- isomerases, 1123

- isomerism, see *cis-trans*-, constitutional, linkage, and stereo isomerism
- isomers** Substances whose molecules have the same numbers of atoms of different elements, but differ in the way the atoms are arranged, 112, 119, 310, 348  
*cis*- and *trans*-, see *cis-trans* isomers
- isosurface, 282
- isotonic, 477
- isotope ratio mass spectroscopy (IRMS)** A technique to determine the ratio of different isotopes of a particular element in molecules of a substance, 19, 30, 43, 97
- isotopes** Atoms of an element with different numbers of neutrons, 19, 29–33, 40, 43  
abundance, 30, 40  
dilution, 1172  
measurement of 32  
table, 40–43
- isotopologues** Molecules that are identical except that the atoms of one or more elements are different isotopes, 68, 82, 306
- Keeler, James, 779
- Kelvin temperature scale** A scale of temperature measurement in which 0 K is  $-273.15\text{ }^{\circ}\text{C}$ , 417
- $\alpha$ -keratin, 1120
- ketals** Functional group having the structure  $\text{R}_2\text{C}(\text{OR}')_2$ , 853, 930
- ketone** Functional group having the structure  $\text{R}_2\text{C}=\text{O}$ , or any substance whose molecules have that functional group, 77, 886, 911–915  
naming, 916–922  
reactivity, 916–917, 924–934  
structure, 916–917, 924–934
- ketoses, 1099
- kinetically  
inert, 669  
stable, 669
- kinetic energies of gas molecules, 426
- kinetic energy** Energy due to motion of the particles (atoms, ion, molecules) of a system, 219–220, 245
- kinetic-molecular model of matter** A model that assumes that all matter is composed of particles with energy, and which can be used to explain and predict physical properties, 20, 43, 431, 436–437
- kinetic-molecular theory** A model that assumes that all matter is composed of particles with energy, which can be used to explain and predict physical properties, 419, 425–429, 436, 447
- Kohlrausch, Friedrich, 532
- Kroto, Harry, 838
- labelled concentration, 202
- labile** Complexes that undergo rapid substitution of ligand species, 1055
- labiality, 1055
- lakes, Cameroon, 457–458
- language issues, 277
- Landis, Floyd, 17–20
- lanthanide contraction, 1039
- lanthanides, 1035
- lattice enthalpy** (lattice energy) The energy evolved when ions in the gas phase come together to form 1 mol of a solid crystal, 461, 983–984
- law of chemical periodicity** The properties of the elements vary periodically with their atomic numbers, 40, 257, 298
- law of conservation of atoms** During chemical reactions atoms are neither created nor destroyed, 129, 149
- law of conservation of energy** (first law of thermodynamics) The total energy of the universe is constant, 221
- law of conservation of mass** The total mass of substances that react is the same as the total mass of substances formed, 129, 149
- law of conservation of matter** Matter is neither created nor destroyed. During a chemical reaction, the numbers of atoms of each element in the substances that react are the same as the numbers of atoms of those elements in the products, 129
- law of equilibrium** For a given reaction at a specified temperature, all equilibrium mixtures have the same value of the reaction quotient ( $Q$ ), 496, 596
- leaving group, 757
- Le Chatelier's principle** A change in any of the factors that influence the condition of equilibrium brings about a change in the relative amounts of reactants and products in the direction that counteracts (often not completely) the applied change, 464, 488
- LED (light-emitting diodes), 1081–1083
- Lee, Huen, 91
- levels  
functional group classification, 779–781  
of operation: observable, molecular, symbolic, 23–24
- levorotatory, 335
- Lewis acid** A species that accepts a lone pair of electrons from another species in a complexation reaction, 197, 204, 541, 786
- Lewis Acid-Base reactions, 196–198
- Lewis base** A species that provides a lone pair of electrons to another species in a complexation reaction, 197, 204, 541, 610, 613–614, 786, 1046
- Lewis, Gilbert Newton, 359
- Lewis model of acids and bases, 541–544
- Lewis structure** A way of representing the distribution of valence electrons in molecules, 360–370, 408
- Liebig, Justus von, 488
- ligand, 542, 1045–1048  
monodentate, 1046  
polydentate, 1046
- ligand-field splitting ( $\Delta_o$ )** The difference between the energy of the electrons in the “split”  $d$  orbitals of transition metal complexes, according to crystal-field theory, 1064
- ligases, 1123
- light, reflection on earth, 100
- limiting reactant** In a reaction mixture with specified amounts of reactants, the reactant that is entirely “consumed,” and which limits the amounts of products formed, 140f, 141f–143, 149–150
- limiting reagent, 140
- line emission spectrum** Radiation emitted by excited atoms, and which consists of only particular wavelengths, 268–269, 297
- line spectra of atomic substances, 255–256
- linkage isomerism** Isomers of complexes due to bonding of a ligand to the metal through different types of donor atoms, 1057
- lipoproteins, 5
- liquids, 20, 436  
kinetic molecular model, 436–437  
temperature dependence of vapour pressures, 438
- liquid state, 433–439
- lithium chemistry, non-typical, 990–991
- living organisms, 877–878
- London forces. *See* dispersion forces
- lone pairs, 361
- lowest unoccupied molecular orbital (LUMO)** The lowest-energy molecular orbital that is not “occupied” by electrons, 407, 408
- low-spin configuration** Configuration of a complex with strong-field ligands, having the minimum number of unpaired electrons, 1067
- lyases, 1123
- macromolecules, 114
- magnesium, 992, 993
- magnetic momentum quantum number, 277
- magnitude of  $K$  and extent of reaction, 501–502
- main group elements** Elements in Groups 1, 2, or 13–18 of the periodic table, 38, 259, 975–1030  
structure overview, 977–978
- malleability of metals, 63f
- maltose, 1110
- manufacture of nitric acid, 141
- Markovnikov's rule** In addition reactions of  $\text{HX}$  to unsymmetrical alkenes, the proton adds preferentially to the C atom that will lead to the most stable carbocation intermediate, 811, 840
- Markovnikov, Vladimir, 809
- Mars atmosphere, 116–117, 413
- mass defect, 1156
- mass number ( $A$ )** The sum of the numbers of protons and neutrons in atoms of an isotope, 29–30
- mass percent** The mass of one component of a mixture divided by the total mass, multiplied by 100%, 466, 482
- mass spectrometer, 306
- mass spectrometry** A technique for measuring relative mass of the atoms

- or molecules comprising a sample of a material, 18, 43, 67–71, 73–74
- mass spectrum, 69–72
- matches, 1103
- materials science** Study and synthesis of structural substances, including ceramics, metals, polymers, and composites, 1075–1076
- matter** Anything that occupies space and has mass, 20–23
- classification of, 20–23
- states (or phases), 20, 413–454, 672–674
- Maxam-Gilbert method, 1137
- Maxwell-Boltzmann distribution curves, 426
- Maxwell, James Clerk, 427
- Maxwell's equation, 427
- Meitner, Lise, 1166
- melodies, molecules, 1095–1097
- Mendeleev, Dmitri, 39
- melting
- conversion, 439–440
- point, 259, 1040
- mental model, 357
- Menten, Maud Leonore, 761–762
- Messenger RNA, 1133
- meso stereoisomers, 342–343
- metabolic acidosis, 582
- metabolic alkalosis, 582
- metabolism, 243
- metallic, 50, 260
- metallic bonding** The mutual attraction between cations in a metallic lattice and the delocalized "sea" of electrons, 62
- metallic elements, 39
- metallic hydrides, 985
- metallic radius** Half the experimentally determined distance between nuclei of adjacent atoms in a metallic crystal, 262
- metallic substances, 63
- metallic versus non-metallic character of elements, 260
- metalloids** Elements with properties intermediate between those metals and non-metals, 39
- semi-metals, 38, 39
- metallurgy** The process of separating desired metals from other substances in ores
- transition elements, 1041–1044
- metals** Mostly malleable solids that are good conductors, modelled as a lattice of positive ions in a "sea" of electrons, 61–63, 82, 329–330, 557
- bonding, 1076–1079
- cations, 609–610
- reducing ability, 983–984
- methane, 93–9, 116–118, 720
- abiogenic, 95
- biogenic, 95
- bonding, 360
- sources, 105–106
- methane clathrate hydrate, 90, 92f
- models of bonding in molecules, 406
- molecules, 90f
- methanogens, 95
- mixtures, 22–23
- methanogens, 720
- methanol production, 127
- methanotrophs 95
- mica, 1004
- micelles, 480
- Michaelis, Leonor, 762
- microfabrication, 1084
- mimicking nature, 619–624
- miscible, 183
- mobility, 983
- modelling** (molecular level) Use of observations of properties of substances as evidence to draw inferences about their nature at the molecular level, 53
- atoms, 253–254, 295–297, 357
- bonding, 357–359, 407
- models** (molecular level) Theories about the nature of substances at the molecular level, and the relationship to properties of the substances, 53–54, 61–63, 64, 81
- models for the electronic structure of benzene molecules, 822
- molal
- concentration, 466
- freezing point depression constant, 471
- molality (m)** The amount of solute (in moles) per kg of solvent, 466, 482
- molar concentration (c)** The amount of solute (in moles) per litre of solution, 200, 204, 466
- molar enthalpy change of fusion ( $\Delta_{\text{fus}}H$ )**
- The change of enthalpy of 1 mol of a solid substance during its conversion to a liquid at its melting point, 162t, 226, 245, 439–441, 448
- molar enthalpy change of solution ( $\Delta_{\text{sol}}H$ )**
- Enthalpy change accompanying dissolution of 1 mol of solute in a large volume of the solvent, 461–462, 482
- molar enthalpy change of vaporization ( $\Delta_{\text{vap}}H$ )** The enthalpy change when 1 mol of a liquid is converted to its gaseous state at its boiling point, 227, 245
- molar mass (M)** The mass (in grams) of 1 mol of a substance, 36–38, 43, 60–61, 63, 69, 471–472, 477–478
- mole** (mol) The unit of the quantity amount of substance, 35, 43
- molar volumes, 419
- molecular formula** Formula that shows the number of atoms of each element in each molecule, 64, 70–71
- molecular ion** Ion formed by ejection of one electron from a molecule during electron impact ionization mass spectrometry, 67, 82
- molecular modelling (*Odyssey*), 4, 18, 20, 22, 28, 53, 55, 62, 65, 76, 90, 113, 114, 160, 162, 169, 170, 171, 174
- molecular polarity, 167–169f, 170–171
- molecular speed, 426–428
- molecular structure, 173, 303–306, 364–367
- shapes, 306–307
- tools, 306–307
- molecular level** Visualized structure or behaviour of the atoms, ions, or molecules of which materials are composed, used to explain observed behaviour of substances, 23, 43, 90, 102–103
- molecular orbital (MO) theory** A way of modelling the bonding in a molecule by imagining that the electrons occupy orbitals that are delocalized over the entire molecule, 397–408, 1076
- molecular recognition** Selective non-covalent interaction between one molecule and others, or a part of others, 303–305, 348, 957, 961
- molecular substances** Substances believed to be composed of molecules, 50, 63–65, 82, 174–175
- solutions in water, 182
- molecular weight** Sum of the atomic weight of atoms in a molecule, 9, 69
- molecules, 50, 52, 69, 71f, 73
- configuration, 337–340
- covalent bonding, 359
- cyclic, 325–329
- melodies, 1095–1097
- replacement, 91f
- spatial arrangement of atoms, 376
- molecularity** The number of reactant particles that participate in an elementary step, 752–754, 765
- mole fraction (x)** The amount (in moles) of a specified component divided by the total amount of all components in a mixture, 424, 466, 482
- monatomic ions, 58, 264–265, 293
- monodentate ligands** Ligands that coordinate to a metal via one donor atom, 1046
- monomers** Building blocks for making polymers, 114, 119, 802–803
- monoprotic acids** Acids that have only one  $\text{H}^+$  ion that can be removed from each molecule, 530, 583
- monosaccharides, 1099, 1100–1102, 1104–1108
- Moseley, H.G.J. 40
- Mulliken, Robert S., 383
- mutarotation** The spontaneous change in optical rotation observed when a pure anomer of a sugar is dissolved in water and equilibrates to an equilibrium mixture of anomers, 1106
- myoglobin, 1121
- NMR spectra, 777
- NMR spectroscopy, 313–317, 446
- $^{13}\text{C}$ , 313, 317, 323
- $^1\text{H}$ , 313
- n-terminal, 1118
- n-type semiconductor, 1081
- naming, 790–791
- nanotechnology** The design, creation, and control of matter on approximately the nanometre ( $10^{-9}$  m) scale to create structures, systems, and devices with novel properties, 837–838, 840, 1091
- nanotubes, 836–839
- natural gas, 93
- natural percent abundance** The percentage of different isotopes of an element in naturally occurring materials, 31
- natural products chemistry** The study of compounds produced by living organisms, 8

- nature of electrons in atoms, 254–255  
 negative feedback, 100  
 neon signs, 12  
**Nernst equation** A mathematical expression for the dependence of cell emf on concentrations of reactants and products, 643–645, 660  
 Nernst, Walter, 489, 643  
**net reaction** Change of concentrations of species resulting from unequal rates of opposite reactions, 494, 516  
 neurotransmitters, 527  
**neutral solution** An aqueous solution in which  $[H^3O^+] = [OH^-]$ . At 25 °C, pH = 7.0, 533  
 neutralization: reaction of acids with bases, 195  
 neutralizing capacity, 552  
**neutrons** Subatomic particles that are neutral, 28–29, 43  
   activation analysis, 1173  
   in nuclei, 1154  
 Newman projections, 318  
 new materials, 81  
 nitration, aromatic compounds, 832  
 nitric acid, 1101  
**nitrides** Functional group having the structure  $RC\equiv N$ , or compounds whose molecules have this functional group, 920  
 nitrogen, 79t, 125–126, 1007–1010  
   atoms, 126f  
   cycle, 977  
   fixation, 125  
   making ammonia, 487  
 nitrous oxide  
   in atmosphere, 96, 103–106  
 noble  
   gas atoms, 58  
   gases, 1022–1024  
 Nocera, Daniel, 215, 619, 653  
 nodal surface, 283  
 nodes, 276  
 non-bonding electrons, 172  
**non-bonding pair** A pair of electrons localized on an atom in a molecule that are not involved in bonding to another atom, 196, 361  
 non-carbon centres, 333–334  
 non-covalent interactions, 303–304  
**non-electrolytes** Substances that do not ionize when dissolved in water, 187, 204  
 non-metallic elements, 39, 259  
 non-polar molecules, 167, 184  
**non-polar substance** Substance whose molecules have zero dipole moment, 167, 174f, 175f, 204  
 non-renewable energy sources, 213  
**normal boiling point** (standard boiling point) The temperature at which the equilibrium vapour pressure of the substance is 1.00 atm, 442  
 northern lights, 12  
 Novoselov, Konstantin, 836  
**nuclear binding energy ( $E_b$ )** Energy required to separate the nucleus of an atom into protons and neutrons, 1155–1158  
 nuclear charge, 289–291  
 nuclear chemistry, 1145–1177  
 nuclear decay, rates, 1158–1164  
**nuclear fission** Reaction in which a large nucleus splits into two or smaller nuclei, 1166–1167  
**nuclear fusion** Reaction in which several smaller nuclei react to form a larger nucleus, 1167–1168  
 nuclear magnetic resonance (NMR) spectroscopy, 8, 306  
 nuclear medicine, 1170–1172  
**nuclear reactions** Reactions involving one or more atomic nuclei, resulting in transformation of isotopes into other isotopes, 1149–1153, 1164–1165  
 nuclear spins, 313f  
**nucleic acids** Biopolymers, either DNA or RNA, made of nucleotides joined together, 1126–1140  
**nucleons** Nuclear particles, either neutrons or protons, 1157  
 nucleophile, 757  
 nucleophilic addition, 924–930, 944  
**nucleophilic substitution reactions** Reactions involving the substitution of one nucleophilic species in molecules or ions of a substance for another atom, group of atoms, or an ion, 757–761, 768, 944–946  
 nucleoside, 1126  
 nucleotides, 1126–1140  
 Nyholm, Ronald, Sir, 376  
 Nyos Lake, 457  
**observable level of chemistry** Behaviours of substances that can be observed directly by human senses, or by instruments, 23, 43  
 ocean acidification, 591–596, 614  
 ocean selector, 106  
**octet rule** A tendency of molecules and polyatomic ions to have structures in which eight electrons are in the valence shell of each atom, 361–369, 408  
 Olah, George, 127  
**oligomer** A polymeric substance whose molecules consist of only a few monomer units, 852, 899  
 oligosaccharides, 719  
 operation, 23–24  
 optical  
   activity, 330, 335–337, 1059  
   fibres, 1086  
**optically active** Substance that rotates the plane of plane-polarized light passing through it, 335, 348  
**orbital** The non-uniform distribution of the electron matter in a standing waveform around the nucleus of an atom, 277, 282–283, 285–287  
   hybridization, 386  
   overlap, 384–386  
   shape of orbitals, 281–282  
**order of a reaction** With respect to each reactant, the exponent of its concentration term in the rate equation, 728, 732–735, 737–739, 757–758, 885–887, 889  
 organic  
   acids, 542–543  
   bases, 542–543  
   chemistry, 885  
   food labels, 13  
**organic compounds** Compounds composed of molecules with carbon-atom-based frameworks, 63, 92, 668, 779–788  
**organometallic compounds** Compound with molecules having bonds between metal atoms and carbon atoms, 879–880, 900  
 orthosilicates, 1004  
**osmosis** The movement of solvent molecules through a semipermeable membrane from a solution of lower solute concentration to one of higher solute concentration, 475–478, 482  
**osmotic pressure** The “back pressure” that must be applied to –prevent osmosis, 475–478, 482  
 Ötzi the iceman, 30, 1162  
 out-of-plane, bending, 76f  
**overall atom efficiency (OAE)** The mass of a desired product as a percentage of the total mass of products, 147, 150  
**overall reaction order** The sum of the exponents on all concentration terms in the rate equation, 728, 768  
**overlap of atomic orbitals** A basic assumption of the valence bond model of bonding in molecules, 385  
**overvoltage** The extra potential needed to make electrolysis occur, above that predicted from the table of standard reduction potentials, 652, 660  
**oxidation** The removal of electrons by one species from another in the competition for electrons occurring in an oxidation-reduction reaction. In organic chemistry, the term is used to describe a decrease of electron density by a carbon atom, 815, 885  
   alcohols, 891  
   alkenes to carbonyl-containing products, 814  
**oxidation-reduction reactions** Reactions that are the result of transfer of electrons from one species to another in a competition for electrons, 190–196, 204, 620, 624–630  
**oxidation state** A measure of the degree of oxidation of an element in a compound compared with the uncombined element, 190, 204, 624–627, 660  
 oxides  
   and hydroxides of metals, acid-base character, 981  
   and oxoacids of nitrogen, 1008  
 oxidizing, 261, 642–643  
**oxidizing agent** Reactant species that removes electrons from a species that is oxidized, 191, 192t, 624  
 oxidoreductases, 1123  
**oxoacids** Acids whose molecules contain oxygen atoms, usually with at least one –OH group, 366–367  
 oxoacids of chlorine, 1020

- oxonium ion** Derivative of  $\text{H}_3\text{O}^+$ , where one or more H atoms are replaced by R groups, 888, 930–931
- oxygen, 2–6, 79t
- molecules, energy states of 3–6
- ozone, 1014
- hole, 415
- molecule, models of bonding, 396
- p-n rectifying junction, 1082
- p-type semiconductor, 1082
- paired electrons, 278
- pairing energy, 1068
- paramagnetic** Substance whose atoms, ions, or molecules have unpaired electrons and that are attracted to a magnetic field, 280, 297
- particles, 21
- partial bond, 371
- partial pressure** The pressure a gas in a mixture would exert if it were the only gas in the container, at the same temperature, 423–424, 447
- parts-per-million (ppm)** The mass of a component of a mixture; may be expressed in grams, per 1000 kg of total, or as  $\mu\text{mol}$ s per mol (of a gas), 467, 482
- Pasteur's, 336–337
- Pauli exclusion principle, 284, 399
- Pauling, Linus, 371, 383
- p-block elements** Elements in Groups 13–18, whose atoms have valence electrons in *p* orbitals, 287
- peptides** Small amino acid polymer (usually comprised of fewer than 50 monomers)
- amphiphiles, 305, 1115–1125
- percent abundance, 40
- percentage ionization, 546–549
- percent yield** The yield of a reaction product expressed as a percentage of the theoretical yield, 143, 150
- perfluoropropane, in atmosphere, 104
- period table of elements, 38–40
- periodic table of the isotopes, 42
- periodic trends, 1039–1040
- periodic variation, 257–268, 292–295
- periodicity** Periodic occurrence of elements, based on atomic numbers, whose properties are similar, 39, 258f, 287–289
- periodicity of electron configurations, 286–287
- peroxides of metals, 989
- petroleum, 110, 111f
- pH** In dilute solutions,  $\text{pH} = -\log_{10}[\text{H}_3\text{O}^+]$ , 532–535, 545–546, 583
- change, 570–571
- controlling, 564–573
- dependance, 602, 647–648
- meters, 645–646
- speciation, 178–180, 187, 523–526, 553–563, 581–582, 591–594, 613–614
- phase, 20
- change, 437–439, 671–672
- diagrams, 442–445
- phenyl, 791
- pheromones** Compound used to exchange information between individuals
- within a species to affect sexual or social behaviour, 775, 840
- phosphate buffers in biochemical systems, 581
- phosphorus, 1010–1013
- photochemical smog** Brown smog produced by photochemical reactions in still air masses containing nitrogen oxides and volatile organic compounds exposed to the sun, 667–670, 706–709
- photodynamic therapy (PDT)** The use of light in medical treatment, 3–6
- photoelectric effect, 273, 274, 275f
- photoelectron spectroscopy (PES)** A technique, based on ejection of electrons by irradiation with high-energy photons, for estimating the energies of electrons in the various orbitals in molecules, 397–398
- photonics, 1086
- photons, 274
- photosensitizers** Substances whose molecules can be electronically excited by absorption of particular wavelengths of light, and transfer their extra energy by collisions to molecules of other substances, 4
- photosynthesis, 620–621
- photosystem I (PSI), 621
- photosystem II (PSII), 621
- physical properties** Behaviour of a substance that does not involve chemical reaction, 28, 43, 52, 896
- pi bond** Covalent bond imagined to be formed by sideways overlap of *p* orbitals, 386, 408
- piezoelectricity** The induction of an electrical current by mechanical distortion of material or vice versa, 1088
- pig iron, 1042–1043
- $\alpha$ -pinene, 775
- Planck's constant, 254, 274
- planar, 810
- plane of symmetry in molecules, 332
- plane-polarized light, 335
- plasmas, 20, 415, 1168
- plastic sulfur, 1014
- pOH** In dilute solutions,  $\text{pOH} = -\log_{10}[\text{OH}^-]$ , 534
- polar and non-polar parts of solute molecules, 184
- polar bond** A bond joining atoms whose electronegativities are different, so that the bonding electrons are unequally shared, 166, 204
- polar covalent bond, 166, 359
- polar molecule, 167, 184
- polarimeter, 330
- polarimetry, 306, 335–33
- polarizability** Ease of distortion of the electron cloud of an atom, ion, or molecule
- electron clouds, 174–175, 979, 1024
- polarization** Distortion of the electron cloud of an atom or a molecule, 204
- electron clouds, 174–175, 979, 1024
- polarizer, 335
- polarizing power** The degree to which a cation can induce polarization of the electron clouds of neighbouring species, 979, 1024
- polar reactions** Reactions in which the mechanism shows electrons moving in pairs when bonds are formed or broken, 784–785
- polar substance** Substance whose molecules have a dipole moment, 167, 174f, 204
- polonium, 1107
- polyamides** Polymer made of amide monomers, joined by peptide bonds, 958–959
- polyatomic ions, 59
- polyatomic molecules, models of bonding, 406–407
- polycyclic aromatic hydrocarbons (PAHs) Compound with fused aromatic rings, 836–839, 840
- polydentate ligands** Ligands that coordinate to a metal via more than one donor atom, 1046
- polydimethylsiloxane, 1005
- polyesters** Polymer whose monomers are joined by ester linkages, 958
- polyethylene, 115
- polymers** Substances with large molecules composed of repeating units of monomers, 114–116, 119, 804t, 958, 1005–1006, 1021
- polymerase chain reaction (PCR)** Method for amplifying small amounts of DNA, 1138
- polymerization of alkenes, 802–803
- polymorphs** Different solid or liquid forms in which a compound can exist, 445–447, 448
- polyprotic acids** Acids that have molecules with two or more protons that can be removed by bases, 530, 551–552, 558–559, 578–579, 583
- polysaccharides** Carbohydrate polymers made of simple sugar monomers held together by glycoside linkages, 1099, 1111–1113
- porphyrins, 4
- positive hole, 1077
- positron emission** Emission of a nuclear particle having the same mass as an electron but a positive charge, 1152
- potassium, 988–991
- production, 988
- potential energy** That component of the energy of a system due to the relative position, composition, or arrangement of particles, 219–220, 245, 742
- powder, white, 49–52
- precipitate, 188
- precipitation of ionic salts, 595–604
- precipitation reactions** Reactions in solutions which a precipitate is formed from cations and anions, 188–190, 204, 605–610
- primary
- batteries, 635
- pollutants, 667, 706
- standard, 574
- pressure (p)** Force on a surface per unit area, 416–417, 462–465, 706

- principal quantum number, 276  
 product-favoured, 501  
 production and properties of oxygen and sulfur, 1014
- products** New substances formed during chemical reaction, 27, 43, 499  
 adding, 511–512  
 removing, 511–512  
 promoter sites, 1133  
 propagation, 803, 1166  
 propane, 110  
 propene, 790  
 propylene, 790  
 properties, physical, 52  
 protective oxide layer on aluminium, 997
- proteins** Large biological polymers  
 comprised of 50 or more amino acid residues, 1095, 1115–1125  
 amino acid  
 biosynthesis, 1134–1136  
 crystal structures, 308–309  
 structures, 561t–562t
- protium, 30  
 proton NMR. *See*  $^1\text{H}$  (NMR)
- protons** Subatomic particles that have a positive charge, 28–29, 43  
 ratio in nuclei, 1154
- purification by recrystallization, 465  
 purines, 1126  
 pyranose, 1105  
 pyrimidines, 1126
- pyrometallurgy** Metallurgy that involves high temperatures, 1041, 1042–1043  
 pyroxenes, 1004
- quanta, 255–256  
 quantum  
 dots, 1091  
 mechanical model, 276–283  
 mechanics, 276
- quantitative  
 aspects of equilibrium constants, 501–507  
 relationships, 229–230
- quantization of energy of electrons in atoms, 269
- quantized** (energy of electrons) Electrons in atoms can have only particular amounts of energy, 255, 269, 297
- quantum number** A parameter in the equation for a standing wave, any “allowed” value of which gives rise to a solution for the equation, 276, 279t, 297
- quartz, 1002
- quorum sensing** Chemical communication between organisms that allows them to detect and respond to the density of their surrounding population, 912, 961
- R* configuration of chiral centres, 338f  
 RNA, 1126, 1133–1140  
 Raoult, François M., 468
- racemate** A 50:50 (equimolar) mixture of a pair of enantiomeric molecules, and so is not optically active, 337, 349, 758
- radiation  
 alpha ( $\alpha$ ) radiation, 1148  
 beta ( $\beta$ ) radiation, 1148  
 gamma ( $\gamma$ ) radiation, 1148  
 Earth, 97, 98f–103  
 health and safety, 1168–1170  
 therapy, 1171
- radiative forcing** Change in the balance between incoming and outgoing radiation of our climate system due to substances in the atmosphere, 101, 105f
- radical, 803  
 radioactive  
 decay, 1149–1155  
 isotopes, 1172  
 series, 1150  
 radioactivity, 1147–1148  
 radiocarbon dating, 1162–1164  
 radioisotopes used in medical diagnostic procedures, 1170  
 radon, 1150
- Raoult's law** The vapour pressure of the solvent is proportional to the mole fraction of solvent in a solution, 468, 482
- rate constant (*k*)** The proportionality constant in a rate equation, 729, 768
- rate-determining step** The slowest step of a reaction mechanism, which limits the rate of the overall reaction, 754–757, 768
- rate equation** A mathematical relationship that expresses experimentally observed dependence of reaction rate on reactant concentrations, 727–728, 730–731, 768
- rate-limiting step, 754  
 rate law, 727
- rate of a chemical reaction** The change in concentration of a substance per unit of time, 725–744, 765  
 rates of nuclear decay, 1158–1164  
 rationalizing the periodic variation of properties, 292–295  
 Rayleigh, Lord, 1022
- reactions  
 changes, 781–785  
 functional groups, 802–815, 816–820  
 reaction species, 499
- reactants** Substances that react to form other substances, 28, 43  
 adding, 511–512  
 amounts, 138t–143, 499  
 concentration, 727–731, 740–741  
 removing, 511–512
- reaction energy diagram** A representation of the changing energy of a tiny system comprising the particles taking part in a single collision event as reaction occurs, 742–743, 747–748, 765, 807
- reaction equations, 507–511
- reaction intermediates** Relatively high energy species formed in one step of a reaction and consumed in a later step, 808
- reaction kinetics** The study of the rates of chemical reactions, 494, 605, 721
- reaction mechanism** Sequence of bond-making and bond-breaking steps that occurs during the conversion of molecules of reactants to molecules of products, 748, 750–757, 765, 783, 784, 789, 807–808, 926–930, 944–946  
 reaction mixtures, 492–494, 499, 511–512  
 reaction order, *see* order of reaction
- reaction quotient (*Q*)** A defined function of concentrations of reactant and product species whose value at equilibrium is the equilibrium constant, 494–501, 516  
 reaction rate. *See* rate of chemical reaction  
 reactions of acetylide anions to form  $\text{C}-\text{C}$  bonds, 817  
 reactions of alkynes producing level 1 functional groups, 818  
 reactions, classification of by change of functional group level, 781–783  
 reactive nitrogen, 125, 488  
 reactive sites, 542–543  
 reactivity  
 oxidizing agents and reducing agents, 261  
 understanding, 773–787, 805–840, 851–855  
 real gases, 431
- rearrangement reactions** Molecules of a reactant reorganize bonds and atoms to yield molecules of an isomeric product, 783, 799, 840
- red phosphorus, 1007  
 redox reactions, 624  
 reduced, 624
- reducing agent** Reactant species from which electrons are taken by a species that is reduced, 191, 192t, 624
- reducing sugars** Sugars that reduce  $\text{Ag}^+$  in the Tollens test or  $\text{Cu}^{2+}$  in the Fehling's reagent, 1109–1110
- reduction** The taking of electrons by one species from another in the competition for electrons occurring in an oxidation-reduction reaction. In organic chemistry, the term is used to describe a gain of electron density by a carbon atom, 190, 204, 885–886  
 carboxylic acids, 887  
 esters, 887  
 potential, 191, 629  
 refraction of light in glasses, 1086f  
 refractive index, 1085  
 refractories, 1087
- regioselective** A label for reactions in which bond-making or bond-breaking is preferred at one molecular site or in one particular direction over others, 809  
 regloselective, 809  
 relationship between *Q* and *K*, 499, 593  
 relative abundances, 68f
- relative atomic mass (*A<sub>r</sub>*)** The mass of an atom of an isotope on a scale in which the mass of a  $^{12}\text{C}$  atom is taken to be 12 exactly, 31–33, 43  
 relative concentrations of the protonated species, 555
- relative molecular mass (*M<sub>r</sub>*)** Mass of an isotopologue on a scale in which the  $^{12}\text{C}$  isotope has a value of 12 exactly, 68–69  
 relative stability, 136  
 renewable energy sources, 110  
 replication, 1131–1132
- resonance** If the valence electrons in a molecule or ion can be distributed in more than one sensible way, then the actual electron distribution is intermediate between these ways, 309, 370–376, 408

- respiration, 218  
 respiratory acidosis, 582  
 respiratory alkalosis, 582  
 restriction endonucleases, 1137  
 reverse osmosis, 474, 477  
 reverse transcriptases, 1139  
 reversible  
   process, 675  
   reactions, 492–493f  
**reversibility** The ability of a reaction to proceed in either direction, depending on the conditions, 492  
 ribonucleic acid (RNA), 1126, 1133–1140  
 ribosomes, 1134  
 ribosomal RNA, 1133  
 ribozymes, 1140  
 ring-flip, 327f  
 Ripmeester, John, 91, 446  
 root-mean-square speed, 427  
 Rosenberg, Barnett, 1031–1032  
 rotation, 317–324, 335–336  
 Rutherford, Ernest, 40, 1148, 1149, 1164  
 Rydberg equation, 269  
 Rydberg, Johannes, 269
- S* configuration of chiral centres, 338f  
 sacrificial anodes, 658  
 salt  
   acidity of aqueous solutions, 982  
   bridge, 631, 1122  
   molten, 650  
 Sanger dideoxy method, 1137  
 sasol process, 750  
 saturation horizon, 594  
 saturated, 788  
   fatty acids, 379  
**saturated hydrocarbons** Hydrocarbons whose molecules contain only single C–C bonds, 111  
**saturated solution** A solution in which solute and dissolved species are in equilibrium, 137, 457, 459, 482, 593, 595–597, 616  
 Sawhorse representations, 318  
**s-block elements** Elements of Group 1 or 2, in which the valence electrons of atoms occupy only *s* orbitals, 287  
 scandium chemistry, 1040–1041  
 scanning electron microscopy (SEM), 1089  
 Schindler, David, 97  
**Schrödinger equation** A generalized mathematical equation for three-dimensional standing “electron waves” around an atom’s nucleus, 276, 2970  
 Schrödinger, Erwin, 295  
**screening** (shielding) The effect of repulsions from other electrons, reducing the charge that the valence electrons “feel” at the nucleus, 289  
 scuba diving, 463  
 secondary  
   batteries, 635  
   pollutants, 706  
**second law of thermodynamics** Any spontaneous process is accompanied by an increase in the entropy of the universe, 672, 681–685, 709  
 second-order reactions, 728, 733–734, 735, 737, 757, 870–872  
 seeds germination, 6–12  
**selective precipitation** Separation of one ion in solution from another by differences in the solubilities of their salts, 609–610, 616  
 selenium, 1014  
**self-assembly** Ability of molecules to arrange themselves in an ordered way as a result of selective molecular recognition, 305, 1091  
**self-ionization of water** A proton-transfer reaction between water molecules to form  $\text{H}_3\text{O}^+(\text{aq})$  ions and  $\text{OH}^-(\text{aq})$  ions, 187–188, 204, 532–533  
**semiconductors** Materials in which the valence band is separated from the conduction band by a smaller energy gap (band gap) than for insulators. Conductivity is normally between that of insulators and metals, 623, 1079–1084  
 semi-conservative replication, 1132  
 semi-metals. *See* metalloids  
 sense strand. *See* coding strand  
 sequestration of carbon dioxide, 108  
 sequence configuration, 337–340  
 shared electrons, 66f  
**shell** Comprising orbitals of an atom that have been derived by use of the same value of *n* in the Schrödinger equation, 277, 297  
**shielding** (screening) The effect of repulsions from other electrons, reducing the charge that the valence electrons “feel” at the nucleus, 289–291, 297  
 sievert (Sv), 1168  
**sigma ( $\sigma$ ) bond** A covalent bond with cylindrical symmetry, including those imagined to be formed from *s* atomic orbitals on each of the bonded atoms, 385, 408  
 silanols, 1005  
 silica, 1002  
 silica gel, 1003  
 silicon production, 1002–1006  
**single bond** Covalent bond pictured as formed by sharing of two electrons between the bonded atoms, 66, 82, 317–322, 360, 391–392  
 singlet oxygen, 3–6  
 skeletal structures, 321–322  
 Sklodovska, Marie, 1150  
 slaked lime, 994  
 slaking, 994  
 slightly soluble, 595  
 snowflakes, 65f  
 $\text{S}_{\text{N}}1$  mechanism, 869–870, 874–877  
 $\text{S}_{\text{N}}1$  reaction, 758–761  
 $\text{S}_{\text{N}}2$  mechanism, 869–874  
   nucleophilic substitution reactions, 757–758, 760–761  
 Smalley, Richard, 213, 838  
 Smil, Vaclav, 488  
 smoke, and seed germination, 6–12  
 soap, 481  
 soda ash, 990  
 Soddy, Frederick, 1149  
 sodium, 988–991  
   chloride, electrolysis of aqueous solutions, 1018f  
   chloride, electrolysis of molten, 988  
   production, 988  
 soft acids and bases, 1034  
 soft-soft, 1034  
 sol, 478, 479  
 solar energy, 620–622  
 solids, 20, 436  
   kinetic molecular model, 436–437  
 solid sol, 478  
 solid state, 433–436, 439–441  
 solubilities of Ionic compounds, 180–181f  
**solubility** The concentration of a substance in a saturated solution, at a specified temperature, 178, 459, 462–465, 482, 595–605  
   complexation, 610–613  
   equilibria, 610–613  
   gases, 457  
   predictions, 599–600  
   product ( $K_{\text{sp}}$ ), 593, 596  
   salts, 593, 600–604  
**solubility product ( $K_{\text{sp}}$ )** The equilibrium constant in a saturated solution of a slightly soluble salt, 596–599, 616  
 soluble molecules, 184–185  
 solute concentration, 202  
**solutes** Dissolved substances in solutions, 178, 202–203  
**solutions** Homogeneous mixtures, 22, 200, 201f–203, 459–460  
 solutions  
   acidity, 552–553  
   behaviour, 457–482  
   homogenous mixtures, 22  
   measure, 552–553  
   reagent, 606–607  
   solvary process, 990  
**solvent** The medium in which other substances are dissolved to form a solution, 178–182, 200, 445  
 solvation, 179  
 southern lights, 12  
 space science, 1173  
 spatial arrangement, 376–383  
 speciation, 488, 490, 554–559  
   acid-base, 553–563, 581–582, 591–594  
   arsenic, 157  
   complexes, 613–614  
   pharmaceutical drugs, 523  
   ions, 1052–1054  
   plot, 525, 555  
 species. *See* chemical species  
**specific heat capacity (*c*)** The amount of heat required to raise the temperature of 1 g of a substance by 1 K, 160t–161, 204  
 specific rotation, 335–336  
**spectator ions** Ions in solution that do not participate in a reaction, 189  
**spectrochemical series** A rank order of ability of ligands to split the *d* orbital energies in complexes, 1064  
 spectroscopic evidence, 793–796, 860–866

- spectroscopy** A method of finding out about the structure of molecules that depends on their interaction with electromagnetic radiation, 2, 74–81, 777–778  
 carbonyl compounds, 922  
 infrared, 74  
 functional groups, 777  
 speeds of gas molecules, 426  
 spherically symmetrical, 281  
 spin, 279
- spin-spin splitting** Multiple absorptions for an NMR signal caused by interaction with nuclear spins of neighbouring atoms, 863
- spontaneity  
 criterion, 671–672  
 reaction, 687–689, 693–696
- spontaneous, 671  
 change, 719–720  
 direction of change, 671–672
- spontaneous direction of reaction**  
 Direction of net reaction that takes a reaction mixture toward chemical equilibrium, 134–136, 149, 500–501, 516  
 predicting, 642–643  
 terminology, 135f–136f, 137, 681–684
- spontaneous reaction, 629
- sports, chemistry of drugs, 17–20
- stabilities of ionic compounds, 180
- stability, 135,  
 constant, 1051
- stable, 135, 149, 500
- staggered conformers, 319
- stainless steel, 1043
- standard ambient temperature and pressure (SATP)** At a temperature of 25 °C and pressure of 1 bar, 420
- standard boiling point** The temperature at which the equilibrium vapour pressure of the substance is 1.00 bar, 442
- standard cell emf ( $E^\circ_{\text{cell}}$ )** The cell emf when all reactants and products are in their standard states, 636, 640–641, 648–649, 660
- solute concentration, 466–468, 545–546
- standard enthalpy change of reaction ( $\Delta_r H^\circ$ )**  
 Enthalpy change of reaction when all the reactants and products are in their standard states, at the temperature of the reaction mixture, 233, 245
- standard entropy change of reaction ( $\Delta_r S^\circ$ )**  
 Entropy change when all the reactants and products are in their standard states, 679–681, 710
- standard free energy change of reaction ( $\Delta_r G^\circ$ )** The free energy change of reaction when all of the reactants and products are present in their standard states, 689–690, 691–693, 942
- standard half-cell reduction potentials ( $E^\circ_{\text{half-cell}}$ )** Half-cell reduction potentials when all reactants and products are in their standard states, 638, 639t, 660
- standard hydrogen electrode (SHE)** A half-cell with  $\text{H}_2(\text{g})$  at 1 bar pressure is bubbled through a solution having  $[\text{H}^+] = 1 \text{ mol L}^{-1}$ , arbitrarily assigned zero reduction potential, 636, 660
- standardization, 574
- standard molar enthalpy change of formation ( $\Delta_f H^\circ$ )** Enthalpy change accompanying the reaction in which 1 mol of a substance in its standard state is formed from its component elemental substances in their standard states, 237, 238t–240, 246
- standard molar enthalpy change of vaporization, 234
- standard molar entropy ( $S^\circ$ )** The entropy of 1 mol of a substance in its standard state, 676–677, 709
- standard molar free energy change of formation ( $\Delta_f G^\circ$ )** The free energy change when 1 mol of a substance in its standard state is formed from its component elements in their standard states, 690–691, 710
- standard states** Defined conditions of substances, at specified temperatures, 232–233
- standing wave, 276f–279
- Stannard, Russell, 254
- Starch, 1112
- state** Solid, liquid, gas, or plasma, 3
- state function** A property whose magnitude depends only on the amount of the substance and the conditions, regardless of its history, 20, 224, 245
- steam-methane reforming, 215
- steam reforming 94
- steel, 1043
- stereocentre** An atom in a molecule around which the spatial arrangement of other atoms gives rise to stereoisomerism, 331–332, 342, 344–345, 348
- stereochemistry** The branch of chemistry concerned with the three-dimensional structures of molecules, 303–304, 330–334, 348  
 carbohydrates, 1102
- stereoisomeric alkene molecules, 323
- stereoisomerism coordination complexes, 1058–1061
- stereoisomers** Molecules that have the same numbers of each type of atom, with the same connectivity, but that differ in the three-dimensional spatial arrangement of the atoms, 310, 323–324, 342–347, 348
- stereoisomers, *cis-trans*, 322
- steric strain, 798
- stoichiometric factor** Ratio of amounts of reactants or products, deduced from the balanced chemical equation, 139, 144
- stoichiometry** Calculation of relative amounts and masses of reactants that react, and of products that are formed, in chemical reactions, 132, 138–140, 144–147, 149
- storage batteries, 635
- straight-chain carbon compounds, 112
- Strassman, Fritz, 1166
- strong acids** Acids that are strong electrolytes, 194, 204, 528, 529f, 535–537, 575–576
- strong bases** Bases that are strong electrolytes, 195, 204, 530
- strong electrolytes** Substances that dissociate completely into ions when dissolving in water, 180, 204
- strong-field ligands** Ligands that interact strongly with the *d* orbitals of a metal ion, causing large ligand-field splitting, 1064
- strontium-90, 1159
- structural formulas** Representations that indicate the connective sequence of all of the atoms of a substance, 67f, 71–73
- structural isomers** (constitutional isomers)  
 Two substances with the same formula but different connectivity of the atoms, 71
- structure and reactivity of carbon compounds, 776
- structure, understanding, 773–787, 851–855
- sublimation, 441
- sub-shell** Each set of orbitals derived by use of the same value of *l* in the Schrödinger equation, 277,
- substance** A single, pure form of matter, 22, 27–28, 35–38, 49–58  
 properties, 52–58
- substituent, 113
- substitution reactions** One atom or group in a molecule is replaced by another atom or group, 757–761, 783, 820, 840, 869–878
- substrate, 757, 1122
- sucrose, 1111
- sugars, 851, 1099, 1102–1104
- sulfate analysis, 146f
- sulfonation, 833–834
- sulfur  
 allotropes, 1014  
 chemistry, 975–976  
 compounds, 1016–1017  
 dioxide, 1016  
 hexafluoride, 418  
 sulfuric acid, 1016  
 superconductors, 1088
- supercritical fluid** A substance at pressure and temperature higher than those at its critical point, 107, 444–445, 448
- superoxides of metals, 989
- supersaturated solution** Solutions in which the concentration of solute is higher than that of a saturated solution, 459, 482, 593
- supramolecular assemblies, 81, 90  
 complex, 90
- surface-active agents, 481
- surface density, 281–282f
- surface tension** Amount of energy required to increase unit surface area, 164, 177, 203
- surfactants** Substances that affect the properties of surfaces, and therefore affect the interaction between two phases, 480–481
- surrounding thermodynamics, 223–224
- swapping, 91
- symbolic level** Use of language, symbolism, or mathematical expressions to represent substances

- and their chemical and physical properties, 23, 43
- symbols, 63
- stretching, 76f
- syn stereochemistry, 802
- syngas** Mixture of  $\text{H}_2(\text{g})$  and  $\text{CO}(\text{g})$  used to make other compounds, 94, 127, 750
- synthesis
- carbon compounds, 776
  - ammonia from nitrogen, 515
- synthesis gas** (syngas) Mixture of  $\text{H}_2(\text{g})$  and  $\text{CO}(\text{g})$  used to make other compounds, 750, 777–778, 884–885, 948, 952, 986
- synthetic chemistry** Creating, through a designed series of reactions, compounds from simpler or more available ones, 10
- system thermodynamics, 223–224
- THG (tetrahydrogestrinone), 18
- table of isotopes, 40–43
- taste, 851
- tellurium, 1014
- temperature** ( $T$ ) A measure of how hot something is, which is related to the average kinetic energy of its atoms, molecules, or ions, 99f, 101f, 102, 222–223, 245, 462–465, 701–706, 741–743
- template strand, 1133
- termination, 803, 1166
- termolecular, 752
- Tershikh, Victor, 446
- testosterone, 325
- use and detection in sport, 17–20
- Thenardite, 145f
- theoretical yield** The maximum mass of a product that can be obtained from specified amounts of starting materials, 143–144, 150
- thermal
- equilibrium, 223
  - inversion, 706–707f
- thermochemistry, 218
- thermodynamically spontaneous, 669
- unstable, 669
- thermodynamics, 135, 218, 221–222, 684–685
- thermophiles, 976
- third law of thermodynamics** There is no disorder in a perfect crystal at 0 K, so it has zero entropy, 675–676
- Thompson, Lonnie, 1145–1146
- three-centre bond, 1000
- titration** A method of quantitative analysis that depends on finding the volume of a solution that contains the amount of one of reagent that reacts exactly with a known amount of another, 573–578, 584
- toluene, 791
- top ten chemicals, 977
- total internal reflection, 1086
- town gas, 986
- trans*, see *cis-trans* isomers
- transcription, 1131, 1133–1134
- transfer RNA, 1133
- transferases, 1123
- transistors, 1081–1083
- transition elements** Members of Groups 3–12 of the periodic table, 38, 1031–1074
- electron configurations, 1037
  - trends, 1039
- transition state** An unstable arrangement of atoms in which the energy of atoms, molecules, or ions in a single collision is at a maximum, 259, 742, 760, 765, 808
- translation, 1131, 1134–1136
- transmutation, 1164
- transuranium elements, 1165
- triple bond, 395
- triple point** A unique pressure and temperature for each substance, at which liquid, solid, and vapour phases may co-exist in equilibrium, 442, 443
- triplet oxygen, 3–6
- tritium, 30
- trivial, 790
- troposphere, 101
- tunable laser spectrometer, 117
- Tyndall effect, 479
- understanding reactions by visualizing mechanisms, 783
- unimolecular, 752
- unit resolution** Mass spectrometry whose level of accuracy is sufficient to distinguish between particles with  $m/z$  values that differ by 1, 67
- units of unsaturation, 115
- universal constants of nature, 36
- universe thermodynamics, 223–224
- unpaired electrons, 278
- unsaturated, 788
- compounds, 788
  - fatty acids, 379
  - hydrocarbons, 114
- unsaturation, units of, 115
- uranium
- 238 radioactive decay series, 1150
  - isotopes, 1150
- van der Waals forces. *See* dispersion forces
- valence band, 1080
- valence bond (VB) model** A way of modelling covalent bonding in which electrons are considered to belong to the atoms from which the molecule is formed, although the bonding electrons are shared, 383–397, 408
- valence electrons** The highest-energy electrons in an atom, ion, or molecule that are presumed to govern the chemical behaviour of the species, 287, 291–292, 360, 369–370
- valence shell electron-pair repulsion (VSEPR) model** A model for predicting the orientation of bonds around an atom in a molecule or ion by assuming that localized regions of electron matter (bonds and non-bonding pairs) attain the orientation of minimum repulsion, 377, 408
- $K_a$  values, 536t
- Van Camp, Loretta, 1031–1032
- van der Waals equation** A modified version of the ideal gas equation, to better model pressure-volume-temperature relationships at low  $T$  and high  $p$ , 432, 448
- van't Hoff factor, 474, 703
- vaporization** Process by which a liquid substance changes to the gaseous state, 161f–165, 177, 204, 437
- molar enthalpy, 227
- vapour pressure** Pressure of vapour above a liquid in a sealed vessel at which liquid and vapour are in equilibrium, 437–438, 448, 468–470
- curves, 438f
  - liquids, temperature dependence, 438
- verbenol, 775
- verbenone, 775
- vision, 5
- visualization, 542–543, 783–784
- visualizing energy changes in the reaction mechanism, 807
- Visudyne™, 3–6
- vitamins, 1123
- volatile organic compounds, 668
- volatility, 163
- voltaic cell** An arrangement that directs the transfer of electrons in a spontaneous oxidation-reduction reaction from one compartment, through a conductor, to another compartment, 630–635, 643–648, 660, 699–700
- volume changing, gas-phase reaction mixture, 512–513
- Walker, Virginia, 91
- Walton, E.T.S., 1164
- water
- arsenic, 1013
  - boiling point, 163–164
  - change of density, 160
  - chemical reaction, 188–200
  - chemistry, 157–212
  - crystallization of solid salts, 981
  - density change with temperature, 160, 175
  - dissolving molecular substance, 182
  - electrostatic, 170f pH
  - gas, 986
  - general, 157–212
  - glass, 1003
  - hard, 994
  - ion mobility, 983
  - ionic salts, 178–179
  - ionization, 532
  - molecule, 170–171, 176f,
  - phase, 442
  - phase diagram, 442
  - properties, 160–165, 176–177
  - pH scale, 532
  - solvent, 178–187
- Watson-Crick model, 1129–1131
- Watson, James, 1129
- wave
- function, 276
  - mechanics, 276

**wavenumber** ( $\tilde{\nu}$ ) The reciprocal of the wavelength of radiation expressed in  $\text{cm}^{-1}$ , 75

**wave-particle duality** The idea that electrons have properties of both particles and waves, 273–275, 297

**weak acids** Acids that are weak electrolytes, 194, 204, 529–530, 535–537, 545–555, 576–577, 889

**weak bases** Bases that are weak electrolytes, 195, 204, 530, 545–555, 580–581, 889

**weak electrolytes** Substances of which only some of the molecules ionize on dissolving in water, 204

**weak-field ligands** Ligands that interact only weakly with the *d* orbitals of the metal ion, causing small ligand-field splitting, 1064

weak polyprotic acids, 530

white phosphorus, 1007

White powder, 49–52

Wolfenden, Richard, 761

Wolfgang, Pauli, 284

Wothers, Peter, 779

X-ray crystallography, 306, 307–309

**Zaitsev's rule** Rule stating that E2 elimination reactions normally yield major products with more highly substituted alkene molecules, 879

zeolites, 1005

zero-order reactions, 734f–735

zinc chemistry, 1040–1042

zone refining, 1002

zwitterion, 559, 1115–1116