

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
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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 H_2 to alkenes: hydration, 813
of H_2 to alkenes: hydrogenation, 802, 805, 816
of H_2O to alkynes: hydration, 819
of HX to alkynes: hydrohalogenation, 818
of X_2 to alkenes: halogenation, 814
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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 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 (α) 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
 CO₂, 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 ¹²C 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 (β) radiation** Electrons (β 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
¹³C 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* ¹³C NMR
 carbon-14 dating techniques, 1162
 carbon-14/carbon-12 ration on CO₂, 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** (δ) 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^+ 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
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- 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 Sklodowska, 1015
- Curie, Pierre, 1015
- Curiosity Rover, 116
- Curl, Robert, 838
- cyanide, 554
- and seed germination, 11
- cyclic alkanes, 115, 322
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- 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 (ρ)** 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 (χ)** 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 (ΔH)** 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
- 1H NMR Spectroscopy, 824
- evidence for aromaticity: 13C 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 MX_3Y_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 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 (β)** (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 (ν)** 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 (γ) 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_2 , 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 $\text{CO}_2(\text{g})$, 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
- ^1H (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
- α -helix, 1120
- hemiacetal** Functional group having the structure $\text{RHC}(\text{OH})\text{OR}'$, 853, 925
 formation, 1104–1106
- hemiketal** Functional group having the structure $\text{R}_2\text{C}(\text{OH})\text{OR}$, 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
- $\text{HOCl}(\text{aq})$ 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 H_3O^+ , 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
- α -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 (Δ_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 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 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}C , 313, 317, 323
- ^1H , 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 H_3O^+ , 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 μmols 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
- photronics, 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
- α -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* ^1H (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 (α) radiation, 1148
 beta (β) radiation, 1148
 gamma (γ) 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
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 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 Ag^+ in the Tollens test or 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_r*)** The mass of an atom of an isotope on a scale in which the mass of a ^{12}C atom is taken to be 12 exactly, 31–33, 43
 relative concentrations of the protonated species, 555
- relative molecular mass (*M_r*)** Mass of an isotopologue on a scale in which the ^{12}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
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 Rutherford, Ernest, 40, 1148, 1149, 1164
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 Rydberg, Johannes, 269
- S* configuration of chiral centres, 338f
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 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 (σ) 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
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 Sklodovska, Marie, 1150
 slaked lime, 994
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 Soddy, Frederick, 1149
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 chloride, electrolysis of molten, 988
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 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_{sp}), 593, 596
 salts, 593, 600–604
solubility product (K_{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
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- 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°_{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°)** 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 $H_2(g)$ and $CO(g)$ used to make other compounds, 94, 127, 750
 synthesis
 carbon compounds, 776
 ammonia from nitrogen, 515
synthesis gas (syngas) Mixture of $H_2(g)$ and $CO(g)$ 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
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 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
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 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
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 crystallization of solid salts, 981
 density change with temperature, 160, 175
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 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 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

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Wolfenden, Richard, 761

Wolfgang, Pauli, 284

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

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zone refining, 1002

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