

SI Units

As pointed out in Chapter 1, most quantities are commonly expressed in a variety of different units. For example, temperature can be reported in °F, °C, or K. Volume is sometimes quoted in liters or cubic centimeters, at other times in quarts, cubic feet, and so on. In 1960, the General Conference of Weights and Measures attempted to end this proliferation of units. It recommended adopting a self-consistent set of units based on the metric system. In the so-called International System of Units (SI) each quantity is represented by a single unit or decimal multiple thereof, using the prefixes listed in Table 1.2. For example, the fundamental SI unit of length is the meter; the length of an object can be expressed in meters, kilometers (1 km = 10³ m), or nanometers (1 nm = 10⁻⁹ m), but *not* in inches, angstroms, or other non-SI units.

Table 1 lists the SI base and derived units for quantities commonly referred to in general chemistry. Perhaps the least familiar of these units to the beginning chemistry student are the ones used to represent force, pressure, and energy.

The *newton* is defined as the force required to impart an acceleration of one meter per second squared to a mass of one kilogram. Recall that Newton's second law can be stated as

$$\text{force} = \text{mass} \times \text{acceleration}$$

The *pascal* is defined as the pressure exerted by a force of one newton acting on an area of one square meter (recall that pressure = force/area).

The *joule* is defined as the work done when a force of one newton (kg·m/s²) acts through a distance of one meter (recall that work = force × distance).

Over the past 40 years, the International System of Units has met with a decidedly mixed reception, at least in the United States. On the one hand, scientists have adopted the joule as the base unit of energy, replacing the calorie. On the other hand, volumes are seldom if ever expressed in m³. The cubic meter is simply too large a unit; the medium-sized test tube used in the general chemistry laboratory has a volume of about 0.00001 m³. The density of water is commonly expressed as 1.00 g/cm³, not as

$$\frac{1.00 \text{ g}}{\text{cm}^3} \times \frac{1 \text{ kg}}{10^3 \text{ g}} \times \frac{(10^2 \text{ cm})^3}{1 \text{ m}^3} = 1.00 \times 10^3 \text{ kg/m}^3$$

(A cubic meter of water weighs about one metric ton!)

Table 1 SI Units

Base Units			Derived Units		
Quantity	Unit	Symbol	Quantity	Unit	Symbol
length	meter	m	volume	cubic meter	m ³
mass	kilogram	kg	force	newton	N
time	second	s	pressure	pascal	Pa
temperature	kelvin	K	energy	joule	J
amount of substance	mole	mol	electric charge	coulomb	C
electric current	ampere	A	electric potential	volt	V

Fundamental Constants

Acceleration of gravity (standard)	9.8066 m/s ²
Atomic mass unit (amu)	1.6605×10^{-24} g
Avogadro constant	6.0221×10^{23} /mol
Electronic charge	1.6022×10^{-19} C
Electronic mass	9.1094×10^{-28} g
Faraday constant	9.6485×10^4 C/mol
Gas constant	0.082058 L·atm/mol·K
	8.3145 J/mol·K
Planck constant	6.6261×10^{-34} J·s
Rydberg constant	2.1799×10^{-18} J
Velocity of light	2.9979×10^8 m/s
π	3.1416
e	2.7183
$\ln x$	$2.3026 \log_{10} x$

Vapor Pressure of Water (mm Hg)

T (°C)	vp	T (°C)	vp
0	4.58	35	42.2
5	6.54	40	55.3
10	9.21	45	71.9
12	10.52	50	92.5
14	11.99	55	118.0
16	13.63	60	149.4
17	14.53	65	187.5
18	15.48	70	233.7
19	16.48	80	355.1
20	17.54	90	525.8
21	18.65	92	567.0
22	19.83	94	610.9
23	21.07	96	657.6
24	22.38	98	707.3
25	23.76	100	760.0
26	25.21	102	815.9
27	26.74	104	875.1
28	28.35	106	937.9
29	30.04	108	1004.4
30	31.82	110	1074.6

Thermodynamic Data

	ΔH_f° (kJ/mol)	S° (kJ/K·mol)	ΔG_f° (kJ/mol) at 25°C		ΔH_f° (kJ/mol)	S° (kJ/K·mol)	ΔG_f° (kJ/mol) at 25°C
Ag(s)	0.0	+0.0426	0.0	ClO ₃ ⁻ (aq)	-104.0	+0.1623	-8.0
Ag ⁺ (aq)	+105.6	+0.0727	+77.1	ClO ₄ ⁻ (aq)	-129.3	+0.1820	-8.5
AgBr(s)	-100.4	+0.1071	-96.9	Cr(s)	0.0	+0.0238	0.0
AgCl(s)	-127.1	+0.0962	-109.8	CrO ₄ ²⁻ (aq)	-881.2	+0.0502	-727.8
AgI(s)	-61.8	+0.1155	-66.2	Cr ₂ O ₃ (s)	-1139.7	+0.0812	-1058.1
AgNO ₃ (s)	-124.4	+0.1409	-33.4	Cr ₂ O ₇ ²⁻ (aq)	-1490.3	+0.2619	-1301.1
Ag ₂ O(s)	-31.0	+0.1213	-11.2	Cu(s)	0.0	+0.0332	0.0
Al(s)	0.0	+0.0283	0.0	Cu ⁺ (aq)	+71.7	+0.0406	+50.0
Al ³⁺ (aq)	-531.0	-0.3217	-485.0	Cu ²⁺ (aq)	+64.8	-0.0996	+65.5
Al ₂ O ₃ (s)	-1675.7	+0.0509	-1582.3	CuO(s)	-157.3	+0.0426	-129.7
Ba(s)	0.0	+0.0628	0.0	Cu ₂ O(s)	-168.6	+0.0931	-146.0
Ba ²⁺ (aq)	-537.6	+0.0096	-560.8	CuS(s)	-53.1	+0.0665	-53.6
BaCl ₂ (s)	-858.6	+0.1237	-810.4	Cu ₂ S(s)	-79.5	+0.1209	-86.2
BaCO ₃ (s)	-1216.3	+0.1121	-1137.6	CuSO ₄ (s)	-771.4	+0.1076	-661.9
BaO(s)	-553.5	+0.0704	-525.1	F ₂ (g)	0.0	+0.2027	0.0
BaSO ₄ (s)	-1473.2	+0.1322	-1362.3	F ⁻ (aq)	-332.6	-0.0138	-278.8
Br ₂ (l)	0.0	+0.1522	0.0	Fe(s)	0.0	+0.0273	0.0
Br ⁻ (aq)	-121.6	+0.0824	-104.0	Fe ²⁺ (aq)	-89.1	-0.1377	-78.9
C(s)	0.0	+0.0057	0.0	Fe ³⁺ (aq)	-48.5	-0.3159	-4.7
CCl ₄ (l)	-135.4	+0.2164	-65.3	Fe(OH) ₃ (s)	-823.0	+0.1067	-696.6
CHCl ₃ (l)	-134.5	+0.2017	-73.7	Fe ₂ O ₃ (s)	-824.2	+0.0874	-742.2
CH ₄ (g)	-74.8	+0.1862	-50.7	Fe ₃ O ₄ (s)	-1118.4	+0.1464	-1015.5
C ₂ H ₂ (g)	+226.7	+0.2008	+209.2	H ₂ (g)	0.0	+0.1306	0.0
C ₂ H ₄ (g)	+52.3	+0.2195	+68.1	H ⁺ (aq)	0.0	0.0000	0.0
C ₂ H ₆ (g)	-84.7	+0.2295	-32.9	HBr(g)	-36.4	+0.1986	-53.4
C ₃ H ₈ (g)	-103.8	+0.2699	-23.5	HCl(g)	-92.3	+0.1868	-95.3
CH ₃ OH(l)	-238.7	+0.1268	-166.3	HCO ₃ ⁻ (aq)	-692.0	+0.0912	-586.8
C ₂ H ₅ OH(l)	-277.7	+0.1607	-174.9	HF(g)	-271.1	+0.1737	-273.2
CO(g)	-110.5	+0.1976	-137.2	HI(g)	+26.5	+0.2065	+1.7
CO ₂ (g)	-393.5	+0.2136	-394.4	HNO ₃ (l)	-174.1	+0.1556	-80.8
CO ₃ ²⁻ (aq)	-677.1	-0.0569	-527.8	H ₂ O(g)	-241.8	+0.1887	-228.6
Ca(s)	0.0	+0.0414	0.0	H ₂ O(l)	-285.8	+0.0699	-237.2
Ca ²⁺ (aq)	-542.8	-0.0531	-553.6	H ₂ O ₂ (l)	-187.8	+0.1096	-120.4
CaCl ₂ (s)	-795.8	+0.1046	-748.1	H ₂ PO ₄ ⁻ (aq)	-1296.3	+0.0904	-1130.3
CaCO ₃ (s)	-1206.9	+0.0929	-1128.8	HPO ₄ ²⁻ (aq)	-1292.1	-0.0335	-1089.2
CaO(s)	-635.1	+0.0398	-604.0	H ₂ S(g)	-20.6	+0.2057	-33.6
Ca(OH) ₂ (s)	-986.1	+0.0834	-898.5	H ₂ SO ₄ (l)	-814.0	+0.1569	-690.1
CaSO ₄ (s)	-1434.1	+0.1067	-1321.8	HSO ₄ ⁻ (aq)	-887.3	+0.1318	-755.9
Cd(s)	0.0	+0.0518	0.0	Hg(l)	0.0	+0.0760	0.0
Cd ²⁺ (aq)	-75.9	-0.0732	-77.6	Hg ²⁺ (aq)	+171.1	-0.0322	+164.4
CdCl ₂ (s)	-391.5	+0.1153	-344.0	HgO(s)	-90.8	+0.0703	-58.6
CdO(s)	-258.2	+0.0548	-228.4	I ₂ (s)	0.0	+0.1161	0.0
Cl ₂ (g)	0.0	+0.2230	0.0	I ⁻ (aq)	-55.2	+0.1113	-51.6
Cl ⁻ (aq)	-167.2	+0.0565	-131.2	K(s)	0.0	+0.0642	0.0

continued

Thermodynamic Data *continued*

	ΔH_f° (kJ/mol)	S° (kJ/K·mol)	ΔG_f° (kJ/mol) at 25°C		ΔH_f° (kJ/mol)	S° (kJ/K·mol)	ΔG_f° (kJ/mol) at 25°C
K ⁺ (aq)	-252.4	+0.1025	-283.3	NaF(s)	-573.6	+0.0515	-543.5
KBr(s)	-393.8	+0.0959	-380.7	NaOH(s)	-425.6	+0.0645	-379.5
KCl(s)	-436.7	+0.0826	-409.1	Ni(s)	0.0	+0.0299	0.0
KClO ₃ (s)	-397.7	+0.1431	-296.3	Ni ²⁺ (aq)	-54.0	-0.1289	-45.6
KClO ₄ (s)	-432.8	+0.1510	-303.2	NiO(s)	-239.7	+0.0380	-211.7
KNO ₃ (s)	-494.6	+0.1330	-394.9	O ₂ (g)	0.0	+0.2050	0.0
Mg(s)	0.0	+0.0327	0.0	OH ⁻ (aq)	-230.0	-0.0108	-157.2
Mg ²⁺ (aq)	-466.8	-0.1381	-454.8	P ₄ (s)	0.0	+0.1644	0.0
MgCl ₂ (s)	-641.3	+0.0896	-591.8	PCl ₃ (g)	-287.0	+0.3117	-267.8
MgCO ₃ (s)	-1095.8	+0.0657	-1012.1	PCl ₅ (g)	-374.9	+0.3645	-305.0
MgO(s)	-601.7	+0.0269	-569.4	PO ₄ ³⁻ (aq)	-1277.4	-0.222	-1018.7
Mg(OH) ₂ (s)	-924.5	+0.0632	-833.6	Pb(s)	0.0	+0.0648	0.0
MgSO ₄ (s)	-1284.9	+0.0916	-1170.7	Pb ²⁺ (aq)	-1.7	+0.0105	-24.4
Mn(s)	0.0	+0.0320	0.0	PbBr ₂ (s)	-278.7	+0.1615	-261.9
Mn ²⁺ (aq)	-220.8	-0.0736	-228.1	PbCl ₂ (s)	-359.4	+0.1360	-314.1
MnO(s)	-385.2	+0.0597	-362.9	PbO(s)	-219.0	+0.0665	-188.9
MnO ₂ (s)	-520.0	+0.0530	-465.2	PbO ₂ (s)	-277.4	+0.0686	-217.4
MnO ₄ ⁻ (aq)	-541.4	+0.1912	-447.2	S(s)	0.0	+0.0318	0.0
N ₂ (g)	0.0	+0.1915	0.0	S ²⁻ (aq)	+33.1	-0.0146	+85.8
NH ₃ (g)	-46.1	+0.1923	-16.5	SO ₂ (g)	-296.8	+0.2481	-300.2
NH ₄ ⁺ (aq)	-132.5	+0.1134	-79.3	SO ₃ (g)	-395.7	+0.2567	-371.1
NH ₄ Cl(s)	-314.4	+0.0946	-203.0	SO ₄ ²⁻ (aq)	-909.3	+0.0201	-744.5
NH ₄ NO ₃ (s)	-365.6	+0.1511	-184.0	Si(s)	0.0	+0.0188	0.0
N ₂ H ₄ (l)	+50.6	+0.1212	+149.2	SiO ₂ (s)	-910.9	+0.0418	-856.7
NO(g)	+90.2	+0.2107	+86.6	Sn(s)	0.0	+0.0516	0.0
NO ₂ (g)	+33.2	+0.2400	+51.3	Sn ²⁺ (aq)	-8.8	-0.0174	-27.2
NO ₂ ⁻ (aq)	-104.6	+0.1230	-32.2	SnO ₂ (s)	-580.7	+0.0523	-519.6
NO ₃ ⁻ (aq)	-205.0	+0.1464	-108.7	Zn(s)	0.0	+0.0416	0.0
N ₂ O ₄ (g)	+9.2	+0.3042	+97.9	Zn ²⁺ (aq)	-153.9	-0.1121	-147.1
Na(s)	0.0	+0.0512	0.0	ZnI ₂ (s)	-208.0	+0.1611	-209.0
Na ⁺ (aq)	-240.1	+0.0590	-261.9	ZnO(s)	-348.3	+0.0436	-318.3
NaCl(s)	-411.2	+0.0721	-384.2	ZnS(s)	-206.0	+0.0577	-201.3

Equilibrium Constants of Weak Acids (K_a)

H_3AsO_4	5.7×10^{-3}	HNO_2	6.0×10^{-4}	N_2H_5^+	1.0×10^{-8}
H_2AsO_4^-	1.8×10^{-7}	H_3PO_4	7.1×10^{-3}	$\text{Al}(\text{H}_2\text{O})_6^{3+}$	1.2×10^{-5}
HAsO_4^{2-}	2.5×10^{-12}	H_2PO_4^-	6.2×10^{-8}	$\text{Ag}(\text{H}_2\text{O})_2^+$	1.2×10^{-12}
HBrO	2.6×10^{-9}	HPO_4^{2-}	4.5×10^{-13}	$\text{Ca}(\text{H}_2\text{O})_6^{2+}$	2.2×10^{-13}
HCHO_2	1.9×10^{-4}	H_2S	1.0×10^{-7}	$\text{Cd}(\text{H}_2\text{O})_4^{2+}$	4.0×10^{-10}
$\text{HC}_2\text{H}_3\text{O}_2$	1.8×10^{-5}	H_2SO_3	1.7×10^{-2}	$\text{Fe}(\text{H}_2\text{O})_6^{3+}$	6.7×10^{-3}
HCN	5.8×10^{-10}	HSO_3^-	6.0×10^{-8}	$\text{Fe}(\text{H}_2\text{O})_6^{2+}$	1.7×10^{-7}
H_2CO_3	4.4×10^{-7}	HSO_4^-	1.0×10^{-2}	$\text{Mg}(\text{H}_2\text{O})_6^{2+}$	3.7×10^{-12}
HCO_3^-	4.7×10^{-11}	H_2Se	1.5×10^{-4}	$\text{Mn}(\text{H}_2\text{O})_6^{2+}$	2.8×10^{-11}
HClO_2	1.0×10^{-2}	H_2SeO_3	2.7×10^{-3}	$\text{Ni}(\text{H}_2\text{O})_6^{2+}$	2.2×10^{-10}
HClO	2.8×10^{-8}	HSeO_3^-	5.0×10^{-8}	$\text{Pb}(\text{H}_2\text{O})_6^{2+}$	6.7×10^{-7}
HF	6.9×10^{-4}	CH_3NH_3^+	2.4×10^{-11}	$\text{Sc}(\text{H}_2\text{O})_6^{3+}$	1.1×10^{-4}
HIO	2.4×10^{-11}	NH_4^+	5.6×10^{-10}	$\text{Zn}(\text{H}_2\text{O})_4^{2+}$	3.3×10^{-10}
HN_3	2.4×10^{-5}				

Equilibrium Constants of Weak Bases (K_b)

AsO_4^{3-}	4.0×10^{-3}	N_3^-	4.2×10^{-10}	HSeO_3^-	3.7×10^{-12}
HAsO_4^{2-}	5.6×10^{-8}	NH_3	1.8×10^{-5}	AlOH^{2+}	8.3×10^{-10}
H_2AsO_4^-	1.8×10^{-12}	N_2H_4	1.0×10^{-6}	AgOH	8.3×10^{-3}
BrO^-	3.8×10^{-6}	NO_2^-	1.7×10^{-11}	CaOH^+	4.5×10^{-2}
CH_3NH_2	4.2×10^{-4}	PO_4^{3-}	2.2×10^{-2}	CdOH^+	2.5×10^{-5}
CHO_2^-	5.3×10^{-11}	HPO_4^{2-}	1.6×10^{-7}	FeOH^{2+}	1.5×10^{-12}
$\text{C}_2\text{H}_3\text{O}_2^-$	5.6×10^{-10}	H_2PO_4^-	1.4×10^{-12}	FeOH^+	5.9×10^{-8}
CN^-	1.7×10^{-5}	HS^-	1.0×10^{-7}	MgOH^+	2.7×10^{-3}
CO_3^{2-}	2.1×10^{-4}	SO_3^{2-}	1.7×10^{-7}	MnOH^+	3.6×10^{-4}
HCO_3^-	2.3×10^{-8}	HSO_3^-	5.9×10^{-13}	NiOH^+	4.5×10^{-5}
ClO_2^-	1.0×10^{-12}	SO_4^{2-}	1.0×10^{-12}	PbOH^+	1.5×10^{-8}
ClO^-	3.6×10^{-7}	HSe^-	6.7×10^{-11}	ScOH^{2+}	9.1×10^{-11}
F^-	1.4×10^{-11}	SeO_3^{2-}	2.0×10^{-7}	ZnOH^+	3.0×10^{-5}
IO^-	4.2×10^{-4}				

Formation Constants of Complex Ions (K_f)

AgBr ₂ ⁻	2×10^7	Cu(CN) ₂ ⁻	1×10^{24}	PdBr ₄ ²⁻	6×10^{13}
AgCl ₂ ⁻	1.8×10^5	Cu(NH ₃) ₄ ²⁺	2×10^{12}	PtBr ₄ ²⁻	6×10^{17}
Ag(CN) ₂ ⁻	2×10^{20}	FeSCN ²⁺	9.2×10^2	PtCl ₄ ²⁻	1×10^{16}
AgI ₂ ⁻	5×10^{10}	Fe(CN) ₆ ³⁻	4×10^{52}	Pt(CN) ₄ ²⁻	1×10^{41}
Ag(NH ₃) ₂ ⁺	1.7×10^7	Fe(CN) ₆ ⁴⁻	4×10^{45}	<i>c</i> -Pt(NH ₃) ₂ Cl ₂	3×10^{29}
Al(OH) ₄ ⁻	1×10^{33}	HgBr ₄ ²⁻	1×10^{21}	<i>t</i> -Pt(NH ₃) ₂ Cl ₂	3×10^{28}
Cd(CN) ₄ ²⁻	2×10^{18}	HgCl ₄ ²⁻	1×10^{15}	<i>c</i> -Pt(NH ₃) ₂ (H ₂ O) ₂ ²⁺	4×10^{23}
CdI ₄ ²⁻	4.0×10^5	Hg(CN) ₄ ²⁻	2×10^{41}	<i>c</i> -Pt(NH ₃) ₂ I ₂	2×10^{33}
Cd(NH ₃) ₄ ²⁺	2.8×10^7	HgI ₄ ²⁻	1×10^{30}	<i>t</i> -Pt(NH ₃) ₂ I ₂	5×10^{32}
Cd(OH) ₄ ²⁻	1.2×10^9	Hg(NH ₃) ₄ ²⁺	2×10^{19}	<i>c</i> -Pt(NH ₃) ₂ (OH) ₂	1×10^{39}
Co(NH ₃) ₆ ²⁺	1×10^5	Ni(CN) ₄ ²⁻	1×10^{30}	Pt(NH ₃) ₄ ²⁺	2×10^{35}
Co(NH ₃) ₆ ³⁺	1×10^{23}	Ni(NH ₃) ₆ ²⁺	9×10^8	Zn(CN) ₄ ²⁻	6×10^{16}
Co(NH ₃) ₅ Cl ²⁺	2×10^{28}	PbI ₄ ²⁻	1.7×10^4	Zn(NH ₃) ₄ ²⁺	3.6×10^8
Co(NH ₃) ₅ NO ₂ ²⁺	1×10^{24}	Pb(OH) ₃ ⁻	8×10^{13}	Zn(OH) ₄ ²⁻	3×10^{14}

Solubility Product Constants (K_{sp})

AgBr	5×10^{-13}	Co(OH) ₂	2×10^{-16}	NiCO ₃	1.4×10^{-7}
AgC ₂ H ₃ O ₂	1.9×10^{-3}	Co ₃ (PO ₄) ₂	1×10^{-35}	Ni ₃ (PO ₄) ₂	1×10^{-32}
Ag ₂ CO ₃	8×10^{-12}	CuCl	1.7×10^{-7}	NiS	1×10^{-21}
AgCl	1.8×10^{-10}	CuBr	6.3×10^{-9}	PbBr ₂	6.6×10^{-6}
Ag ₂ CrO ₄	1×10^{-12}	CuI	1.2×10^{-12}	PbCO ₃	1×10^{-13}
AgI	1×10^{-16}	Cu ₃ (PO ₄) ₂	1×10^{-37}	PbCl ₂	1.7×10^{-5}
Ag ₃ PO ₄	1×10^{-16}	CuS	1×10^{-36}	PbCrO ₄	2×10^{-14}
Ag ₂ S	1×10^{-49}	Cu ₂ S	1×10^{-48}	PbF ₂	7.1×10^{-7}
AgSCN	1.0×10^{-12}	FeCO ₃	3.1×10^{-11}	PbI ₂	8.4×10^{-9}
AlF ₃	1×10^{-18}	Fe(OH) ₂	5×10^{-17}	Pb(OH) ₂	1×10^{-20}
Al(OH) ₃	2×10^{-31}	Fe(OH) ₃	3×10^{-39}	PbS	1×10^{-28}
AlPO ₄	1×10^{-20}	FeS	2×10^{-19}	Pb(SCN) ₂	2.1×10^{-5}
BaCO ₃	2.6×10^{-9}	GaF ₃	2×10^{-16}	PbSO ₄	1.8×10^{-8}
BaCrO ₄	1.2×10^{-10}	Ga(OH) ₃	1×10^{-35}	Sc(OH) ₃	2×10^{-31}
BaF ₂	1.8×10^{-7}	GaPO ₄	1×10^{-21}	SnS	3×10^{-28}
BaSO ₄	1.1×10^{-10}	Hg ₂ Br ₂	6×10^{-23}	SrCO ₃	5.6×10^{-10}
Bi ₂ S ₃	1×10^{-99}	Hg ₂ Cl ₂	1×10^{-18}	SrCrO ₄	3.6×10^{-5}
CaCO ₃	4.9×10^{-9}	Hg ₂ I ₂	5×10^{-29}	SrF ₂	4.3×10^{-9}
CaF ₂	1.5×10^{-10}	HgS	1×10^{-52}	SrSO ₄	3.4×10^{-7}
Ca(OH) ₂	4.0×10^{-6}	Li ₂ CO ₃	8.2×10^{-4}	TlCl	1.9×10^{-4}
Ca ₃ (PO ₄) ₂	2.5×10^{-33}	MgCO ₃	6.8×10^{-6}	TlBr	3.7×10^{-6}
CaSO ₄	7.1×10^{-5}	MgF ₂	7×10^{-11}	TlI	5.6×10^{-8}
CdCO ₃	6×10^{-12}	Mg(OH) ₂	6×10^{-12}	Tl(OH) ₃	2×10^{-44}
Cd(OH) ₂	5×10^{-15}	Mg ₃ (PO ₄) ₂	1×10^{-24}	Tl ₂ S	1×10^{-20}
Cd ₃ (PO ₄) ₂	1×10^{-33}	Mn(OH) ₂	2×10^{-13}	ZnCO ₃	1.1×10^{-10}
CdS	1×10^{-29}	MnS	5×10^{-14}	Zn(OH) ₂	4×10^{-17}

Properties of the Elements

Appendix 2

Element	At. No.	mp (°C)	bp (°C)	E.N.	Ion. Ener. (kJ/mol)	At. Rad. (nm)	Ion. Rad. (nm)
H	1	-259	-253	2.2	1312	0.037	(-1)0.208
He	2	-272	-269		2372	0.05	
Li	3	186	1326	1.0	520	0.152	(+1)0.060
Be	4	1283	2970	1.6	900	0.111	(+2)0.031
B	5	2300	2550	2.0	801	0.088	
C	6	3570	subl.	2.5	1086	0.077	
N	7	-210	-196	3.0	1402	0.070	
O	8	-218	-183	3.5	1314	0.066	(-2)0.140
F	9	-220	-188	4.0	1681	0.064	(-1)0.136
Ne	10	-249	-246		2081	0.070	
Na	11	98	889	0.9	496	0.186	(+1)0.095
Mg	12	650	1120	1.3	738	0.160	(+2)0.065
Al	13	660	2327	1.6	578	0.143	(+3)0.050
Si	14	1414	2355	1.9	786	0.117	
P	15	44	280	2.2	1012	0.110	
S	16	119	444	2.6	1000	0.104	(-2)0.184
Cl	17	-101	-34	3.2	1251	0.099	(-1)0.181
Ar	18	-189	-186		1520	0.094	
K	19	64	774	0.8	419	0.231	(+1)0.133
Ca	20	845	1420	1.0	590	0.197	(+2)0.099
Sc	21	1541	2831	1.4	631	0.160	(+3)0.081
Ti	22	1660	3287	1.5	658	0.146	
V	23	1890	3380	1.6	650	0.131	
Cr	24	1857	2672	1.6	653	0.125	(+3)0.064
Mn	25	1244	1962	1.5	717	0.129	(+2)0.080
Fe	26	1535	2750	1.8	759	0.126	(+2)0.075
Co	27	1495	2870	1.9	758	0.125	(+2)0.072
Ni	28	1453	2732	1.9	737	0.124	(+2)0.069
Cu	29	1083	2567	1.9	746	0.128	(+1)0.096
Zn	30	420	907	1.6	906	0.133	(+2)0.074
Ga	31	30	2403	1.6	579	0.122	(+3)0.062
Ge	32	937	2830	2.0	762	0.122	
As	33	814	subl.	2.2	944	0.121	
Se	34	217	685	2.5	941	0.117	(-2)0.198
Br	35	-7	59	3.0	1140	0.114	(-1)0.195
Kr	36	-157	-152	3.3	1351	0.109	
Rb	37	39	688	0.8	403	0.244	(+1)0.148
Sr	38	770	1380	0.9	550	0.215	(+2)0.113
Y	39	1509	2930	1.2	616	0.180	(+3)0.093
Zr	40	1852	3580	1.4	660	0.157	
Nb	41	2468	5127	1.6	664	0.143	
Mo	42	2610	5560	1.8	685	0.136	
Tc	43	2200	4700	1.9	702	0.136	
Ru	44	2430	3700	2.2	711	0.133	
Rh	45	1966	3700	2.2	720	0.134	

continued

continued

Element	At. No.	mp (°C)	bp (°C)	E.N.	Ion. Ener. (kJ/mol)	At. Rad. (nm)	Ion. Rad. (nm)
Pd	46	1550	3170	2.2	805	0.138	
Ag	47	961	2210	1.9	731	0.144	(+1)0.126
Cd	48	321	767	1.7	868	0.149	(+2)0.097
In	49	157	2000	1.7	558	0.162	(+3)0.081
Sn	50	232	2270	1.9	709	0.140	
Sb	51	631	1380	2.0	832	0.141	
Te	52	450	990	2.1	869	0.137	(−2)0.221
I	53	114	184	2.7	1009	0.133	(−1)0.216
Xe	54	−112	−107	3.0	1170	0.130	
Cs	55	28	690	0.8	376	0.262	(+1)0.169
Ba	56	725	1640	0.9	503	0.217	(+2)0.135
La	57	920	3469	1.1	538	0.187	(+3)0.115
Ce	58	795	3468	1.1	528	0.182	(+3)0.101
Pr	59	935	3127	1.1	523	0.182	(+3)0.100
Nd	60	1024	3027	1.1	530	0.182	(+3)0.099
Pm	61	1027	2727	1.1	536	0.181	
Sm	62	1072	1900	1.1	543	0.180	
Eu	63	826	1439	1.1	547	0.204	(+2)0.097
Gd	64	1312	3000	1.1	592	0.179	(+3)0.096
Tb	65	1356	2800	1.1	564	0.177	(+3)0.095
Dy	66	1407	2600	1.1	572	0.177	(+3)0.094
Ho	67	1461	2600	1.1	581	0.176	(+3)0.093
Er	68	1497	2900	1.1	589	0.175	(+3)0.092
Tm	69	1356	2800	1.1	597	0.174	(+3)0.091
Yb	70	824	1427	1.1	603	0.193	(+3)0.089
Lu	71	1652	3327	1.1	524	0.174	(+3)0.089
Hf	72	2225	5200	1.3	654	0.157	
Ta	73	2980	5425	1.5	761	0.143	
W	74	3410	5930	1.7	770	0.137	
Re	75	3180	5885	1.9	760	0.137	
Os	76	2727	4100	2.2	840	0.134	
Ir	77	2448	4500	2.2	880	0.135	
Pt	78	1769	4530	2.2	870	0.138	
Au	79	1063	2966	2.4	890	0.144	(+1)0.137
Hg	80	−39	357	1.9	1007	0.155	(+2)0.110
Tl	81	304	1457	1.8	589	0.171	(+3)0.095
Pb	82	328	1750	1.9	716	0.175	
Bi	83	271	1560	1.9	703	0.146	
Po	84	254	962	2.0	812	0.165	
At	85	302	334	2.2			
Rn	86	−71	−62		1037	0.14	
Fr	87	27	677	0.7			
Ra	88	700	1140	0.9	509	0.220	
Ac	89	1050	3200	1.1	490	0.20	
Th	90	1750	4790	1.3	590	0.180	
Pa	91	1600	4200	1.4	570		
U	92	1132	3818	1.4	590	0.14	

Exponential Notation on the Calculator

On all scientific calculators it is possible to enter numbers in exponential notation. The method used depends on the brand of calculator. Most often, it involves using a key labeled **EXP**, **EE**, or **EEX**. Check your instruction manual for the procedure to be followed. To make sure you understand it, try entering the following numbers:

$$2.4 \times 10^6 \quad 3.16 \times 10^{-8} \quad 6.2 \times 10^{-16}$$

Multiplication, division, addition, and subtraction can be carried out directly on your calculator. Try the following exercises:

(a) $(6.0 \times 10^2) \times (4.2 \times 10^{-4}) = ?$

(b) $\frac{6.0 \times 10^2}{4.2 \times 10^{-4}} = ?$

(c) $3.6 \times 10^{-4} + 4 \times 10^{-5} = ?$

(d) $3.6 \times 10^{-4} - 4 \times 10^{-5} = ?$

The answers, expressed in exponential notation and following the rules of significant figures, are (a) 2.5×10^{-1} (b) 1.4×10^6 (c) 4.0×10^{-4} (d) 3.2×10^{-4} .

Exponential (or ordinary) numbers are readily raised to powers using a calculator. To square a number, use the x^2 key. For example,

$$(3 \times 10^4)^2 = 9 \times 10^8$$

For other powers, use the y^x key. To cube a number, y , enter that number, press the y^x key, enter 3, and read the answer. That way, you should find that

$$(2 \times 10^{-5})^3 = 8 \times 10^{-15}$$

Roots of exponentials are obtained in a similar way. To extract a square root, use the $\sqrt{x}$ key. For other roots, use the y^x key. To obtain a cube root, enter the number, press the y^x key, enter 1/3 (0.33333333) and read the answer:

$$(2.0 \times 10^{-5})^{1/3} = 2.7 \times 10^{-2}$$

(Many calculators have a $\sqrt[x]{y}$ key, in which case, enter $x = 3$ rather than 1/3.)

Try the following operations on your calculator.

$$(3.12)^5 = ? \quad \text{answer: } 2.96 \times 10^2$$

$$(3.12 \times 10^{-2})^5 = ? \quad \text{answer: } 2.96 \times 10^{-8}$$

$$(3.12)^{1/5} = ? \quad \text{answer: } 1.26$$

$$(3.12 \times 10^{-2})^{1/5} = ? \quad \text{answer: } 0.500$$

Logarithms and Inverse Logarithms

The logarithm of a number n to the base m is defined as the power to which m must be raised to give the number n . Thus

$$\text{if } m^x = n, \text{ then } \log_m n = x$$

In other words, a *logarithm* is an *exponent*, which may be a whole number (e.g., 1, -1) but more often is not (e.g., 1.500, -0.301).

In general chemistry, you will encounter two kinds of logarithms.

1. *Common logarithms*, where the base is 10, ordinarily denoted as $\log_{10}$. If $10^x = n$, then $\log_{10} n = x$. Examples include the following:

$$\log_{10} 100 = 2.00 \quad (10^2 = 100)$$

$$\log_{10} 1 = 0.000 \quad (10^0 = 1)$$

$$\log_{10} 0.001 = -3.000 \quad (10^{-3} = 0.001)$$

2. *Natural logarithms*, where the base is the quantity $e = 2.718$ Many of the equations used in general chemistry are expressed most simply in terms of natural logarithms, denoted as $\ln$. If $e^x = n$, then $\ln n = x$.

$$\begin{aligned}\ln 100 &= 4.605 && (\text{i.e., } 100 = e^{4.605}) \\ \ln 1 &= 0 && (\text{i.e., } 1 = e^0) \\ \ln 0.001 &= -6.908 && (\text{i.e., } 0.001 = e^{-6.908})\end{aligned}$$

Notice that

(a) $\log_{10} 1 = \ln 1 = 0$. The logarithm of 1 to any base is zero, because any number raised to the zero power is 1. That is

$$10^0 = e^0 = 2^0 = \cdots = n^0 = 1$$

(b) Numbers larger than 1 have a positive logarithm; numbers smaller than 1 have a negative logarithm. For example,

$$\begin{aligned}\log_{10} 100 &= 2 && \ln 100 = 4.605 \\ \log_{10} 10 &= 1 && \ln 10 = 2.303 \\ \log_{10} 0.1 &= -1 && \ln 0.1 = -2.303 \\ \log_{10} 0.01 &= -2 && \ln 0.01 = -4.605\end{aligned}$$

(c) The common and natural logarithms of a number are related by the expression

$$\ln n = 2.303 \log_{10} n$$

That is, the natural logarithm of a number is 2.303 . . . times its base-10 logarithm.

(d) Finally, if $x \leq 0$, both $\log x$ and $\ln x$ are undefined.

An *inverse logarithm* (antilogarithm) is the number corresponding to a given logarithm. In general,

$$\text{if } m^x = n, \text{ then inverse } \log_m x = n$$

For example,

$$\begin{aligned}10^2 &= 100 && \text{inverse } \log_{10} 2 = 100 \\ 10^{-3} &= 0.001 && \text{inverse } \log_{10} (-3) = 0.001\end{aligned}$$

In other words, the numbers whose base-10 logarithms are 2 and -3 are 100 and 0.001, respectively. The same reasoning applies to natural logarithms.

$$\begin{aligned}e^{4.606} &= 100 && \text{inverse } \ln 4.606 = 100 \\ e^{-6.908} &= 0.001 && \text{inverse } \ln -6.908 = 0.001\end{aligned}$$

The numbers whose natural logarithms are 4.606 and -6.908 are 100 and 0.001, respectively. Notice that if the inverse logarithm is positive, the corresponding number is larger than 1; if it is negative, the number is smaller than 1.

Finding Logarithms and Inverse Logarithms on a Calculator

To obtain a base-10 logarithm using a calculator, all you need to do is enter the number and press the **LOG** key. This way you should find that

$$\begin{aligned}\log_{10} 2.00 &= 0.301 \dots \\ \log_{10} 0.526 &= -0.279 \dots\end{aligned}$$

Similarly, to find a natural logarithm, you enter the number and press the **LN** key.

$$\begin{aligned}\ln 2.00 &= 0.693 \dots \\ \ln 0.526 &= -0.642 \dots\end{aligned}$$

To find the logarithm of an exponential number, you enter the number in exponential form and take the logarithm in the usual way. This way you should find that

$$\begin{aligned}\log_{10} 2.00 \times 10^3 &= 3.301 \dots & \ln 2.00 \times 10^3 &= 7.601 \dots \\ \log_{10} 5.3 \times 10^{-12} &= -11.28 \dots & \ln 5.3 \times 10^{-12} &= -25.96 \dots\end{aligned}$$

The base-10 logarithm of an exponential number can be found in a somewhat different way by applying the relation

$$\log_{10} (C \times 10^n) = n + \log_{10} C$$

Thus

$$\begin{aligned}\log_{10} 2.00 \times 10^3 &= 3 + \log_{10} 2.00 = 3 + 0.301 = 3.301 \\ \log_{10} 5.3 \times 10^{-12} &= -12 + \log_{10} 5.3 = -12 + 0.72 = -11.28\end{aligned}$$

The method used to find inverse logarithms depends on the type of calculator. On certain calculators, you enter the number and then press, in succession, the **INV** and either **LOG** or **LN X** keys. With other calculators, you press the **10^x** or **e^x** key. Either way, you should find that

$$\begin{aligned}\text{inverse } \log_{10} 1.632 &= 42.8 \dots & \text{inverse } \ln 1.632 &= 5.11 \dots \\ \text{inverse } \log_{10} -8.82 &= 1.5 \times 10^{-9} & \text{inverse } \ln -8.82 &= 1.5 \times 10^{-4}\end{aligned}$$

Significant Figures in Logarithms and Inverse Logarithms

For base-10 logarithms, the rules governing significant figures are as follows:

1. *In taking the logarithm of a number, retain after the decimal point in the log as many digits as there are significant figures in the number.* (This part of the logarithm is often referred to as the *mantissa*; digits that precede the decimal point comprise the *characteristic* of the logarithm.) To illustrate this rule, consider the following:

$$\begin{aligned}\log_{10} 2.00 &= 0.301 & \log_{10} (2.00 \times 10^3) &= 3.301 \\ \log_{10} 2.0 &= 0.30 & \log_{10} (2.0 \times 10^1) &= 1.30 \\ \log_{10} 2 &= 0.3 & \log_{10} (2 \times 10^{-3}) &= 0.3 - 3 = -2.7\end{aligned}$$

2. *In taking the inverse logarithm of a number, retain as many significant figures as there are after the decimal point in the number.* Thus

$$\begin{aligned}\text{inverse } \log_{10} 0.301 &= 2.00 & \text{inverse } \log_{10} 3.301 &= 2.00 \times 10^3 \\ \text{inverse } \log_{10} 0.30 &= 2.0 & \text{inverse } \log_{10} 1.30 &= 2.0 \times 10^1 \\ \text{inverse } \log_{10} 0.3 &= 2 & \text{inverse } \log_{10} (-2.7) &= 2 \times 10^{-3}\end{aligned}$$

These rules take into account the fact that, as mentioned earlier,

$$\log_{10} (C \times 10^n) = n + \log_{10} C$$

The digits that appear before (to the left of) the decimal point specify the value of n , that is, the power of 10 involved in the expression. In that sense, they are not experimentally significant. In contrast, the digits that appear after (to the right of) the decimal point specify the value of the logarithm of C ; the number of such digits reflects the uncertainty in C . Thus

$$\begin{aligned}\log_{10} 209 &= 2.320 & (3 \text{ sig. fig.}) \\ \log_{10} 209.0 &= 2.3201 & (4 \text{ sig. fig.})\end{aligned}$$

The rules for significant figures involving natural logarithms and inverse logarithms are somewhat more complex than those for base-10 logs. However, for simplicity we will assume that the rules listed above apply here as well. Thus

$$\begin{aligned}\ln 209 &= 5.342 & (3 \text{ sig. fig.}) \\ \ln 209.0 &= 5.3423 & (4 \text{ sig. fig.})\end{aligned}$$

Operations Involving Logarithms

Because logarithms are exponents, the rules governing the use of exponents apply as well. The rules that follow are valid for all types of logarithms, regardless of the base. We illustrate the rules with natural logarithms; that is where you are most likely to use them in working with this text.

Multiplication: $\ln(xy) = \ln x + \ln y$

$$\text{Example: } \ln(2.50 \times 1.25) = \ln 2.50 + \ln 1.25 = 0.916 + 0.223 = 1.139$$

Division: $\ln(x/y) = \ln x - \ln y$

$$\text{Example: } \ln(2.50/1.25) = 0.916 - 0.223 = 0.693$$

Raising to a Power: $\ln(x^n) = n \ln x$

$$\text{Example: } \ln(2.00)^4 = 4 \ln 2.00 = 4(0.693) = 2.772$$

Extracting a Root: $\ln(x^{1/n}) = \frac{1}{n} \ln x$

$$\text{Example: } \ln(2.00)^{1/3} = \frac{\ln 2.00}{3} = \frac{0.693}{3} = 0.231$$

Taking a Reciprocal: $\ln(1/x) = -\ln x$

$$\text{Example: } \ln(1/2.00) = -\ln 2.00 = -0.693$$

In Chapter 7, we used valence bond theory to explain bonding in molecules. It accounts, at least qualitatively, for the stability of the covalent bond in terms of the overlap of atomic orbitals. By invoking hybridization, valence bond theory can account for the molecular geometries predicted by electron-pair repulsion. Where Lewis structures are inadequate, as in SO_2 , the concept of resonance allows us to explain the observed properties.

A major weakness of valence bond theory has been its inability to predict the magnetic properties of molecules. We mentioned this problem in Chapter 7 with regard to the O_2 molecule, which is paramagnetic, even though it has an even number (12) of valence electrons. The octet rule, or valence bond theory, would predict that all the electrons in O_2 should be paired, which would make it diamagnetic.

This discrepancy between experiment and theory (and many others) can be explained in terms of an alternative model of covalent bonding, the molecular orbital (MO) approach. Molecular orbital theory treats bonds in terms of orbitals characteristic of the molecule as a whole. To apply this approach, we carry out three basic operations.

1. The atomic orbitals of atoms are combined to give a new set of molecular orbitals characteristic of the molecule as a whole. *The number of molecular orbitals formed is equal to the number of atomic orbitals combined.* When two H atoms combine to form H_2 , two s orbitals, one from each atom, yield two molecular orbitals. In another case, six p orbitals, three from each atom, give a total of six molecular orbitals.

2. The molecular orbitals are arranged in order of increasing energy. The relative energies of these orbitals are ordinarily deduced from experiment. Spectra and magnetic properties of molecules are used.

3. The *valence electrons* in a molecule are distributed among the available molecular orbitals. The process followed is much like that used with electrons in atoms. In particular, we find the following:

- (a) *Each molecular orbital can hold a maximum of two electrons.* When an orbital is filled the two electrons have opposed spins, in accordance with the Pauli principle (Chapter 7).

- (b) *Electrons go into the lowest energy molecular orbital available.* A higher orbital starts to fill only when each orbital below it has its quota of two electrons.

- (c) *Hund's rule is obeyed.* When two orbitals of equal energy are available to two electrons, one electron goes into each, giving two half-filled orbitals.

Diatomic Molecules of the Elements

To illustrate molecular orbital theory, we apply it to the diatomic molecules of the elements in the first two periods of the periodic table.

Hydrogen and Helium (Combination of 1s Orbitals)

Molecular orbital (MO) theory predicts that two 1s orbitals will combine to give two molecular orbitals. One of these has an energy lower than that of the atomic orbitals from which it is formed (Figure 1). Placing electrons in this orbital gives a species that is more stable than the isolated atoms. For that reason the lower molecular orbital in Figure 1 is called a *bonding orbital*. The other molecular orbital has a higher energy than the corresponding atomic orbitals. Electrons entering it are in an unstable, higher energy state. It is referred to as an *antibonding orbital*.

The electron density in these molecular orbitals is shown at the right of Figure 1. Notice that the bonding orbital has a higher density between the nuclei. This accounts for its stability. In the antibonding orbital, the chance of finding the electron between the nuclei is very small. The electron density is concentrated at the far ends of the “molecule.” This means that the nuclei are less shielded from each other than they are in the isolated atoms.

The electron density in both molecular orbitals is symmetrical about the axis between the two nuclei. This means that both of these are sigma orbitals. In MO

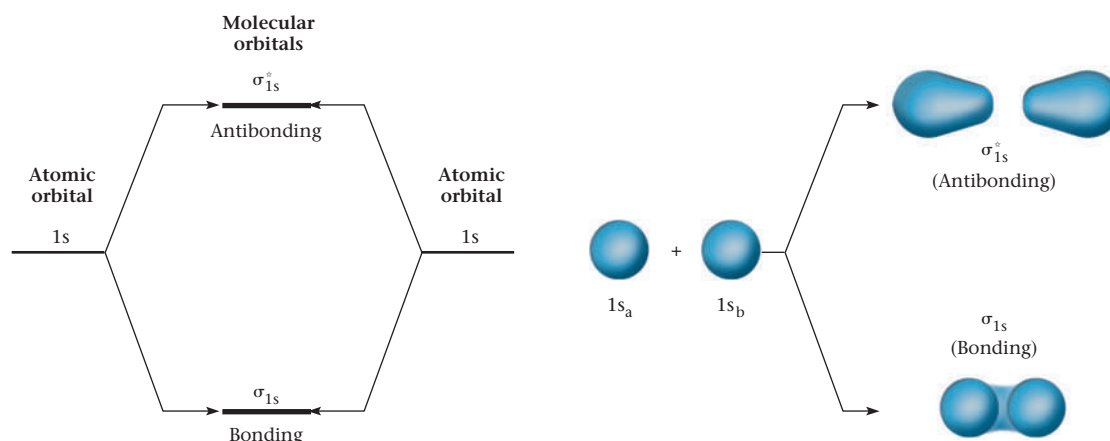


Figure 1 Molecular orbital formation. Two molecular orbitals are formed by combining two 1s atomic orbitals.

notation, the 1s bonding orbital is designated as σ_{1s} . The antibonding orbital is given the symbol σ_{1s}^* . An asterisk designates an antibonding orbital.

In the H_2 molecule, there are two 1s electrons. They fill the σ_{1s} orbital, giving a single bond. In the He_2 molecule, there would be four electrons, two from each atom. These would fill the bonding and antibonding orbitals. As a result, the number of bonds (the *bond order*) in He_2 is zero. The general relation is

$$\text{no. of bonds} = \text{bond order} = \frac{B - AB}{2}$$

where B is the number of electrons in bonding orbitals and AB is the number of electrons in antibonding orbitals. In H_2 , $B = 2$ and $AB = 0$, so we have one bond. In He_2 , $B = AB = 2$, so the number of bonds is zero. The He_2 molecule should not and does not exist.

Second Period Elements (Combination of 2s and 2p Orbitals)

Among the diatomic molecules of the second period elements are three familiar ones, N_2 , O_2 , and F_2 . The molecules Li_2 , B_2 , and C_2 are less common but have been observed and studied in the gas phase. In contrast, the molecules Be_2 and Ne_2 are either highly unstable or nonexistent. Let us see what molecular orbital theory predicts about the structure and stability of these molecules. We start by considering how the atomic orbitals containing the valence electrons (2s and 2p) are used to form molecular orbitals.

Combining two 2s atomic orbitals, one from each atom, gives two molecular orbitals. These are very similar to the ones shown above. They are designated as σ_{2s} (sigma, bonding, 2s) and σ_{2s}^* (sigma, antibonding, 2s).

Consider now what happens to the 2p orbitals. In an isolated atom, there are three such orbitals, oriented at right angles to each other. We call these atomic orbitals, p_x , p_y , and p_z (top of Figure 2). When two p_x atomic orbitals, one from each atom, overlap head-to-head, they form two sigma orbitals. These are a bonding orbital, σ_{2p} , and an antibonding orbital, σ_{2p}^* . The situation is quite different when the p_z orbitals overlap. Because they are oriented parallel to one another, they overlap side-to-side (Figure 2c). The two molecular orbitals formed in this case are pi orbitals; one is a bonding orbital, π_{2p} , the other a nonbonding orbital, π_{2p}^* . In an entirely similar way, the p_y orbitals of the two atoms interact to form another pair of pi molecular orbitals, π_{2p} and π_{2p}^* (these orbitals are not shown in Figure 2).

The relative energies of the molecular orbitals available for occupancy by the valence electrons of the second period elements are shown in Figure 3. This order applies at least through N_2 .*

*It appears that beyond N_2 the σ_{2p} orbital lies below the two π_{2p} orbitals. This does not affect the filling order, because in O_2 all of these orbitals are filled.

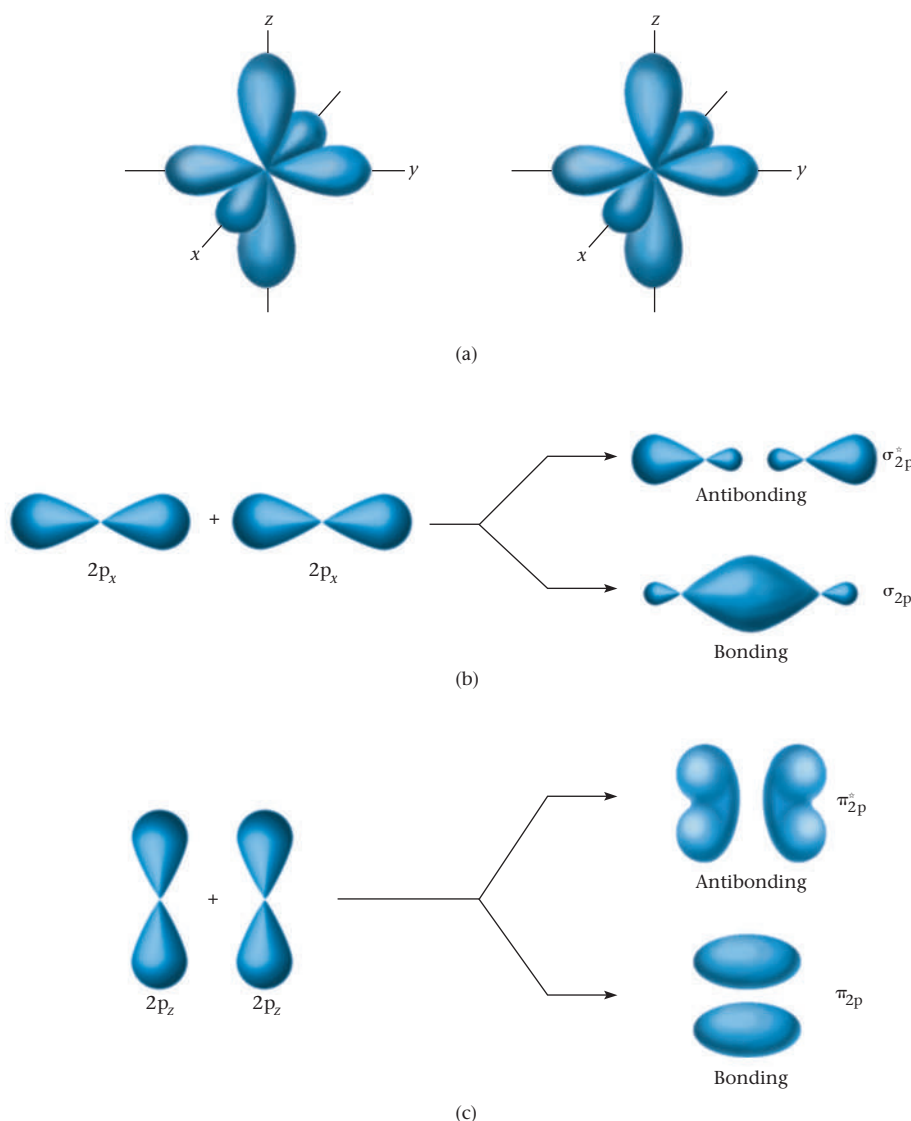


Figure 2 When p orbitals from two different atoms (a) overlap, there are two quite different possibilities. If they overlap head-to-head (b), two sigma molecular orbitals are produced. If, on the other hand, they overlap side-to-side (c), two pi molecular orbitals result.

To obtain the MO structure of the diatomic molecules of the elements in the second period, we fill the available molecular orbitals in order of increasing energy. The results are shown in Table 1. Note the agreement between MO theory and the properties of these molecules. In particular, the number of unpaired electrons predicted agrees with experiment. There is also a general correlation between the predicted bond order:

$$\text{bond order} = \frac{B - AB}{2}$$

and the bond energy. We would expect a double bond (C_2 or O_2) to be stronger than a single bond (Li_2 , B_2 , and F_2). A triple bond, as in N_2 , should be still stronger.

A major triumph of MO theory is its ability to explain the properties of O_2 . It explains how the molecule can have a double bond and, at the same time, have two unpaired electrons.

For example, using MO theory we can predict the electronic structure, bond order, and number of unpaired electrons in the peroxide ion.

Recalling that oxygen is in Group 16 of the periodic table, the number of valence electrons is 14 ($2 \times 6 + 2$), and the orbital diagram is

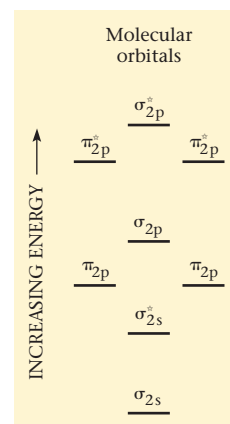
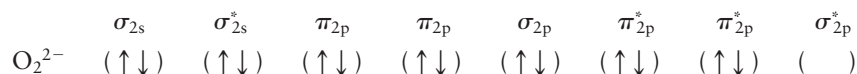


Figure 3 Relative energies, so far as filling order is concerned, for the molecular orbitals formed by combining 2s and 2p atomic orbitals.

Table 1 Predicted and Observed Properties of Diatomic Molecules of Second Period Elements

	Occupancy of Orbitals							
	σ_{2s}	σ_{2s}^*	π_{2p}	π_{2p}^*	σ_{2p}	π_{2p}^*	π_{2p}^*	σ_{2p}^*
Li ₂	(↑↓)	()	()	()	()	()	()	()
Be ₂	(↑↓)	(↑↓)	()	()	()	()	()	()
B ₂	(↑↓)	(↑↓)	(↑)	(↑)	()	()	()	()
C ₂	(↑↓)	(↑↓)	(↑↓)	(↑↓)	()	()	()	()
N ₂	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)	()	()	()
O ₂	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑)	(↑)	()
F ₂	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)	()
Ne ₂	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)

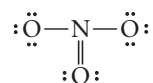
	Predicted Properties		Observed Properties	
	Number of Unpaired e ⁻	Bond Order	Number of Unpaired e ⁻	Bond Energy (kJ/mol)
Li ₂	0	1	0	105
Be ₂	0	0	0	Unstable
B ₂	2	1	2	289
C ₂	0	2	0	628
N ₂	0	3	0	941
O ₂	2	2	2	494
F ₂	0	1	0	153
Ne ₂	0	0	0	Nonexistent

Thus there are eight electrons in bonding orbitals, six in antibonding orbitals. The bond order is $\frac{8-6}{2} = 1$. There are no unpaired electrons. These conclusions are in agreement with the Lewis structure of the peroxide ion: $(:\ddot{\text{O}}-\ddot{\text{O}}:)^{2-}$.

Polyatomic Molecules; Delocalized π Electrons

The bonding in molecules containing more than two atoms can also be described in terms of molecular orbitals. We will not attempt to do this; the energy level structure is considerably more complex than the one we considered. However, one point is worth mentioning. In polyatomic species, *a pi molecular orbital can be spread over the entire molecule* rather than being concentrated between two atoms.

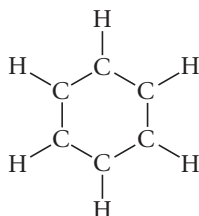
This principle can be applied to species such as the nitrate ion, whose Lewis structure is



Valence bond theory (Chapter 7) explains the fact that the three N—O bonds are identical by invoking the idea of resonance, with three contributing structures. MO theory,

on the other hand, considers that the skeleton of the nitrate ion is established by the three sigma bonds while the electron pair in the pi orbital is *delocalized*, shared by all of the atoms in the molecule. According to MO theory, a similar interpretation applies with all of the “resonance hybrids” described in Chapter 7, including SO_2 , SO_3 , and CO_3^{2-} .

Another species in which delocalized pi orbitals play an important role is benzene, C_6H_6 . There are 30 valence electrons in the molecule, 24 of which are required to form the sigma bond framework:



The remaining six electrons are located in three π orbitals, which according to MO theory extend over the entire molecule. Figure 4 is one way of representing this structure; more commonly it is shown simply as

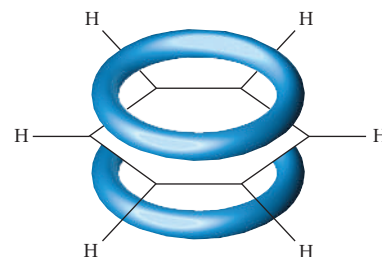


Figure 4 In benzene, three electron pairs are not localized on particular carbon atoms. Instead, they are spread out over two lobes of the shape shown, one above the plane of the benzene ring and the other below it.

Metals; Band Theory

In Chapter 9, we considered a simple picture of metallic bonding, the electron-sea model. The molecular orbital approach leads to a refinement of this model known as *band theory*. Here, a crystal of a metal is considered to be one huge molecule. Valence electrons of the metal are fed into delocalized molecular orbitals, formed in the usual way from atomic orbitals. A huge number of these MOs are grouped into an energy band; the energy separation between adjacent MOs is extremely small.

For purposes of illustration, consider a lithium crystal weighing one gram, which contains roughly 10^{23} atoms. Each Li atom has a half-filled 2s atomic orbital (elect. conf. $\text{Li} = 1s^2 2s^1$). When these atomic orbitals combine, they form an equal number, 10^{23} , of molecular orbitals. These orbitals are spread over an energy band covering about 100 kJ/mol. It follows that the spacing between adjacent MOs is of the order of

$$\frac{100 \text{ kJ/mol}}{10^{23}} = 10^{-21} \text{ kJ/mol}$$

Because each lithium atom has one valence electron and each molecular orbital can hold two electrons, it follows that the lower half of the valence band (shown in color in Figure 5) is filled with electrons. The upper half of the band is empty. Electrons near the top of the filled MOs can readily jump to empty MOs only an infinitesimal distance above them. This is what happens when an electrical field is applied to the crystal; the movement of electrons through delocalized MOs accounts for the electrical conductivity of lithium metal.

The situation in beryllium metal is more complex. We might expect all of the 2s molecular orbitals to be filled because beryllium has the electron configuration $1s^2 2s^2$. However, in a crystal of beryllium, the 2p MO band overlaps the 2s (Figure 5). This means that, once again, there are vacant MOs that differ only infinitesimally in energy from filled MOs below them. This is indeed the basic requirement for electron conductivity; it is characteristic of all metals, including lithium and beryllium.

Materials in which there is a substantial difference in energy between occupied and vacant MOs are poor electron conductors. Diamond, where the gap between the filled valence band and the empty conduction band is 500 kJ/mol, is an insulator. Silicon and germanium, where the gaps are 100 kJ/mol and 60 kJ/mol, respectively, are semiconductors.

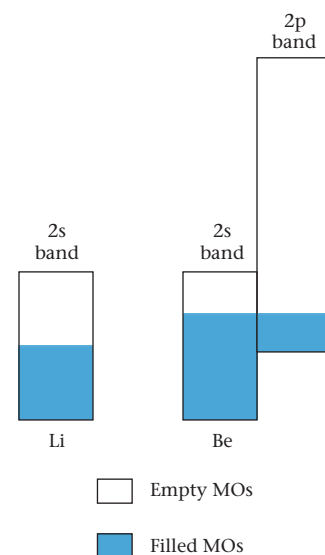


Figure 5 In both lithium and beryllium metal, there are vacant MOs only slightly higher in energy than filled MOs. This is the basic requirement for metallic conductivity.

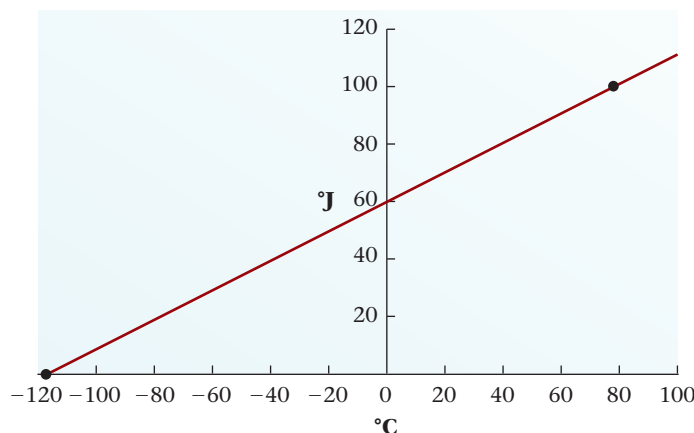
Answers to Even-Numbered and Challenge Questions and Problems

Appendix 5

Chapter 1

2. (a) element
(b) mixture
(c) compound
(d) mixture
4. (a) heterogeneous mixture
(b) heterogeneous mixture
(c) solution
6. (a) chromatography
(b) distillation or chromatography
8. (a) Cu (b) C (c) Br (d) Al
10. (a) manganese (b) gold (c) lead (d) silver
12. (a) yardstick (b) buret/pipet (c) thermometer
14. 177°C ; $4.50 \times 10^2 \text{ K}$
16. 35°C ; 95°F
18. (a) 3 (b) 4 (c) 4 (d) 1 (e) 5
20. (a) 17.25 cm (b) 169 lb
(c) $5.00 \times 10^2^{\circ}\text{C}$ (d) 198 oz
22. (a) $4.0206 \times 10^3 \text{ mL}$
(b) 1.006 g
(c) $1.001 \times 10^2^{\circ}\text{C}$
24. b and c
26. 5 is exact; 4000 is ambiguous; 17 has two and 18.5 has three
28. (a) 10.6 (b) 80.1 (c) 0.40 (d) 0.0923
(e) 1.4×10^{-25}
30. 0.04 m^3
32. (a) less than (b) greater than (c) equal
34. (a) 215.6 mL (b) 13.16 in^3 (c) 0.2278 qt
36. (a) 1.15078 mi (b) 1852 m (c) 25 mph
38. (a) USD 3.09 (b) USD 43 (c) $2.1 \times 10^2 \text{ mi}$
40. $1.85 \times 10^{-3} \text{ g/mL}$
42. $3.97 \times 10^{14} \text{ L}$
44. 393.8 mg
46. 1.07 g/mL
48. 1.6 g/mL
50. 508 m
52. $3.88 \times 10^4 \text{ g}$; 85.4 lb
54. supersaturated; 5 g
56. (a) homogeneous; 4.7 g more (b) 9.1 g
58. 479 rems; 1.6×10^3 mammograms
60. 320.0 g
62. $6.5 \times 10^{-4} \text{ in}$
64. 8.2 g/mL
66. (a) I (b) I (c) I (d) E (e) E
68. See pages 16–19
70. 3
72. (a) A (b) $\approx 23^{\circ}\text{C}$ (c) no; (see answer to (a))

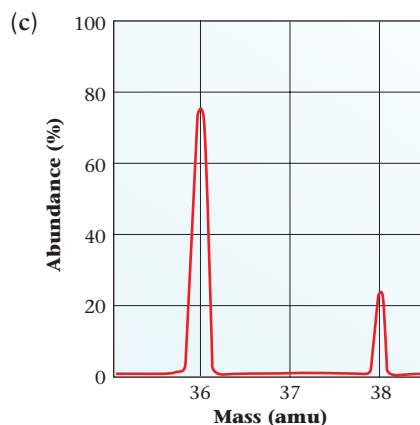
73. (a)



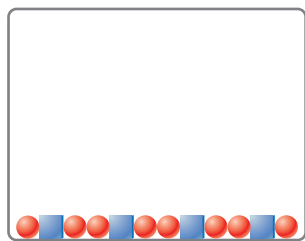
- (b) 0.51
- (c) 60
- (d) $^{\circ}\text{F} = 0.512(^{\circ}\text{C}) + 60$
74. $320^{\circ}\text{F} = 160^{\circ}\text{C}$
75. 1.2 km^2
76. 21.9 cm
77. $8.1 \times 10^{-3} \text{ g Pb}$
78. 6.87 g/cm^3

Chapter 2

2. See page 24
4. (a) none (b) conservation of mass
(c) none
6. Rutherford; see pages 25–26
8. (a) $86 p^+$ (b) $134 n$
10. (a) $^{54}_{26}\text{Fe}$; $^{56}_{26}\text{Fe}$
(b) They differ in the number of neutrons. Fe-54 has 28, whereas Fe-56 has 30.
12. (a) 95 (b) 241 (c) $^{241}_{95}\text{Am}$
14. (a) A is arsenic: $33p^+$, $42n$, $33e^-$
(b) L is vanadium: $23p^+$, $28n$, $23e^-$
(c) Z is xenon: $54p^+$, $77n$, $54e^-$
16. (a) isobars: Cr-54 and Fe-54; Fe-58 and Ni-58
isotopes: Fe-54 and Fe-58
(b) number of protons
(c) Cr-54 and Ni-58
18. (a) $<$ (c) $<$ (b) $<$ (d)
20. O-16
22. b
24. 20.2 amu
26. 64.94 amu; $^{65}_{29}\text{Cu}$
28. lightest isotope 78.6%; heaviest isotope 11.4%
30. (a) two: HCl-35 and HCl-37 (b) 36 and 38



32. 6×10^{13} atoms
 34. (a) 7.00×10^{20} atoms (b) 1.631×10^{-22} g
 36. (a) 8.400×10^3 neutrons (b) 3.535×10^{11} neutrons
 38. 8.96×10^{23} atoms
 40. (a) sulfur (b) scandium (c) selenium
 (d) silicon (e) strontium
 42. (a) nonmetal (b) transition metal (c) nonmetal
 (d) metalloid (e) metal
 44. (a) 5 (b) 3 (c) 2
 46. (a) 1 (b) 7 (c) 4
 48. (a) CH_3COOH , $\text{C}_2\text{H}_4\text{O}_2$ (b) CH_3Cl
 50. (a) $128p^+$, $128e^-$ (b) $48p^+$, $50e^-$
 (c) $18p^+$, $18e^-$ (d) $16p^+$, $18e^-$
 52. Al-27; metal
 Te-128; 5;
 nonmetal; 18; 5; 80
 C-14; 2
 54. (a) and (d)
 56. (a) SiS_2 (b) PH_3 (c) P_2O_5
 (d) RnF_4 (e) NCl_3
 58. (a) tellurium dichloride (b) tetraiodine nanoxide
 (c) xenon trioxide (d) tetrasulfur tetranitride
 60. (a) BaI_2 , Ba_3N_2 (b) FeO , Fe_2O_3
 62. (a) K_2HPO_4 (b) Mg_3N_2 (c) PbBr_4
 (d) ScCl_3 (e) $\text{Ba}(\text{C}_2\text{H}_3\text{O}_2)_2$
 64. (a) lead(II) acetate
 (b) aluminum hydroxide
 (c) strontium hydrogen carbonate
 (d) copper(II) phosphate
 (e) rubidium oxide
 66. (a) $\text{HNO}_3(aq)$ (b) K_2SO_4 (c) $\text{Fe}(\text{ClO}_4)_3$
 (d) $\text{Al}(\text{IO}_3)_3$ (e) $\text{H}_2\text{SO}_3(aq)$
 68. $\text{HBrO}_2(aq)$; cobalt(III) periodate; PtCl_4 ;
 nitrous acid; N_2O_3
 70. (a) Ge (b) W (c) Sr (d) Bi
 72. (a) $\text{C}_2\text{H}_7\text{N}$ (b) $\text{C}_2\text{H}_5\text{NH}_2$
 74. (a) always true (b) usually true (c) never true
 76. $9.64 \times 10^3 \text{ cm}^3$
 78. a
 80. only #4.
 82.

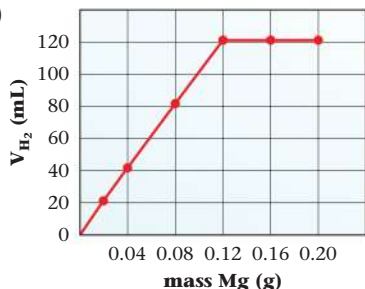


84. $^{234}_{90}\text{Th}$
 86. $^{126}_{52}\text{Te}^{2-}$
 88. c
 89. (a) Ratio of C in ethane to C in ethylene/g H is 3:2.
 (b) CH_3 , CH_2 ; C_2H_6 , C_2H_4
 90. 3.71 g/cm^3 ; lots of space between atoms
 91. $2.3443 \times 10^{-23} \text{ g}$
 92. (a) 2.5×10^{24} molecules (b) 2.3×10^{-20}
 (c) $\approx 2.9 \times 10^2$ molecules
 93. 8.2 L

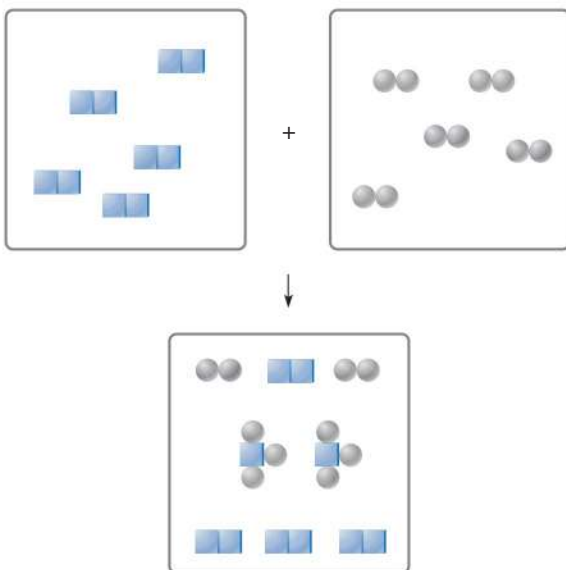
Chapter 3

2. (a) $5.93 \times 10^{17} \text{ g}$
 (b) $7.65 \times 10^{-22} \text{ mol}$
 4. (a) $18 e^-$ (b) 1.084×10^{25} (c) 2.411×10^{23}
 6. (a) 1.66 mol (b) 7.79×10^{25}
 8. (a) 190.2 (b) 84.01 (c) 396.63
 10. (a) 0.3226
 (b) 0.001824
 (c) 0.01110
 12. (a) 108 g (b) 537 g (c) 451 g
 14.
- | | Number of Grams | Number of Moles | Number of Molecules | Number of O Atoms |
|-----|-----------------|------------------------|------------------------|------------------------|
| (a) | 0.1364 g | 7.100×10^{-4} | 4.276×10^{20} | 2.993×10^{21} |
| (b) | 239.8 g | 1.248 | 7.515×10^{23} | 5.261×10^{24} |
| (c) | 13.8 g | 7.17×10^{-2} | 4.32×10^{22} | 3.02×10^{23} |
| (d) | 0.00253 g | 1.32×10^{-5} | 7.93×10^{18} | 5.55×10^{19} |
16. 0.70 M
 18. (a) $[\text{K}^+] = 0.757 \text{ M}$; $[\text{O}^{2-}] = 0.379 \text{ M}$
 (b) $[\text{Na}^+] = [\text{HCO}_3^-] = 0.425 \text{ M}$
 (c) $[\text{Sc}^{3+}] = 0.0684 \text{ M}$; $[\text{IO}_2^-] = 0.205 \text{ M}$
 (d) $[\text{Mg}^{2+}] = 0.407 \text{ M}$; $[\text{PO}_4^{3-}] = 0.272 \text{ M}$
 20. (a) Dissolve $2.50 \times 10^2 \text{ g}$ of $\text{Ni}(\text{NO}_3)_2$ in 2.00 L of solution
 (b) Dissolve 184 g of CuCl_2 in 2.00 L of solution
 (c) Dissolve 241 g of $\text{C}_6\text{H}_8\text{O}_6$ in 2.00 L of solution
 22. (a) 303.9 mL (b) $1.074 \times 10^2 \text{ mL}$
 24. 0.295 M
 26. 67.49% C; 4.602% H; 9.841% N; 5.619% O; 12.45% Cl
 28. 5.48 g
 30. 54.0%
 32. 38.40% C; 1.50% H; 52.3% Cl; 7.80% O
 34. molar mass = 1.50×10^2 ; R = vanadium
 36. Ni_2S_3 ; nickel(III) sulfide
 38. (a) $\text{C}_8\text{H}_{20}\text{Pb}$ (b) $\text{C}_6\text{H}_8\text{O}_7$ (c) $\text{N}_2\text{H}_6\text{Cl}_2\text{Pt}$
 40. $\text{C}_8\text{H}_8\text{O}_3$
 42. $\text{C}_7\text{H}_5\text{O}_3\text{SN}$
 44. Simplest formula: CH_4N Molecular formula: $\text{C}_2\text{H}_8\text{N}_2$
 46. (a) 47.24% (b) 8.366 g
 48. (a) $\text{C}_6\text{H}_{12}\text{O}_6(s) + 6\text{O}_2(g) \longrightarrow 6\text{CO}_2(g) + 6\text{H}_2\text{O}$
 (b) $\text{XeF}_4(g) + 2\text{H}_2\text{O}(l) \longrightarrow \text{Xe}(g) + \text{O}_2(g) + 4\text{HF}(g)$
 (c) $4\text{NaCl}(s) + 2\text{H}_2\text{O}(g) + 2\text{SO}_2(g) + \text{O}_2(g) \longrightarrow$
 $2\text{Na}_2\text{SO}_4(s) + 4\text{HCl}(g)$
 50. (a) $2\text{Sc}(s) + 3\text{S}(s) \longrightarrow \text{Sc}_2\text{S}_3(s)$
 (b) $2\text{Sc}(s) + 3\text{Cl}_2(g) \longrightarrow 2\text{ScCl}_3(s)$

- (c) $2\text{Sc}(s) + \text{N}_2(g) \longrightarrow 2\text{ScN}(s)$
 (d) $4\text{Sc}(s) + 3\text{O}_2(g) \longrightarrow 2\text{Sc}_2\text{O}_3(s)$
52. (a) $2\text{H}_2\text{S}(g) + \text{SO}_2(g) \longrightarrow 3\text{S}(s) + 2\text{H}_2\text{O}(g)$
 (b) $2\text{CH}_4(g) + 2\text{NH}_3(g) + 3\text{O}_2(g) \longrightarrow 2\text{HCN}(g) + 6\text{H}_2\text{O}(g)$
 (c) $\text{Fe}_2\text{O}_3(s) + 3\text{H}_2(g) \longrightarrow 2\text{Fe}(s) + 3\text{H}_2\text{O}(g)$
 (d) $\text{UO}_2(s) + 4\text{HF}(g) \longrightarrow \text{UF}_4(s) + 2\text{H}_2\text{O}(g)$
 (e) $\text{C}_2\text{H}_5\text{OH}(l) + 3\text{O}_2(g) \longrightarrow 2\text{CO}_2(g) + 3\text{H}_2\text{O}(l)$
54. (a) 3.131 (b) 3.264
 (c) 1.222 (d) 0.1816
56. (a) 882.2 g (b) 16.7 g
 (c) 2.368 g (d) 38.60 g
58. (a) $\text{SiO}_2(s) + 2\text{C}(s) \longrightarrow \text{Si}(s) + 2\text{CO}(g)$
 (b) 0.7120 mol
 (c) 197.0
60. (a) 98.4 g (b) 76 L
62. (a) 294 mL (b) 5.8×10^2 g
64. (a) 0.3166 mol (b) 68.60 g/mol
66. (a) $\text{Cl}_2(g) + 3\text{F}_2(g) \longrightarrow 2\text{ClF}_3(g)$
 (b) F_2 (c) 2.45 mol (d) 0.52 mol
68. 9.4×10^2 g
70. (a) $4\text{NH}_3(g) + 5\text{O}_2(g) \longrightarrow 4\text{NO}(g) + 6\text{H}_2\text{O}(g)$
 (b) 7.502 g NO (c) 3.34 g (d) 82.9%
72. 2.76×10^3 g; 526 mL
74. (a)



- (b) Mg (c) Mg
 (d) acid (e) 4
 (f) 122 mL; 11 mL
76. 54.3 mL
78. $2\text{AB}_3 + 3\text{C} \longrightarrow 3\text{CB}_2 + 2\text{A}$
- 80.



82. (a) Both boxes A and B have the same number of atoms as As and O_2 .
 (b) There are more discrete particles in Box A.
 (c) Both boxes have the same mass.
84. 2.509×10^{26} atoms
86. (a) EQ (b) LT (c) LT
 (d) $4\text{PH}_3(g) + 8\text{O}_2(g) \longrightarrow \text{P}_4\text{O}_{10}(s) + 6\text{H}_2\text{O}(g)$; GT
 (e) GT
88. 893 g/mol
89. 6.01×10^{23} atoms
90. 3.657 g CaO ; 2.972 g Ca_3N_2
91. 34.7%
92. (a) V_2O_3 ; V_2O_5 (b) 2.271 g
93. 28%
94. 13.2 g NaClO_3 ; 15.6 g NaHCO_3 ; 15.3 g Na_2CO_3 ; 55.9 g NaCl
95. 3.23×10^{24}

Chapter 4

2. (a) BaCl_2 ; soluble (b) $\text{Mg}(\text{OH})_2$; insoluble
 (c) $\text{Cr}_2(\text{CO}_3)_3$; insoluble (d) K_3PO_4 ; soluble
4. (a) NaOH (b) Na_2CO_3 (c) Na_3PO_4
6. (a) $\text{Fe}^{3+}(aq) + 3\text{OH}^-(aq) \longrightarrow \text{Fe}(\text{OH})_3(s)$
 (b) $\text{Ba}^{2+}(aq) + \text{SO}_4^{2-}(aq) \longrightarrow \text{BaSO}_4(s)$
 $\text{Mg}^{2+}(aq) + 2\text{OH}^-(aq) \longrightarrow \text{Mg}(\text{OH})_2(s)$
8. (a) $\text{Ag}^+(aq) + \text{Cl}^-(aq) \longrightarrow \text{AgCl}(s)$
 (b) $\text{Co}^{2+}(aq) + 2\text{OH}^-(aq) \longrightarrow \text{Co}(\text{OH})_2(s)$
 (c) no reaction
 (d) $\text{Cu}^{2+}(aq) + \text{CO}_3^{2-}(aq) \longrightarrow \text{CuCO}_3(s)$
 (e) $\text{Ba}^{2+}(aq) + \text{SO}_4^{2-}(aq) \longrightarrow \text{BaSO}_4(s)$
10. (a) $3\text{Ba}^{2+}(aq) + 2\text{PO}_4^{3-}(aq) \longrightarrow \text{Ba}_3(\text{PO}_4)_2(s)$
 (b) $\text{Zn}^{2+}(aq) + 2\text{OH}^-(aq) \longrightarrow \text{Zn}(\text{OH})_2(s)$
 (c) no reaction
 (d) $\text{Co}^{3+}(aq) + \text{PO}_4^{3-}(aq) \longrightarrow \text{CoPO}_4(s)$
12. (a) 0.04976 M (b) 1.43 M (c) 0.04195 M
14. (a) $2\text{Al}^{3+}(aq) + 3\text{CO}_3^{2-}(aq) \longrightarrow \text{Al}_2(\text{CO}_3)_3(s)$
 (b) 0.108 M (c) 0.379 g
16. (a) $\text{Al}^{3+}(aq) + 3\text{OH}^-(aq) \longrightarrow \text{Al}(\text{OH})_3(s)$
 (b) 0.553 g
 (c) 0.0430 M
18. (a) weak acid (b) strong acid
 (c) weak base (d) weak base
20. (a) HClO (b) HCHO_2 (c) $\text{HC}_2\text{H}_3\text{O}_2$
 (d) H^+ (e) H_2SO_3
22. (a) $\text{C}_7\text{H}_9\text{N}$ (b) OH^-
 (c) $\text{C}_8\text{H}_6\text{NH}$ (d) NH_3
24. (a) $\text{HC}_2\text{H}_3\text{O}_2(aq) + \text{OH}^-(aq) \longrightarrow \text{H}_2\text{O} + \text{C}_2\text{H}_3\text{O}_2^-(aq)$
 (b) $(\text{C}_2\text{H}_5)_2\text{NH}(aq) + \text{H}^+(aq) \longrightarrow (\text{C}_2\text{H}_5)_2\text{NH}_2^+(aq)$
 (c) $\text{HF}(aq) + \text{OH}^-(aq) \longrightarrow \text{H}_2\text{O} + \text{F}^-(aq)$
26. (a) $\text{H}^+(aq) + \text{C}_5\text{H}_5\text{N}(aq) \longrightarrow \text{C}_5\text{H}_5\text{NH}^+(aq)$
 (b) $\text{H}^+(aq) + \text{OH}^-(aq) \longrightarrow \text{H}_2\text{O}$
 (c) correct
 (d) $\text{NH}_3(aq) + \text{H}^+(aq) \longrightarrow \text{NH}_4^+(aq)$
 (e) correct
28. 15.5 mL
30. (a) 0.2395 M
 (b) 9.320 M
 (c) 16.40 M
32. 1.80×10^2 g/mol

34. 5.630%; Yes
 36. 74.3%
 38. one
 40. (a) C = -4; H = +1
 (b) O = -2; C = +4
 (c) O = -2; I = +7
 (d) H = +1; N = -2
 42. (a) H = +1, I = +5, O = -2
 (b) Na = +1, Mn = +7, O = -2
 (c) Sn = +4, O = -2
 (d) F = -1, O = -2, N = +3
 (e) Na = +1, O = $-\frac{1}{2}$
 44. (a) oxidation (b) reduction
 (c) reduction (d) oxidation
 46. (a) reduction (b) reduction
 (c) oxidation (d) oxidation
 48. (a) As oxidized; Mn reduced
 MnO_4^- —oxidizing agent; As_2O_3 —reducing agent
 (b) N oxidized; C reduced
 CO_3^{2-} —oxidizing agent; N_2H_4 —reducing agent
 50. 30.32%
 52. 27.5 g
 54. 0.0941 M
 56. yes
 58. 0.379%
 60. (a) 4 HCl : 1 HNO_3
 (b) 7.9 mL HNO_3 ; 42 mL HCl
 62. 1.03 g
 64. (a) SA/WB (b) WA/SB (c) PPT
 (d) PPT (e) NR
 66. (a) (1) (b) (3) (c) (2)
 68. (a) weak (b) non
 (c) strong (d) weak
 70. (a) F (b) T (c) F (d) F (e) T
 71. 0.794 g CaC_2O_4 ; yes
 72. 0.29 L
 73. 1.09 g Cu; 3.09 g Ag
 74. 0.0980 M Fe^{2+} ; 0.0364 M Fe^{3+}
 75. oxalic acid
 76. 5.27 g
 77. 65.97 g MgCl_2 ; 165.0 g NaNO_3 ; 69.06 g BaCl_2
 78. (a) 1.11 g
 (b) $[\text{OH}^-] = 0$; $[\text{Ba}^{2+}] = 0.125 \text{ M}$; $[\text{Al}^{3+}] = 0.0415 \text{ M}$;
 $[\text{NO}_3^-] = 0.375 \text{ M}$
- Chapter 5**
 2. $V = 2.5 \times 10^3 \text{ L}$; $n_{\text{He}} = 2.14 \times 10^4 \text{ mol}$;
 $T = 298 \text{ K}$
 4. (a) $3.20 \times 10^2 \text{ mm Hg}$ 0.422 atm 6.20 psi
 (b) $1.50 \times 10^3 \text{ mm Hg}$ 1.98 atm 201 kPa
 (c) 599 mm Hg 11.6 psi 79.8 kPa
 (d) 1.600 atm 23.5 psi 162.1 kPa
 6. 323°C
 8. (a) 2.00 atm (b) 3.21 atm
 10. 31.5 psi (gauge pressure); 46.2 psi (actual pressure)
 12. $1.02 \times 10^3 \text{ mm Hg}$
 14. 0.76 mol
 16. 93.3 g; 93.3 mL
 18. 1217 g
 20. (a) 0.0470 mol; 2.07 g
 (b) -33°C ; 3.72 g
 (c) 36.9 L; 125.3 g
 (d) 11.2 atm; 1.072 mol
 22. (a) 1.19 g/L
 (b) 2.10 g/L
 (c) 1.90 g/L
 24. 0.0146 g/L in Mars, 1.80 g/L on earth
 26. (a) 98.8 g/mol
 (b) COCl_2
 28. (a) 28.6 g/mol
 (b) exhaled air = 1.12 g/L; ordinary air = 1.13 g/L
 30. element = H; compound = PH_3 – phosphine
 32. (a) $2\text{NF}_3(\text{g}) + 3\text{H}_2\text{O}(\text{g}) \longrightarrow \text{NO}(\text{g}) + \text{NO}_2(\text{g}) + 6\text{HF}(\text{g})$
 (b) 1.74 L
 34. (a) 3.72 L
 (b) 2.64 L
 36. $3.2 \times 10^3 \text{ g}$
 38. 2.83 L
 40. (a) $2\text{C}_9\text{H}_{18}\text{O}_6(\text{s}) + 21\text{O}_2(\text{g}) \longrightarrow 18\text{H}_2\text{O}(\text{g}) + 18\text{CO}_2(\text{g})$
 (b) 13.8 atm
 42. 3.04 atm; HCl
 44. CH_4 : 1.06 atm
 C_2H_6 : 0.11 atm
 C_3H_8 : 0.030 atm
 46. 134 mL
 48. 2.19 atm
 50. (a) $2\text{NH}_4\text{NO}_3(\text{s}) \longrightarrow 2\text{N}_2(\text{g}) + \text{O}_2(\text{g}) + 4\text{H}_2\text{O}(\text{g})$
 (b) 2.38 atm
 (c) $P_{\text{N}_2} = 0.681 \text{ atm}$; $P_{\text{O}_2} = 0.341 \text{ atm}$; $P_{\text{H}_2\text{O}} = 1.37 \text{ atm}$
 52. (a) 729 mm Hg (b) 4.52×10^{-4}
 (c) 2.00×10^{-2} (d) 231 mm Hg
 (e) 976 mm Hg
 54. (a) speed of effusion: $\text{Xe} < \text{CH}_2\text{F}_2 < \text{F}_2 < \text{CH}_4$
 (b) time: $\text{CH}_4 < \text{F}_2 < \text{CH}_2\text{F}_2 < \text{Xe}$
 56. 3.74 times faster
 58. (a) yes (b) 100.1 g/mol
 60. 15.8 s
 62. (a) 291 m/s (b) 145.3 m/s
 64. (a) more
 (b) less
 66. (a) 84 g/L
 (b) 65.5 g/L
 (c) $\approx 340 \text{ atm}$
 68. (a) $2\text{C}_8\text{H}_{18}(\text{l}) + 25\text{O}_2(\text{g}) \longrightarrow 16\text{CO}_2(\text{g}) + 18\text{H}_2\text{O}(\text{l})$
 (b) $1.5 \times 10^4 \text{ L}$
 70. (a) 1.000
 (b) 0.5535
 (c) 1.000
 (d) 1.000
 72. H_2SO_4
 74. C = 32.0%; H = 6.72%; N = 18.7%; O = 42.6%;
 $\text{C}_2\text{H}_5\text{NO}_2$
 76. (a) 0.00387 mol (b) 0.032 g
 78. (a) Both gases have the same number of moles.
 (b) CO_2
 (c) CO_2
 (d) Both gases have the same average translational energy.
 (e) Both gases have the same partial pressure.

80. (a) same (b) N_2 (A) (c) same
(d) NH_3 (B) (e) P stays the same (f) $1/2$
82. (a) $tank_A = tank_B$
(b) $tank_A = 2(tank_B)$
(c) $tank_A = tank_B$
84. (a) A (b) B (c) B
86. (a) C (b) 2.5 atm (c) 4.0 atm
(d) 4.0 atm (same)



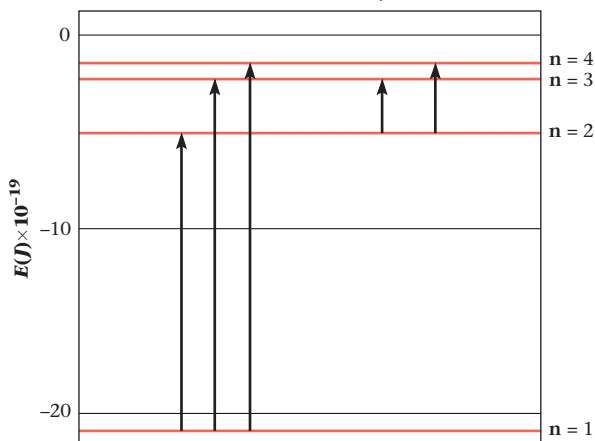
(e) 4.0 atm



88. Ideal gas pressures: at $40^\circ C = 25.0$ mm Hg; at $70^\circ C = 27.3$ mm Hg; at $100^\circ C = 29.7$ mm Hg
Vapor pressures: at $40^\circ C = 55.3$ mm Hg; at $70^\circ C = 233.7$ mm Hg; at $100^\circ C = 760$ mm Hg
Vapor pressure implies the presence of some liquid together with the vapor. As T increases, more liquid becomes gas, increasing n and thus P .
89. 74.3% O_2 ; 17.2% N_2 ; 8.43% CO_2
90. 3.0 ft from NH_3 end
91. (a) 1.05 atm (b) 1.27 atm (c) 0.624 M
92. 78.7%
93. 6.62 m
94. 0.897 atm

Chapter 6

2. (a) $5.83 \times 10^{14} s^{-1}$ (b) 3.86×10^{-19} J/photon
(c) 233 kJ/mol
4. (a) 232 nm (b) ultraviolet
(c) 8.55×10^{-19} J/photon
6. (a) 127 nm (b) ultraviolet
8. 48 kJ
10. (a) 434 nm (b) visible (c) yes
- 12.



14. (a) 2.624×10^3 nm (b) infrared
16. 7455 nm
18. (a) $m_\ell = -2, -1, 0, +1, +2$
(b) $m_\ell = 0$
(c) $\ell = 0; m_\ell = 0$ $\ell = 1, m_\ell = -1, 0, +1$
 $\ell = 2; m_\ell = -2, -1, 0, +1, +2$
 $\ell = 3; m_\ell = -3, -2, -1, 0, +1, +2, +3$
 $\ell = 4; m_\ell = -4, -3, -2, -1, 0, +1, +2, +3, +4$
20. (a) 3s (b) 4d (c) 4f (d) 2s
22. (a) 3p (b) 5s (c) 6f
24. (a) 9 (b) 3 (c) 7 (d) 5
26. (a) 2 (b) 2 (c) 10
28. (b) No 1p sublevel (d) m_ℓ cannot exceed 1
(e) $m_\ell = 0$
30. (a) $1s^2 2s^2 2p^6 3s^2 3p^4$
(b) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^1$
(c) $1s^2 2s^2 2p^6 3s^2 3p^2$
(d) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2$
(e) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^3$
32. (a) $[10Ne]3s^2$ (b) $[54Xe]6s^2 4f^{14} 5d^6$
(c) $[18Ar]4s^2 3d^{10} 4p^2$ (d) $[18Ar]4s^2 3d^3$
(e) $[54Xe]6s^2 4f^{14} 5d^{10} 6p^5$
34. (a) Eu (b) Zr (c) P (d) Ne
36. (a) 6/12 (b) 12/25 (c) 18/42
38. (a) impossible (b) ground (c) impossible
(d) excited (e) excited
40. 1s 2s 2p 3s 3p 4s 3d
(a) $(\uparrow\downarrow) (\uparrow\downarrow) (\uparrow\downarrow)(\uparrow\downarrow)(\uparrow\downarrow) (\uparrow)$
(b) $(\uparrow\downarrow) (\uparrow\downarrow) (\uparrow\downarrow)(\uparrow) (\uparrow)$
(c) $(\uparrow\downarrow) (\uparrow\downarrow) (\uparrow\downarrow)(\uparrow\downarrow)(\uparrow\downarrow) (\uparrow\downarrow) (\uparrow\downarrow)(\uparrow\downarrow)(\uparrow\downarrow) (\uparrow\downarrow) (\uparrow\downarrow)(\uparrow\downarrow)(\uparrow) (\uparrow) (\uparrow)$
(d) $(\uparrow\downarrow) (\uparrow\downarrow) (\uparrow\downarrow)(\uparrow\downarrow)(\uparrow\downarrow) (\uparrow\downarrow) (\uparrow\downarrow)(\uparrow\downarrow)(\uparrow)$
42. (a) Li (b) Cl (c) Na
44. (a) Sn, Sb, Te (b) K, Rb, Cs, Fr (c) Ge, As, Sb, Te
(d) none
46. (a) 1 (b) 0 (c) 3
48. (a) Ca (b) K, Ga (c) none (d) none
50. (a) F: $1s^2 2s^2 2p^5$ F^- : $1s^2 2s^2 2p^6$
(b) Sc: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^1$ Sc^{3+} : $1s^2 2s^2 2p^6 3s^2 3p^6$
(c) Mn^{2+} : $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5$
 Mn^{5+} : $1s^2 2s^2 2p^6 3s^2 3p^6 3d^2$
(d) O^- : $1s^2 2s^2 2p^5$ O^{2-} : $1s^2 2s^2 2p^6$
52. (a) 0 (b) 0 (c) 0 (d) 0
54. (a) $Cl < S < Mg$ (b) $Mg < S < Cl$
(c) $Mg < S < Cl$
56. (a) K (b) Cl (c) Cl
58. (a) P (b) V^{4+} (c) K^+ (d) Co^{3+}
60. (a) $Kr < K < Rb < Cs$ (b) $Ar < Si < Al < Cs$
62. (a) 3.558×10^7 nm (b) microwave
(c) 3.363×10^{-3} kJ/mol
64. (a) Si (b) Na (c) Y (d) At (e) O
66. (a) (2) and (4) (b) (1) and (3) (c) (1)
(d) (2) (e) (1)
68. (a) spin (b) less energy (c) 5 (d) yes
70. (a) See pages 130–133.
(b) See page 125, Figure 6.2.
(c) See page 138, Figure 6.12.
72. (a) true (b) false; inversely proportional to n^2
(c) false; as soon as 4p is full

74. (a) True

(b) True

(c) False; absorbed

76. +2954 kJ

77. $\Delta E = 2.180 \times 10^{-18} \left(\frac{1}{4} - \frac{1}{n^2} \right)$

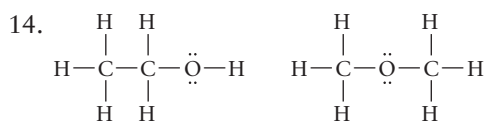
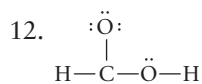
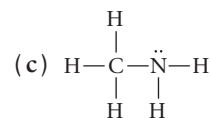
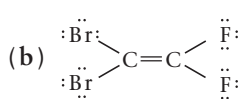
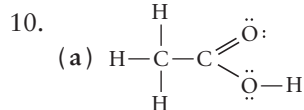
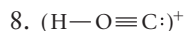
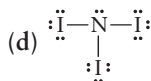
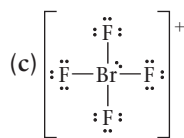
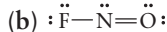
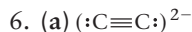
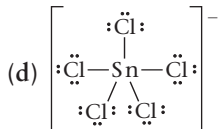
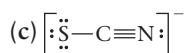
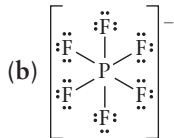
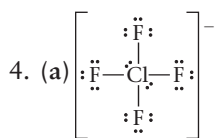
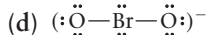
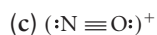
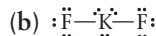
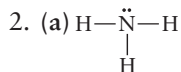
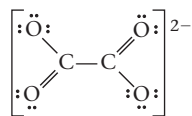
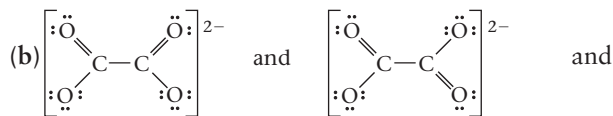
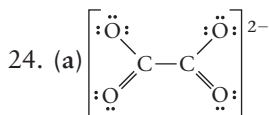
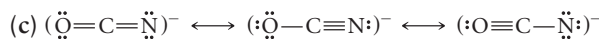
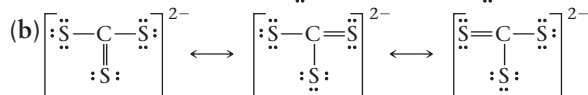
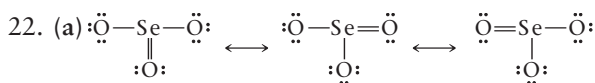
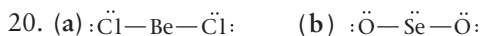
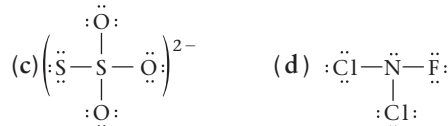
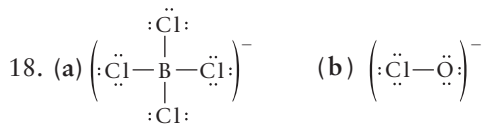
$$\lambda = \frac{hc}{\Delta E} = \frac{(6.626 \times 10^{-34})(2.998 \times 10^8)(1 \times 10^9)}{2.180 \times 10^{-18} \left(\frac{1}{4} - \frac{1}{n^2} \right)}$$

$$= \frac{91.12}{\left(\frac{1}{4} - \frac{1}{n^2} \right)} = \frac{364.5 n^2}{n^2 - 4}$$

78. $1s^4 1p^4$ 79. (a) s sublevel: $m_\ell = 0 = 3e^-$;p sublevel: $m_\ell = -1, 0, 1 = 9e^-$;d sublevel: $m_\ell = -2, -1, 0, 1, 2 = 15e^-$ (b) $n = 3, \ell = 0, 1, 2$; total electrons = 27(c) $1s^3 2s^3 2p^2 \quad 1s^3 2s^3 2p^9 3s^2$ 80. (a) $3.42 \times 10^{-19} \text{ J}$

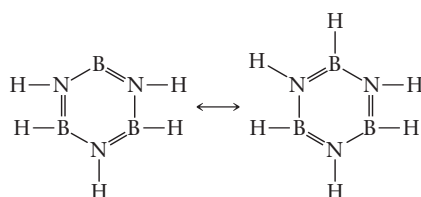
(b) 581 nm

Chapter 7

16. (a) Br_2 (b) CH_4 (c) CO (d) SiF_4 

(c) No. Different skeleton.

26.

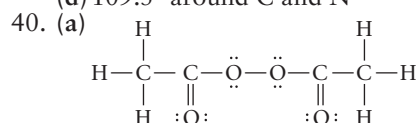


28. (a) 0 (b) 0 (c) 0

30. Structure I

32. (a) bent
(c) trigonal pyramid(b) bent
(d) linear34. (a) linear
(c) tetrahedron(b) bent
(d) bent36. (a) square pyramid
(c) octahedral(b) square planar
(d) trigonal bipyramid

38. (a) 120° (b) 120°
 (c) 120° around N; 109.5° around O (left)
 (d) 109.5° around C and N



(b) around CH_3 — 109.5° ; around CO — 120° ; around O — 109.5°

42. 1 = 120° ; 2 = 109.5° ; 3 = 120°

44. a, b, c are dipoles

46. a, b, d

48. First structure is polar; dipoles do not cancel.

50. (a) sp^2 (b) sp^3 (c) sp^3 (d) sp
 52. (a) sp (b) sp^2 (c) sp^3 (d) sp^2
 54. (a) sp^3d^2 (b) sp^3d^2 (c) sp^3d^2 (d) sp^3d

56. (a) $6e^-$ pairs; sp^3d^2 (b) $6e^-$ pairs; sp^3d^2
 (c) $5e^-$ pairs; sp^3d

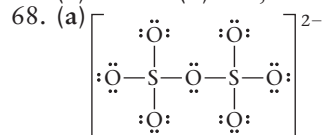
58. C_1 and $\text{C}_2 = \text{sp}^2$, C_3 and $\text{N} = \text{sp}$

60. (a) sp^3 (b) sp^2 (c) sp (d) sp^2

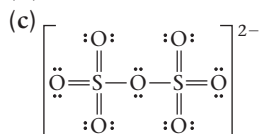
62. (a) sp^3 (b) sp^3 (c) sp^3

64. 6 σ , 3 π

66. (a) 4 σ (b) 3 σ , 1 π (c) 2 σ , 2 π (d) 4 σ , 1 π



(b) Each S atom has a formal charge of 2.



(d) Each S atom has a formal charge of -1.

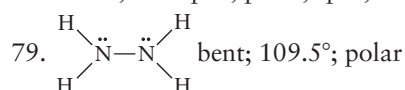
70. AX_2E_2 2 2 bent sp^3 polar
 AX_3 3 0 trigonal planar sp^2 nonpolar
 AX_4E_2 4 2 square planar sp^3d^2 nonpolar
 AX_5 5 0 trigonal bipyramid sp^3d nonpolar

72. (a) C (b) N

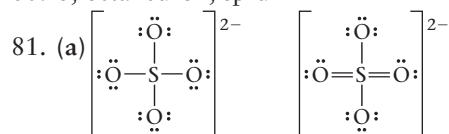
74. PH_3 and H_2S —unshared pairs on central atom

76. SnCl_2 and SO_2 ; unshared pairs occupy more space

78. $x = 3$; T-shaped; polar; sp^3d ; 90° , 180° ; 3 σ bonds



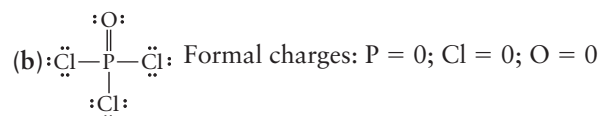
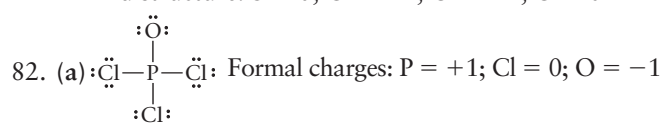
80. 6; octahedron; sp^3d^2



(b) tetrahedral for both (c) sp^3 ; sp^3

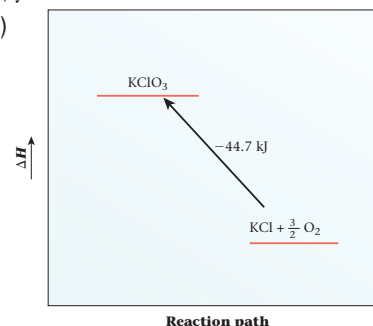
(d) 1st structure: O = -1; S = 2

2nd structure: S = 0; O = -1; O = -1, O = 0



Chapter 8

2. 2.06°C
 4. $0.140 \text{ J/g} \cdot ^\circ\text{C}$
 6. $3.7 \times 10^2 \text{ J}$
 8. (a) no (b) -669 J (c) 24.2°C
 10. $1.3 \times 10^2 \text{ mL}$
 12. (a) 18.6 mL (b) 34.0°C
 14. (a) 81.3 kJ (b) 86.2 kJ (c) -167.5 kJ
 (d) $-3.48 \times 10^3 \text{ kJ/mol}$
 16. (a) -218 kJ (b) 77.6 kJ
 (c) $1.40 \times 10^2 \text{ kJ}$ (d) $5.67 \text{ kJ}^\circ\text{C}$
 18. 27.0°C
 20. 2.00 mL
 22. (a) $\text{KClO}_3(\text{s}) \longrightarrow \text{KCl}(\text{s}) + \frac{3}{2}\text{O}_2(\text{g}) \Delta H^\circ = -44.7 \text{ kJ}$
 (b) yes
 (c)

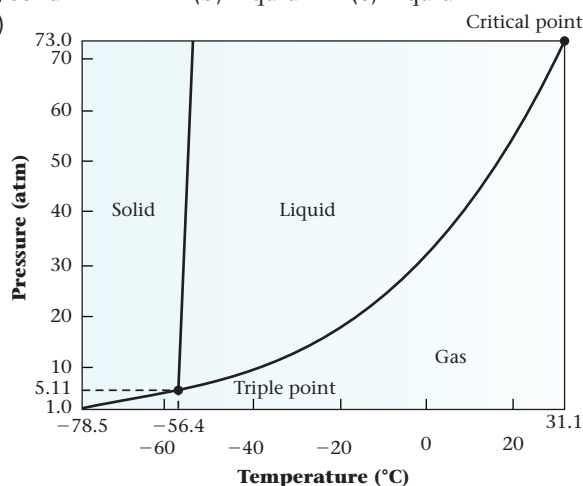


- (d) -1.09 kJ (e) 41.1 g
 24. (a) 13.4 kJ (b) 0.965 kJ
 26. (a) $2\text{C}_3\text{H}_5(\text{NO}_3)_3(\text{l}) \longrightarrow 3\text{N}_2(\text{g}) + 6\text{CO}_2(\text{g}) + 5\text{H}_2\text{O}(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}); \Delta H = -2.84 \times 10^3 \text{ kJ}$
 (b) -911 kJ
 28. (a) $\text{C}_{57}\text{H}_{104}\text{O}_6(\text{s}) + 83\text{O}_2(\text{g}) \longrightarrow 57\text{CO}_2(\text{g}) + 52\text{H}_2\text{O}(\text{l}) \Delta H^\circ = -3.022 \times 10^4 \text{ kJ}$
 (b) $1.78 \times 10^3 \text{ kJ}$
 (c) 0.804 lb
 30. benzene
 32. -48.9 kJ
 34. (a) $2\text{Mg}(\text{s}) + \text{SiO}_2(\text{s}) + 2\text{C}(\text{s}) + 2\text{Cl}_2(\text{g}) \longrightarrow 2\text{CO}(\text{g}) + 2\text{MgCl}_2(\text{s}) + \text{Si}(\text{s})$
 (b) -592.7 kJ
 (c) yes
 36. -35.6 kJ
 38. (a) $\text{K}(\text{s}) + \frac{1}{2}\text{Cl}_2(\text{g}) + \frac{3}{2}\text{O}_2(\text{g}) \longrightarrow \text{KClO}_3(\text{s}) \Delta H = -397.7 \text{ kJ}$
 (b) $\text{C}(\text{s}) + 2\text{Cl}_2(\text{g}) \longrightarrow \text{CCl}_4(\text{l}) \Delta H = -135.4 \text{ kJ}$
 (c) $\frac{1}{2}\text{H}_2(\text{g}) + \frac{1}{2}\text{I}_2(\text{g}) \longrightarrow \text{HI}(\text{g}) \Delta H = 26.5 \text{ kJ}$
 (d) $2\text{Ag}(\text{s}) + \frac{1}{2}\text{O}_2(\text{g}) \longrightarrow \text{Ag}_2\text{O}(\text{s}) \Delta H = -31.0 \text{ kJ}$
 40. (a) -1134.7 kJ (b) -101.9 kJ
 42. (a) $\text{N}_2\text{H}_4(\text{l}) + \text{O}_2(\text{g}) \longrightarrow \text{N}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g}) \Delta H = -534.2 \text{ kJ}$
 (b) 14.0 kJ of heat are evolved
 44. (a) -153.9 kJ (b) -1036.0 kJ (c) -714.8 kJ
 46. (a) -50.3 kJ (b) -84.5 kJ
 48. (a) $\text{CaCO}_3(\text{s}) + 2\text{NH}_3(\text{g}) \longrightarrow \text{CaCN}_2(\text{s}) + 3\text{H}_2\text{O}(\text{l}) \Delta H^\circ = 90.1 \text{ kJ}$
 (b) -351.6 kJ/mol

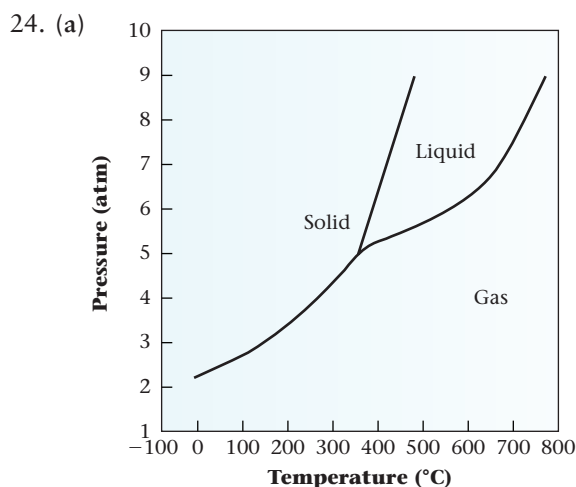
50. -680 kJ/mol
 52. -3.36 kJ
 54. $1.20 \times 10^2 \text{ L-atm}$
 56. (a) -18 J (b) $+64 \text{ J}$
 58. (a) yes (b) -102 J
 60. (a) 29.6 kJ (b) 2.76 kJ (c) 26.8 kJ
 62. (a) $\text{CH}_3\text{OH}(l) + \frac{3}{2}\text{O}_2(g) \longrightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(g)$
 $\Delta H = -638.4 \text{ kJ}$
 (b) $\Delta E = -642.1 \text{ kJ}$
 64. $1.00 \text{ BTU/lb-}^\circ\text{F}$
 66. 29 min
 68. $-8.451 \times 10^4 \text{ kJ}$
 70. $\Delta E = -885 \text{ kJ}$; $\Delta H = -890 \text{ kJ}$
 72. 0.793
 74. $1.65 \times 10^{-6} ^\circ\text{C}$
 76. (a) yes (b) — (c) no (d) yes
 78. Piston goes down.
 80. $c_A > c_B$
 82. c, d, e
 84. 2.1×10^{28} photons
 85. (a) $1.69 \times 10^5 \text{ J}$ (b) 505 g
 86. 22%
 87. (a) -851.5 kJ (b) $6.6 \times 10^3 ^\circ\text{C}$ (c) yes
 88. 76.0%
 89. 7.5 g
 90. $3.50 \times 10^2 \text{ kJ}$

Chapter 9

2. (a) 50°C : 297 mm Hg ; 60°C : 307 mm Hg
 (b) $297 \text{ mm Hg} > 269 \text{ mm Hg}$
 $307 \text{ mm Hg} < 389 \text{ mm Hg}$
 (c) 269 mm Hg at 50°C 307 mm Hg at 60°C
 4. (a) 0.75 mg (b) 0.14 mm Hg
 6. (a) 2.4 mg (b) 2.6 mg (c) 0.40 mm Hg ; yes
 8. (a) 29.5 kJ/mol (b) 39.8°C
 10. 97°C
 12. 17°C
 14. 29 kJ/mol
 16. (a) liquid (b) vapor (c) liquid
 18. (a) vapor (b) 20°C (c) liquid
 (d) triple point (e) normal boiling point
 (f) deposition (g) no (h) yes
 20. (a) solid (b) liquid (c) liquid
 22. (a)

(b) $\approx 30 \text{ atm}$

(c) yes

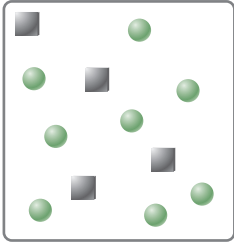


- (b) 600°C (c) sublimates
 26. $\text{He} < \text{Ne} < \text{Ar} < \text{Xe}$
 28. dipole forces: b, d; dispersion forces: all
 30. b and c
 32. (a) Na_2CO_3 is ionic.
 (b) N_2H_4 has hydrogen bonding.
 (c) Benzoic acid has larger dispersion forces.
 (d) CO has dipole forces.
 34. a and b
 36. (a) LiCl—ionic bonds
 (b) CH_3OH —hydrogen bonds
 (c) H_2O —hydrogen bonds
 (d) Cl_2 —larger dispersion forces
 38. (a) H-bonds (b) dispersion forces
 (c) dispersion and dipole forces (d) dispersion forces
 40. (a) molecular (b) ionic (c) metallic
 42. (a) metallic, network covalent
 (b) network covalent, metallic (c) metallic
 44. (a) metallic (b) molecule (c) network covalent
 (d) ionic (e) molecule
 46. (a) NO (b) CaO (c) SiO_2 (d) O_2
 48. (a) C atoms (b) Si and C atoms
 (c) ions (d) C_2H_2 molecules
 50. face-centered
 52. $V = 0.05631 \text{ nm}^3$; $r = 0.1355 \text{ nm}$
 54. (a) 0.698 nm (b) 0.987 nm
 56. (a) 0.700 nm (b) 0.404 nm
 58. 1 Cs^+ , 1 Cl^-
 60. (a) $1.43 \times 10^{-8} \text{ cm}$ (b) $1.22 \times 10^{-23} \text{ cm}^3$
 (c) 3.66 g/cm^3 (d) 2.71 g/cm^3
 62. (a) 52% (b) 74% (c) 68%
 64. 0.0436 atm
 66. (a) F (b) T (c) F (d) T
 68. (a) GT (b) MI (c) LT (d) EQ (e) MI
 70. (a) I (b) G (c) L/G
 72. (a) Covalent bonds are between nonmetal atoms and they hold a molecule together. An ionic bond is a bond between ions.
 (b) boiling point—temperature and pressure for a liquid to become vapor;
 critical point—temperature and pressure where liquid cannot exist
 (c) deposition—gas to solid; sublimation—solid to gas

- (d) freezing point—temperature and pressure for a liquid to become solid;
triple point—temperature and pressure where boiling, freezing, and subliming all occur
74. (a) A (b) A (c) $\approx 34^\circ\text{C}$
(d) gas (e) ≈ 200 mm Hg
75. 6.65×10^3 kJ
76. 6.05×10^{23} atoms/mol
77. (a) liquid and vapor (b) 26.7 mm Hg
(c) 3.4 atm
78. 41%
79. 80 atm; 0.60°C ; see *Scientific American*, February 2000
80. $\frac{r_{\text{cation}}}{r_{\text{anion}}} = 0.414$
81. $P_{\text{C}_3\text{H}_8}$ is the vapor pressure of propane, which decreases exponentially with T . P_{N_2} is gas pressure, which decreases linearly with T .

Chapter 10

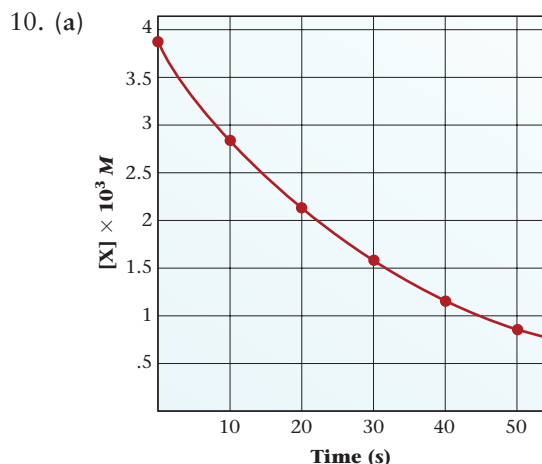
2. (a) 41.2% (b) 58.8% (c) 0.357
4. 0.15 M
6. 4.8×10^{-7} mol; 0.10 ppm
8. (a) 0.05413 M (b) 7.076 mL (c) 139 g
10. (a) 3.18 m ; 36.4%; 6.36×10^5
(b) 4.411 m ; 44.28%; 0.0736
(c) 1.17 m ; 8.26×10^5 ; 0.0206
(d) 13.06%; 8.694×10^5 ; 0.01481
12. (a) Add 46.5 g of $\text{Ba}(\text{OH})_2$ to enough water to make 750.0 mL of solution.
(b) Add enough water to 55.1 mL of 0.493 M $\text{Ba}(\text{OH})_2$ to make 750.0 mL of solution.
14. (a) 109.3 g
(b) K_2S : 0.4953 M; K^+ : 0.9906 M; S^{2-} : 0.4953 M
16. (a) 15.7 M (b) 1.89 M
18. (a) 0.678 m ; 8.56%
(b) 2.39 M; 2.88 m
(c) 3.59 M; 41.4%
20. 1.23 m
22. (a) benzene — both nonpolar
(b) octane; glycerol is more similar to water (OH groups)
(c) CHCl_3 — similar dispersion forces
(d) CBr_4 — both nonpolar
24. (a) ethanol (b) NH_3
(c) propionic acid (d) sodium iodide
26. (a) $\Delta H = -13.0$ kJ (b) no
28. (a) 1.3×10^{-6} M/mm Hg
(b) 9.1×10^{-4} M
(c) 1.1 g
30. (a) 62 mg (b) 56 mg (c) $1.0 \times 10^{1\%}$
32. -11°C
34. (a) 26.1 mm Hg (b) 27.0 mm Hg (c) 23.0 mm Hg
36. Make a solution made up of 161.6 g water and 103.4 g of urea.
38. 2.46 mm Hg
40. (a) 5.7 g; 3.3 g (b) 9.3 g; 5.4 g
42. (a) 15 m (b) 2.1×10^2 mL ethylene glycol
44. $9.08^\circ\text{C}/m$
46. 183.1 g/mol
48. 403 g/mol

50. $\text{C}_6\text{H}_4\text{N}_2\text{O}_4$
52. 1.50×10^5 g/mol
54. boiling point: $\text{Al}(\text{ClO}_3)_3 > (\text{NH}_4)_2\text{Cr}_2\text{O}_7 > \text{MgSO}_4 > \text{CH}_3\text{OH}$
freezing point: $\text{CH}_3\text{OH} > \text{MgSO}_4 > (\text{NH}_4)_2\text{Cr}_2\text{O}_7 > \text{Al}(\text{ClO}_3)_3$
56. 9.74 atm
58. (a) 2.0 (b) (ii)
60. Li
62. (a) 2.002 M (b) 2.17 m
(c) 196 atm (d) -16.1°C
64. (a) $4.9^\circ\text{C}/m$ (b) 3
66. (a) 5.5×10^{-7} mol/L (b) 0.12
68. 3.0 atm
70.  4 M Ca^{2+} ; 8 M Cl^-

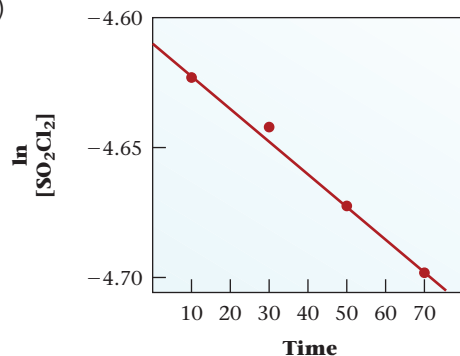
72. (a) solution 2 (b) same (c) solution 2
(d) same (e) solution 1
74. HF molecules
76. b
78. (a) less (b) greater (c) greater (d) less
80. (a) Check electrical conductivity.
(b) Solubility of gas decreases with increasing temperature.
(c) Number of moles of water is large so X_{solute} is small.
(d) Colligative property; the presence of a solute decreases vapor pressure.
82. 1.1 g/mL
83. Add 1.03×10^3 g of water.
84. 43.1%
85. 48%
86. $0.0018 \text{ g}/\text{cm}^3$ —intoxicated
87. (a) 2.08 M
(b) 1.872 mol
(c) 47.4 L
88. 0.055
89. $V_{\text{gas}} = \frac{n_{\text{gas}} \times RT}{P_{\text{gas}}}$; $n_{\text{gas}} = k \times P_{\text{gas}}$; $V_{\text{gas}} = kRT$
 V_{gas} depends only on temperature.

Chapter 11

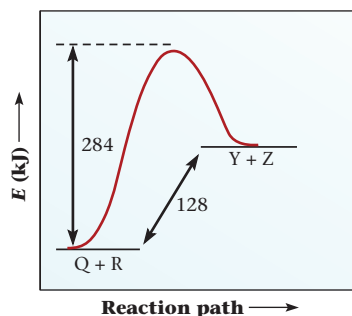
2. (a) $\text{rate} = \frac{-\Delta[\text{N}_2\text{O}]}{2\Delta t}$ (b) $\text{rate} = \frac{\Delta[\text{O}_2]}{\Delta t}$
4. (a) Time (min) 0 10 20 30 40 50
Moles AB_2 0.384 0.276 0.217 0.140 0.098 0.071
(b) 7.7×10^{-3} mol/min
(c) 1.73×10^{-3} mol/min
6. (a) 0.058 mol/L $\cdot$ s (b) 0.029 mol/L $\cdot$ s
(c) 0.048 mol/L $\cdot$ s
8. (a) $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \longrightarrow 2\text{NH}_3(\text{g})$
(b) $\text{rate} = \frac{\Delta[\text{NH}_3]}{2\Delta t}$ (c) 0.0186 mol/L $\cdot$ min



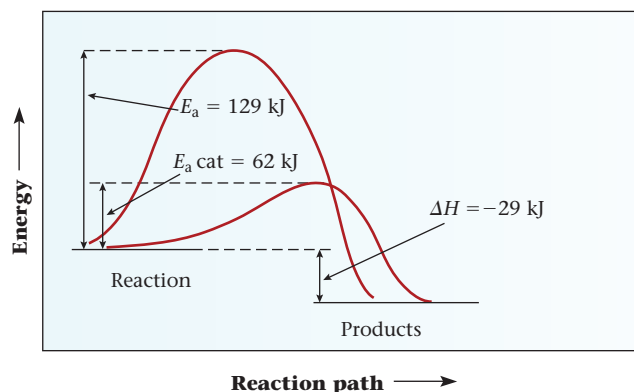
- (b) $3.7 \times 10^{-5} \text{ mol/L} \cdot \text{s}$ (c) $4.8 \times 10^{-5} \text{ mol/L} \cdot \text{s}$
 (d) instantaneous rate < average rate
12. (a) 0, 0, 0 (b) 2, 1, 3 (c) 0, 2, 2 (d) 1, 1, 2
14. (a) $\text{mol/L} \cdot \text{min}$ (b) $\text{L}^2/\text{mol}^2 \cdot \text{min}$
 (c) $\text{L/mol} \cdot \text{min}$ (d) $\text{L/mol} \cdot \text{min}$
16. (a) 0 (b) $\text{rate} = k[\text{Y}]^0$ (c) $k = 0.045 \text{ M/h}$
18. (a) $0.0756 \text{ mol/L} \cdot \text{h}$ (b) 0.300 M
 (c) 0.143 M (d) $0.00801 \text{ L/mol} \cdot \text{h}$
20. (a) $\text{rate} = 2.5 \times 10^{-4} \text{ mol/L} \cdot \text{min}$
 (b) $2.5 \times 10^{-4} \text{ mol/L} \cdot \text{min}$
 (c) any concentration
22. (a) $4.05 \text{ L}^2/\text{mol}^2 \cdot \text{min}$ (b) 0.230 M
 (c) 0.0915 M
24. (a) 1 (b) $\text{rate} = k[\text{Y}]$ (c) 1.44 min^{-1}
26. (a) second-order with respect to NO_2 ; zero-order with respect to CO ; second-order overall
 (b) $\text{rate} = k[\text{NO}_2]^2$
 (c) $k = 0.297 \text{ L/mol} \cdot \text{s}$
 (d) $0.0526 \text{ mol/L} \cdot \text{s}$
28. (a) first-order with respect to O_2 ; second-order with respect to NO
 (b) $\text{rate} = k[\text{NO}]^2[\text{O}_2]$
 (c) $99.3 \text{ L}^2/\text{mol}^2 \cdot \text{min}$
 (d) $4.59 \times 10^{-4} \text{ M/min}$
30. (a) first-order in CH_3COCH_3 , first-order in H^+ , zero-order in I_2
 (b) $\text{rate} = k[\text{CH}_3\text{COCH}_3][\text{H}^+]$
 (c) $2.6 \times 10^{-5} \text{ L/mol} \cdot \text{s}$
 (d) $6.8 \times 10^{-5} \text{ mol/L} \cdot \text{s}$
32. (a) $\text{rate} = k[\text{CH}_3\text{CO}_2\text{CH}_3][\text{OH}^-]$ (b) $0.26 \text{ L/mol} \cdot \text{s}$
 (c) $0.51 \text{ mol/L} \cdot \text{s}$
34. second-order
36. (a)



- (b) 0.0015 min^{-1} (c) 462 min
 (d) 567 min (e) $2.30 \times 10^{-5} \text{ M/min}$
38. (a) $4.05 \times 10^{-3} \text{ s}^{-1}$ (b) 171 s (c) 0.152 M
40. (a) 0.758 g (b) 3.22 months (c) 4.9 months
42. (a) 0.0331 h^{-1} (b) $1.53 \times 10^{-3} \text{ mol/L} \cdot \text{h}$
 (c) $2.4 \times 10^1 \text{ h}$
44. 112 g
46. 16 days
48. 15 hours
50. (a) 2.37 mg/min (b) 156 min (c) 2.37 mg/min
 (d) 2.37 mg/min
52. (a) 10.0 min (b) 1.2 h
54. (a) $0.0153 \text{ L/mol} \cdot \text{s}$ (b) 327 s (c) 47.6 s
 (d) $2.51 \times 10^{-4} \text{ mol/L} \cdot \text{s}$
56. $2.9 \text{ L/mol} \cdot \text{min}$
58. 57%
60. $E_a = 2.2 \times 10^2 \text{ kJ/mol}$
- 62.



64. Decrease by 31%
66. (a) At 25°C : 148 chirps/min; at 35°C : 220 chirps/min
 (b) $3.0 \times 10^1 \text{ kJ}$ (c) 49%
68. (a) 0.062 s^{-1} (b) 35°C
70. 86 kJ/mol
- 72.



74. 357 kJ
76. (a) $\text{rate} = k[\text{Cl}]^2$
 (b) $\text{rate} = k[\text{N}_2\text{O}_2][\text{O}_2]$
 (c) $\text{rate} = k[\text{I}^-][\text{HClO}]$
78. yes
80. (1) $\text{rate} = k \times [\text{NO}_3] \times [\text{NO}]$
 $k_2 \times [\text{NO}_3] = k_1 \times [\text{NO}] \times [\text{O}_2]$

$$\text{rate} = \frac{kk_1}{k_2} \times [\text{NO}]^2 \times [\text{O}_2]$$

$$(2) \text{ rate} = k \times [\text{N}_2\text{O}_2] \times [\text{O}_2] \quad k_2 \times [\text{N}_2\text{O}_2] = k_1 \times [\text{NO}]^2$$

$$\text{rate} = \frac{kk_1}{k_2} \times [\text{NO}]^2 \times [\text{O}_2]$$

82. 0.097 mol/L · s

84. ≈ 15 times faster86. 7×10^{17} years; very unlikely

$$88. \ln\left(\frac{k_2}{k_1}\right) = \frac{1}{RT}(E_{\text{uncat}} - E_{\text{cat}})$$

90. (a) decreases (b) increases (c) stays the same
(d) decreases (e) increases

92. 1 represents the decrease of [X] with time

2 represents the increase of [Z] with time

3 represents the increase of [Y] with time

94. (a) A (b) C (c) A

96. (a) 8 kJ (b) A (c) -360 kJ (d) 368 kJ

(e) B (f) activated complex

98. Expt. 1: rate = 0.05 mol/L · min

Expt. 2: $k = 0.5/\text{min}$; rate = 0.1 mol/L · min; $E_a = 32$ kJExpt. 3: rate = 0.1 mol/L · min; E_a cannot be determinedExpt. 4: rate = 0.06 mol/L · min; $E_a = 32$ kJ

99. (a) 174 kJ (b) 46 L/mol · s (c) 1.8 mol/L · s

100. 12 min

$$101. \frac{-d[A]}{a \, dt} = k[A]; \frac{-d[A]}{[A]} = ka \, dt; \ln \frac{[A_o]}{[A]} = akt$$

$$102. \text{rate} = k[A]^2[B][C]$$

$$103. (a) \frac{-d[A]}{dt} = k[A]^2; \frac{-d[A]}{[A]^2} = k \, dt; \frac{1}{[A]} - \frac{1}{[A_o]} = kt$$

$$(b) \frac{-d[A]}{dt} = k[A]^3; \frac{-d[A]}{[A]^3} = k \, dt;$$

$$\frac{1}{2[A]^2} - \frac{1}{2[A_o]^2} = kt;$$

$$\frac{1}{[A]^2} - \frac{1}{[A_o]^2} = 2kt$$

104. 0.90 g; 54 mg no more than three times a day

105. A: 134 mm Hg; X: 244 mm Hg; Y: 122 mm Hg

Chapter 12

2. (a) ≈ 75 s (b) greater than; equal to
4.

Time (min)	0	1	2	3	4	5	6
P_A (atm)	1.000	0.778	0.580	0.415	0.355	0.325	0.325
P_B (atm)	0.400	0.326	0.260	0.205	0.185	0.175	0.175
P_C (atm)	0.000	0.148	0.280	0.390	0.430	0.450	0.450

6. (a) $K = P_{\text{CO}_2}$

$$(b) K = \frac{(P_{\text{CO}_2})^2(P_{\text{H}_2})^5}{P_{\text{C}_2\text{H}_6}}$$

$$(c) K = \frac{(P_{\text{NH}_3})^4(P_{\text{O}_2})^5}{(P_{\text{NO}})^4(P_{\text{H}_2\text{O}})^6}$$

$$(d) K = \frac{1}{P_{\text{NH}_3}}$$

$$8. (a) K = \frac{(P_{\text{Cl}_2})[\text{I}^-]^2}{[\text{Cl}^-]^2}$$

$$(b) K = \frac{[\text{CH}_3\text{NH}_3^+]}{[\text{CH}_3\text{NH}_2][\text{H}^+]}$$

$$(c) K = \frac{[\text{Au}(\text{CN})_4^{2-}]}{[\text{Au}^{2+}][\text{CN}^-]^4}$$

$$10. (a) \text{C}_3\text{H}_6\text{O}(l) \rightleftharpoons \text{C}_3\text{H}_6\text{O}(g) \quad K = P_{\text{C}_3\text{H}_6\text{O}}$$

$$(b) 7\text{H}_2(g) + 2\text{NO}_2(g) \rightleftharpoons 2\text{NH}_3(g) + 4\text{H}_2\text{O}(g)$$

$$K = \frac{(P_{\text{NH}_3})^2(P_{\text{H}_2\text{O}})^4}{(P_{\text{H}_2})^7(P_{\text{NO}_2})^2}$$

$$(c) \text{H}_2\text{S}(g) + \text{Pb}^{2+}(aq) \rightleftharpoons \text{PbS}(s) + 2\text{H}^+(aq)$$

$$K = \frac{[\text{H}^+]^2}{(P_{\text{H}_2\text{S}})[\text{Pb}^{2+}]}$$

$$12. (a) 2\text{H}_2\text{O}(g) + 2\text{SO}_2(g) \rightleftharpoons 2\text{H}_2\text{S}(g) + 3\text{O}_2(g)$$

$$(b) \text{IF}(g) \rightleftharpoons \frac{1}{2}\text{F}_2(g) + \frac{1}{2}\text{I}_2(g)$$

$$(c) \text{Cl}_2(g) + 2\text{Br}^-(aq) \rightleftharpoons 2\text{Cl}^-(aq) + \text{Br}_2(l)$$

$$(d) 2\text{NO}_3^-(aq) + 8\text{H}^+(aq) + 3\text{Cu}(s) \rightleftharpoons 2\text{NO}(g) + 3\text{Cu}^{2+}(aq) + 4\text{H}_2\text{O}(g)$$

$$14. (a) K' = \frac{P_{\text{NOCl}}}{(P_{\text{NO}})(P_{\text{Cl}_2})^{1/2}}$$

$$(b) K'' = \frac{(P_{\text{NO}})(P_{\text{Cl}_2})}{(P_{\text{NOCl}})^2}$$

$$(c) K'' = \frac{1}{(K')^2}$$

16. (a) 67 (b) 0.015

18. (a) 9×10^{15}

20. 0.48

22. 0.838

24. (a) $\text{NOBr}(g) \rightleftharpoons \text{NO}(g) + \frac{1}{2}\text{Br}_2(g)$ (b) $K = 0.090$

26. 3.39

28. (a) No; $Q \neq K$ (b) $\longrightarrow$ 30. (a) $\longleftarrow$ (b) $\longleftarrow$ (c) $\longrightarrow$ 32. $\longrightarrow$

34. 2.3 atm

36. $P_{\text{I}_2} = 0.32$ atm; $P_{\text{Cl}_2} = 0.96$ atm38. $P_{\text{NO}} = 0.42$ atm; $P_{\text{NO}_2} = 0.32$ atm40. $P_Q = P_R = 0.188$ atm; $P_Z = 0.308$ atm42. (a) $P_{\text{NO}} = P_{\text{SO}_3} = 2.25$ atm; $P_{\text{NO}_2} = 0.25$ atm(b) $P = 5.00$ atm before and after; true only if $\Delta n_g = 0$

44. (a) 0.46 atm (b) 14.0 g

46. $P_{\text{H}_2} = P_{\text{I}_2} = 0.021$ atm

48. (a) reactants (b) products (c) same

50. (a) (1) increase (2) increase (3) no effect (4) increase
(5) increase

(b) none; (5) will decrease it

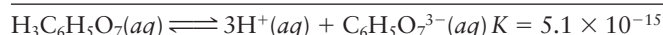
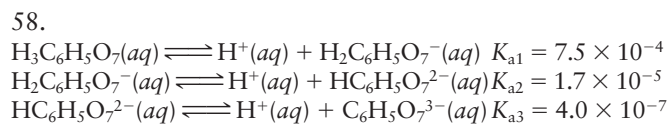
52. (a) $\longrightarrow$ (b) $\longrightarrow$ (c) $\longrightarrow$

54. (a) 0.23 (b) $P_{X_2} = 4.3 \text{ atm}$; $P_{X_{2R}} = 0.98 \text{ atm}$
 (c) $P_{X_2} = 2.41 \text{ atm}$; $P_{X_{2R}} = 0.56 \text{ atm}$
56. (a) 5.9
 (b) $P_{\text{SO}_2} = 1.93 \text{ atm}$; $P_{\text{Cl}_2} = 0.73 \text{ atm}$; $P_{\text{SO}_2\text{Cl}_2} = 0.22 \text{ atm}$
58. 0.132
60. -57 kJ
62. (a) $P_{\text{S}(\text{CH}_2\text{CH}_2\text{Cl})_2} = 0.168 \text{ atm}$; $P_{\text{SCL}_2} = 1.07 \text{ atm}$;
 $P_{\text{C}_2\text{H}_4} = 2.51 \text{ atm}$
 (b) 0.0249
64. 5.40 g
66. (a) 0.283 (b) 0.21
68. (a) $3\text{A(g)} \rightleftharpoons 2\text{B(g)}$
 (b) no; pressures still changing at 250 s
70. b
72. Will decrease and then level off sooner at a somewhat higher level
74. Endothermic; more product at a higher temperature
76. Balanced equation; temperature
77. 27
78. $K = \frac{(P_C)^c(P_D)^d}{(P_A)^a(P_B)^b} = \frac{([\text{C}]\text{RT})^c([\text{D}]\text{RT})^d}{([\text{A}]\text{RT})^a([\text{B}]\text{RT})^b}$
 $= \frac{[\text{C}]^c[\text{D}]^d}{[\text{A}]^a[\text{B}]^b} (\text{RT})^{(c+d)-(a+b)}$
 $\Delta n_g = (c + d) - (a + b)$; $K = K_c(\text{RT})^{\Delta n_g}$
79. $P_{\text{N}_2} = 0.33 \text{ atm}$; $P_{\text{H}_2} = 0.99 \text{ atm}$; $P_{\text{NH}_3} = 0.34 \text{ atm}$
80. 0.0442
81. 0.52 atm
82. 1.1
83. 25; 0.65 atm
84. (a) 0.22 atm (b) 0.4 g
85. 9.57
86. 2.29

Chapter 13

2. (a) Brønsted-Lowry acid: H_2O , HCN
 Brønsted-Lowry base: CN^- , OH^-
 acid-base pairs: H_2O , OH^- ; HCN , CN^-
- (b) Brønsted-Lowry acid: H_3O^+ , H_2CO_3
 Brønsted-Lowry base: HCO_3^- , H_2O
 acid-base pairs: H_3O^+ , H_2O ; H_2CO_3 , HCO_3^-
- (c) Brønsted-Lowry acid: $\text{HC}_2\text{H}_3\text{O}_2$, H_2S
 Brønsted-Lowry base: HS^- , $\text{C}_2\text{H}_3\text{O}_2^-$
 acid-base pairs: $\text{HC}_2\text{H}_3\text{O}_2$, $\text{C}_2\text{H}_3\text{O}_2^-$; H_2S , HS^-
4. as acid: HAsO_4^{2-} as base: CH_3O^- , CO_3^{2-} , HAsO_4^{2-}
6. (a) HAsO_4^{2-} (b) $\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2$ (c) ClO_3^-
 (d) NH_3 (e) $\text{C}_2\text{H}_3\text{O}_2^-$
8. (a) acid: $\text{HCO}_3^-(\text{aq}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq})$
 (b) base: $\text{HCO}_3^-(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{OH}^-(\text{aq}) + \text{H}_2\text{CO}_3(\text{aq})$
10. (a) $\text{Zn}(\text{H}_2\text{O})_3\text{OH}^+(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{Zn}(\text{H}_2\text{O})_2(\text{OH})_2(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
 (b) $\text{HSO}_4^-(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{SO}_4^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
 (c) $\text{HNO}_2(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{NO}_2^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
 (d) $\text{Fe}(\text{H}_2\text{O})_6^{2+}(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{Fe}(\text{H}_2\text{O})_5\text{OH}^+(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
 (e) $\text{HC}_2\text{H}_3\text{O}_2(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{C}_2\text{H}_3\text{O}_2^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
 (f) $\text{H}_2\text{PO}_4^-(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{HPO}_4^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
12. (a) $(\text{CH}_3)_3\text{N}(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons (\text{CH}_3)_3\text{NH}^+(\text{aq}) + \text{OH}^-(\text{aq})$
 (b) $\text{HC}_2\text{O}_4^-(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{C}_2\text{O}_4(\text{aq}) + \text{OH}^-(\text{aq})$

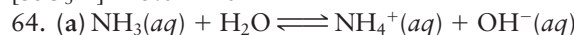
- (c) $\text{CN}^-(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{HCN}(\text{aq}) + \text{OH}^-(\text{aq})$
 (d) $\text{S}^{2-}(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{HS}^-(\text{aq}) + \text{OH}^-(\text{aq})$
 (e) $\text{BrO}_3^-(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{HBrO}_3(\text{aq}) + \text{OH}^-(\text{aq})$
 (f) $\text{H}_2\text{C}_6\text{O}_5\text{H}_7^-(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{C}_6\text{O}_5\text{H}_7(\text{aq}) + \text{OH}^-(\text{aq})$
14. (a) 2.57 acidic
 (b) -0.18 acidic
 (c) 12.84 basic
 (d) 8.19 basic
16. (a) $[\text{H}^+] = 5.8$; $[\text{OH}^-] = 1.7 \times 10^{-15}$
 (b) $[\text{H}^+] = 7.8 \times 10^{-10}$; $[\text{OH}^-] = 1.3 \times 10^{-5}$
 (c) $[\text{H}^+] = 1.5 \times 10^{-4}$; $[\text{OH}^-] = 6.7 \times 10^{-11}$
 (d) $[\text{H}^+] = 8.3 \times 10^{-13}$; $[\text{OH}^-] = 0.012$
18. (a) $1.4 \times 10^{-6} \text{ M}$ $7.2 \times 10^{-9} \text{ M}$ 5.86 8.14 No
 (b) $5.2 \times 10^{-14} \text{ M}$ 0.19 M 13.28 0.72 Yes
 (c) $2.3 \times 10^{-12} \text{ M}$ $4.3 \times 10^{-3} \text{ M}$ 11.63 2.37 Yes
 (d) 2.75 M $3.64 \times 10^{-15} \text{ M}$ -0.44 14.44 No
20. Solution R is more basic; solution Q has a smaller pH.
22. (a) A: $4.8 \times 10^{-13} \text{ M}$ B: $1.4 \times 10^{-12} \text{ M}$
 C: $6.9 \times 10^{-7} \text{ M}$
 (b) B: 11.85 C: 6.16
 (c) A is basic, B is basic, C is acidic
24. (a) cola: $7.9 \times 10^{-4} \text{ M}$; green tea: $1.6 \times 10^{-6} \text{ M}$
 (b) ratio: 5.0×10^2 ; cola is 500 times more acidic than green tea
26. (a) $[\text{H}^+] = 1.90 \text{ M}$; $\text{pH} = -0.28$; same pH in 10.0-mL sample
 (b) $[\text{H}^+] = 0.021 \text{ M}$; $\text{pH} = 1.67$ in 1.28 L of solution;
 $[\text{H}^+] = 0.21 \text{ M}$; $\text{pH} = 0.67$ in 0.128 L of solution
28. (a) $[\text{OH}^-] = 0.0293 \text{ M}$; $[\text{H}^+] = 3.4 \times 10^{-13} \text{ M}$;
 $\text{pH} = 12.47$
 (b) $[\text{OH}^-] = 0.199 \text{ M}$; $[\text{H}^+] = 5.02 \times 10^{-14} \text{ M}$;
 $\text{pH} = 13.30$
30. 0.792
32. 11.94
34. (a) $\text{HSO}_3^-(\text{aq}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{SO}_3^{2-}(\text{aq})$
 $K_a = \frac{[\text{H}^+][\text{SO}_3^{2-}]}{[\text{HSO}_3^-]}$
 (b) $\text{HPO}_4^{2-}(\text{aq}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{PO}_4^{3-}(\text{aq})$
 $K_a = \frac{[\text{H}^+][\text{PO}_4^{3-}]}{[\text{HPO}_4^{2-}]}$
 (c) $\text{HNO}_2(\text{aq}) \rightleftharpoons \text{NO}_2^-(\text{aq}) + \text{H}^+(\text{aq})$
 $K_a = \frac{[\text{H}^+][\text{NO}_2^-]}{[\text{HNO}_2]}$
36. (a) 3.74 (b) 7.17 (c) 10.31
38. (a) $\text{C} < \text{D} < \text{B} < \text{A}$ (b) A
40. $\text{HCl} > \text{HF} > \text{HClO} > \text{HCN}$
42. $\text{HCl} < \text{HF} < \text{HClO} < \text{HCN}$
44. 8.7×10^{-12}
46. 1.91×10^{-10}
48. 1.0×10^{-4}
50. 3.77
52. (a) 2.0×10^{-2} (b) 2.8×10^{-2}
54. (a) $3.07 \times 10^{-3} \text{ M}$ (b) $3.3 \times 10^{-12} \text{ M}$
 (c) 2.51 (d) 1.3%
56. 2.29; 1.3%



60. $\text{pH} = 2.00$; $[\text{HX}^-] = 1.0 \times 10^{-2} \text{ M}$; $[\text{X}^{2-}] = 9.7 \times 10^{-8} \text{ M}$

62. $\text{pH} = 1.05$; $[\text{HSeO}_3^-] = 0.088 \text{ M}$,

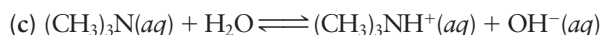
$[\text{SeO}_3^{2-}] = 5.0 \times 10^{-8} \text{ M}$



$$K_b = \frac{[\text{NH}_4^+][\text{OH}^-]}{[\text{NH}_3]}$$



$$K_b = \frac{[\text{H}_2\text{S}][\text{OH}^-]}{[\text{HS}^-]}$$

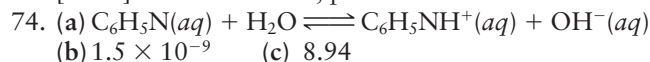


$$K_b = \frac{[(\text{CH}_3)_3\text{NH}^+][\text{OH}^-]}{[(\text{CH}_3)_3\text{N}]}$$

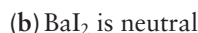
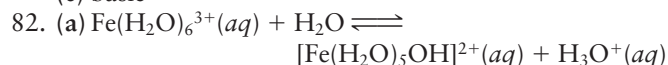


70. (a) 6.7×10^{-11} (b) 6.7×10^{-10}

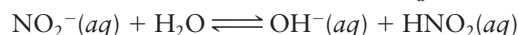
72. $[\text{OH}^-] = 1.3 \times 10^{-4} \text{ M}$; $\text{pH} = 10.11$



76. $2.1 \times 10^2 \text{ g}$



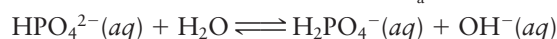
$$K_a = 5.6 \times 10^{-10}$$



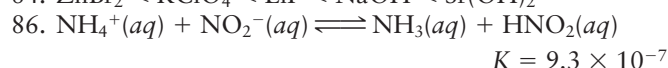
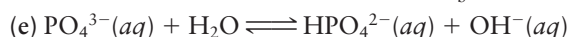
$$K_b = 1.7 \times 10^{-11}$$



$$K_a = 4.5 \times 10^{-13}$$



$$K_b = 1.6 \times 10^{-7}$$



Equilibrium is in the direction of the reactants; reaction unlikely.

88. 68 L

90. 5.5 g

92. 4.6 g

94. 9.8×10^{-9}

96. c

98. (a) LT (b) LT (c) EQ

(d) MI (e) LT (f) GT



102. Dissolve 0.10 mol in water, measure pH. If $\text{pH} > 7$, solid is basic; $\text{pH} < 13.0$, it is a weak base. If $\text{pH} < 7$, solid is acidic; if $\text{pH} > 1.0$, it is a weak acid.

103. 1.52

104. (a) -5.58 kJ (b) -6.83 kJ

105. 13.06

106. $1.7 \times 10^2 \text{ mL}$

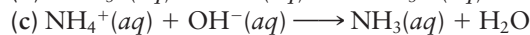
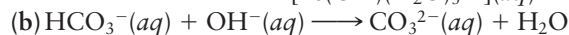
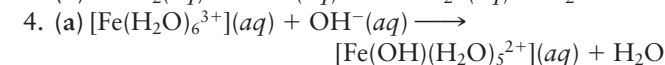
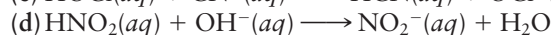
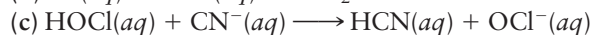
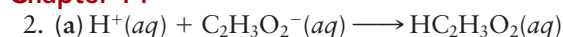
107. -1.64°C

108. 12.62

109. HA

110. 5.2×10^{-7}

Chapter 14



6. (a) 5.6×10^4 (b) 1.0×10^{14} (c) 48
 (d) 6.0×10^{10}

8. (a) 6.7×10^{11} (b) 4.8×10^3 (c) 5.6×10^4

10. (a) $[\text{OH}^-] = 9.67 \times 10^{-9}$; $\text{pH} = 5.99$

(b) $[\text{OH}^-] = 9.60 \times 10^{-8}$; $\text{pH} = 6.98$

(c) $[\text{OH}^-] = 1.95 \times 10^{-7}$; $\text{pH} = 7.29$

(d) $[\text{OH}^-] = 3.1 \times 10^{-7}$; $\text{pH} = 7.50$

(e) $[\text{OH}^-] = 4.75 \times 10^{-7}$; $\text{pH} = 7.68$

12. 4.25

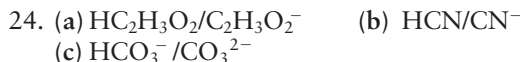
14. (a) 8.51 (b) pH remains the same.

16. 7.55

18. d

20. 5.08

22. 9.59



26. (a) 0.18:1 (b) 0.10

(c) $9.2 \times 10^2 \text{ mL}$ (d) $4.8 \times 10^2 \text{ mL}$

28. (a) 0.429 M OH^- ; 0.0249 M H^+

(b) 0.429 M OH^- ; 0.247 M H^+

(c) 0.429 M OH^- ; 0.504 M H^+

(d) 0.429 M OH^- ; 0.811 M H^+

(e) 0.429 M OH^- ; 1.22 M H^+

30. (a) 4.288

(b) 3.659

(c) 4.857

32. (a) 4.288 (b) 1.23 (c) 12.76

(d) In both problems (a) is the same. The pH in (b) and (c) differ dramatically.

(e) Dilution does not affect pH but drastically reduces the buffer capacity.

34. (a) 4.47 (b) 4.67 (c) 0.22

36. (a) 0.64 (b) 37% (c) 65%

38. (a) methyl orange (b) phenolphthalein

(c) all three will work (d) methyl orange

40. (a) 3.2×10^{-10} (b) 8.5 – 10.5
 (c) blue

42. (a) 35.5 mL (b) 7 (c) $[K^+] = [Cl^-] = 0.109\text{ M}$
 44. (a) $HSO_3^-(aq) + OH^-(aq) \longrightarrow SO_3^{2-}(aq) + H_2O$
 (b) 0.109 M
 (c) $[Na^+] = [K^+] = [SO_3^{2-}] = 0.0749\text{ M}$;
 $[OH^-] = [HSO_3^-] = 1.1 \times 10^{-4}\text{ M}$
 (d) 10.04

46. (a) $BrO_3^-(aq) + H^+(aq) \rightleftharpoons HBrO(aq)$
 (b) 64.6 mL
 (c) 4.68
 (d) $[H^+] = [BrO^-] = 2.07 \times 10^{-5}\text{ M}$;
 $[K^+] = [NO_3^-] = [HBrO] = 0.171\text{ M}$

48. (a) $H^+(aq) + OH^-(aq) \rightleftharpoons H_2O$
 (b) H_2O , K^+ , Br^-
 (c) 32.5 mL
 (d) 1. 0.57; 2. 1.06; 3. 7

50. (a) $C_{17}H_{19}O_3N(aq) + H^+(aq) \rightleftharpoons C_{17}H_{19}O_3NH^+(aq)$
 (b) $C_{17}H_{19}O_3NH^+$, Cl^- (c) 71.8 mL (d) 10.52
 (e) 7.87 (f) 4.54

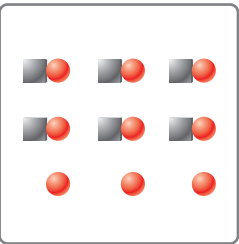
52. (a) 2.86 (b) 4.18 (c) 8.30

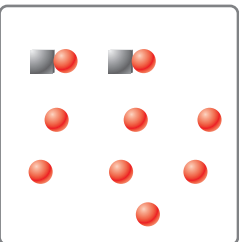
54. 14.2 L

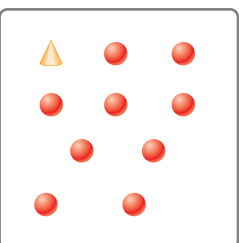
56. (a) 45.1 g/mol (b) 5.9×10^{-4} (c) 1.7×10^{-11}

58. 62 mL

60. (a) 2.30 (b) 2.10

62. (a)  buffer

- (b)  buffer

- (c)  base

64. (a) EQ (b) GT (c) GT (d) MI (e) LT

66. a and d

68. Measure freezing point of solution:

1 L HCl has 2.0×10^{-3} mol particles (H^+ , Cl^- ions)

1 L $HCHO_2$ has $\approx 6.0 \times 10^{-3}$ mol particles ($HCHO_2$ molecules)

1 L $C_6H_5NH_3^+$ has $\approx 8.0 \times 10^{-2}$ mol particles ($C_6H_5NH_3^+$, Cl^- ions)

Or, one could measure the pH at the equivalence point after titration with a strong base.

$HCl < HCHO_2 < C_6H_5NH_3^+$

70. 2.87

71. 33 mL

72. $1.1 \times 10^2\text{ g/mol}$

73. $\frac{[NH_4^+]}{[NH_3]} = 5.7 \times 10^2$

74. (a) 1.61 (b) 3.22 (c) 8.44
 (d) 5.92 (e) 10.89

75. $x = 2$

76. (a) 0.8239 (b) 0.80

77. 4.6×10^{-6}

78. 6.0 g

79. 15.1 g

80. (a) Yes, excess OH^- in solution.

- (b) 1.172 M (c) 2.26 mL

Chapter 15

2. (a) $3 \times 10^{-3}\text{ M}$ (b) $5 \times 10^{-5}\text{ M}$

4. 1.8×10^{-4}

6. (a) $AgCl(s) \rightleftharpoons Ag^+(aq) + Cl^-(aq)$

$$K_{sp} = [Ag^+] \times [Cl^-]$$

- (b) $Al_2(CO_3)_3(s) \rightleftharpoons 2Al^{3+}(aq) + 3CO_3^{2-}(aq)$

$$K_{sp} = [Al^{3+}]^2 \times [CO_3^{2-}]^3$$

- (c) $MnS_2(s) \rightleftharpoons Mn^{4+}(aq) + 2S^{2-}(aq)$

$$K_{sp} = [Mn^{4+}] \times [S^{2-}]^2$$

- (d) $Mg(OH)_2(s) \rightleftharpoons Mg^{2+}(aq) + 2OH^-(aq)$

$$K_{sp} = [Mg^{2+}] \times [OH^-]^2$$

8. (a) $PbO_2(s) \rightleftharpoons Pb^{4+}(aq) + 2O^{2-}(aq)$

- (b) $Hg_3(PO_4)_2(s) \rightleftharpoons 3Hg^{2+}(aq) + 2PO_4^{3-}(aq)$

- (c) $Ni(OH)_3(s) \rightleftharpoons Ni^{3+}(aq) + 3OH^-(aq)$

- (d) $Ag_2SO_4(s) \rightleftharpoons 2Ag^+(aq) + SO_4^{2-}(aq)$

10. (a) $[Li^+] = 0.016\text{ M}$ (b) $[NO_2^-] = 0.024\text{ M}$

- (c) $[Sn^{2+}] = 2.9 \times 10^{-19}\text{ M}$

12. (a) 4.0×10^{-5} (b) 0.18 M (c) 2×10^{-11}

14. (a) $[Ba^{2+}] = [C_2O_4^{2-}] = 1.3 \times 10^{-3}\text{ M}$

- (b) $[OH^-] = 2.9 \times 10^{-8}\text{ M}$

- (c) $[Pb^{2+}] = 2 \times 10^{-15}\text{ M}$

16. (a) $3 \times 10^{-4}\text{ M}$ (b) $1 \times 10^{-10}\text{ M}$ (c) $6 \times 10^{-6}\text{ M}$

18. (a) 8.5×10^{-5} (b) 1.7×10^{-13} (c) 8.2×10^{-33}

20. (a) $6 \times 10^{-3}\text{ g/L}$ (b) $5 \times 10^{-8}\text{ g/L}$ (c) $1 \times 10^{-3}\text{ g/L}$

22. 5.49×10^{-16}

24. (a) yes (b) no

26. 9.1×10^{-15}

28. (a) $[Cd^{2+}] = 1.4 \times 10^{-5}\text{ M}$

- (b) 8.64

- (c) $1.0 \times 10^1\%$

30. yes; $1.0 \times 10^{-2}\text{ M}$

32. (a) yes

- (b) $[Ag^+] = 1.6 \times 10^{-2}\text{ M}$; $[CO_3^{2-}] = 3 \times 10^{-8}\text{ M}$;

- $[Na^+] = 6.22 \times 10^{-4}\text{ M}$; $[NO_3^-] = 1.7 \times 10^{-2}\text{ M}$

34. (a) $Pb(OH)_2$ (b) 9.26

36. (a) $PbCrO_4$ (b) $3 \times 10^{-12}\text{ M}$

38. Both $BaCO_3$ and $CaCO_3$ will precipitate.

40. (a) $CaF_2(s) + 2H^+(aq) \rightleftharpoons Ca^{2+}(aq) + 2HF(aq)$

- (b) $CuCO_3(s) + 2H^+(aq) \rightleftharpoons Cu^{2+}(aq) + H_2CO_3(aq)$

- (c) $Ti(OH)_3(s) + 3H^+(aq) \rightleftharpoons Ti^{3+}(aq) + 3H_2O$

- (d) $Sn(OH)_6^{2-}(aq) + H^+(aq) \rightleftharpoons Sn(OH)_5^-(aq) + H_2O$

- (e) $Cd(NH_3)_4^{2+}(aq) + H^+(aq) \rightleftharpoons Cd(NH_3)_3^{2+}(aq) + NH_4^+(aq)$

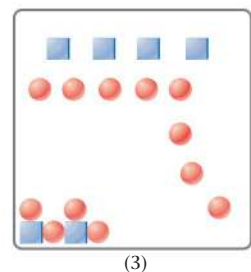
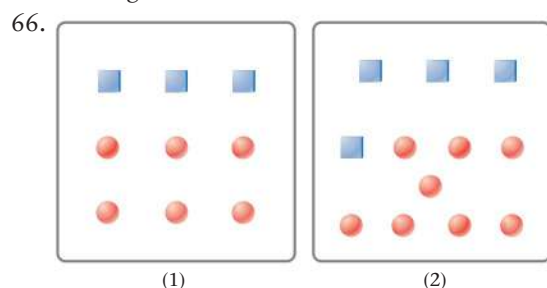
42. (a) $Cu(OH)_2(s) + 4NH_3(aq) \longrightarrow Cu(NH_3)_4^{2+}(aq) + 2OH^-(aq)$

- (b) $Cd^{2+}(aq) + 4NH_3(aq) \longrightarrow Cd(NH_3)_4^{2+}(aq)$

- (c) $Pb^{2+}(aq) + 2NH_3(aq) + 2H_2O \longrightarrow Pb(OH)_2(s) + 2NH_4^+(aq)$

44. (a) $\text{Al}^{3+}(aq) + 4\text{OH}^{-}(aq) \rightleftharpoons \text{Al}(\text{OH})_4^{-}(aq)$
 (b) $\text{Al}^{3+}(aq) + \text{PO}_4^{3-}(aq) \rightleftharpoons \text{AlPO}_4(s)$
 (c) $\text{Al}(\text{OH})_3(s) + 3\text{H}^{+}(aq) \rightleftharpoons \text{Al}^{3+}(aq) + 3\text{H}_2\text{O}$
 46. $\text{Co}(\text{OH})_2(s) + 2\text{H}^{+}(aq) \rightleftharpoons \text{Co}^{2+}(aq) + 2\text{H}_2\text{O};$
 $K = 2 \times 10^{12}$

48. (a) 1.6×10^3 (b) yes
 50. (a) 4×10^{-7} (b) 0.03 mol/L
 52. 2×10^2
 54. (a) 1.2×10^{-2} (b) 3 M
 56. 6.8×10^{-4}
 58. 8.2×10^{-4}
 60. (a) $\leftarrow$ (b) $\leftarrow$ (c) $\leftarrow$
 62. (a) $3.8 \times 10^{-4} \text{ M}$ (b) no (c) 0.022 M
 64. $\approx 2 \text{ mg}$



68. a
 70. yes
 72. (a) (3) (b) (5) (c) (2) (d) (1)
 73. In HCN: $2 \times 10^{-3} \text{ M}$; In H_2O : $2 \times 10^{-6} \text{ M}$
 74. $1.9 \times 10^{-4} \text{ mol/L}$
 75. $1.4 \times 10^{-4} \text{ M}$
 76. (a) $1 \times 10^{-5} \text{ M}$ (b) $\text{Al}(\text{OH})_3, \text{Fe}(\text{OH})_3$
 (c) virtually all (d) 1.6 g
 77. (a) 8×10^5 (b) 4×10^3
 78. 5.7×10^{31}

Chapter 16

2. (a) spontaneous (b) nonspontaneous
 (c) nonspontaneous
 4. (a) no (b) no (c) yes
 6. a
 8. (a) $\text{O}_2(g)$ with 758 mm Hg pressure
 (b) glucose(s)
 (c) $\text{Hg}(l)$
 10. (a) - (b) + (c) +
 12. (a) can't say (b) + (c) - (d) +
 14. (a) - (b) + (c) +
 16. (c) < (b) < (a) < (d)
 18. (a) 180.8 J/K (b) 605.9 J/K
 (c) 2.9 J/K (d) -93.1 J/K
 20. (a) -976.1 J/K (b) -816.0 J/K (c) -97.4 J/K
 22. (a) -0.1319 kJ/K (b) -0.2712 kJ/K
 (c) -0.5330 kJ/K

24. (a) -294 kJ (b) 140.9 kJ (c) -498 kJ
 26. (a) -980.6 kJ; spontaneous
 (b) -893.6; spontaneous
 (c) -394.7 kJ; spontaneous
 (d) -298; spontaneous
 28. (a) -793.6 kJ (b) 224.2 kJ (c) -1226.6 kJ
 30. (a) -184.1 kJ/mol (b) -166.4 kJ/mol
 (c) -53.5 kJ/mol
 32. $\Delta G^\circ = -6.0 \times 10^1 \text{ kJ}$; plausible
 34. at 27°C: -359.3 kJ at 39°C: -359.5 kJ
 36. (a) 0.132 kJ/K; yes (b) 0.0956 kJ/mol · K
 (c) -510.9 kJ/mol
 38. (a) -0.918 kJ/K (b) -0.159 kJ/mol · K
 40. (a) spontaneous at high T ; nonspontaneous at low T
 (b) spontaneous at low T ; nonspontaneous at high T
 (c) spontaneous at any T ; temperature has no effect
 42. (a) spontaneous above 1157°C
 (b) spontaneous below -142°C
 (c) spontaneous at any T
 44. 197°C
 46. (a) $\Delta G = 492 \text{ kJ} - T(0.327 \text{ kJ/K})$
 (b) 1504 K; spontaneous above 1504 K
 48. Heated with C (coke)
 50. 282 K
 52. not at equilibrium at any temperature when $P = 1 \text{ atm}$
 54. 332 K = 59°C
 56. (a) no; $\Delta G = 20.3 \text{ kJ}$
 (b) yes; $\Delta G = -12.3 \text{ kJ}$
 58. (a) 368.0 kJ (b) 323 kJ
 60. (a) 55.7 kJ (b) $1.1 \times 10^{-5} \text{ M}$
 (c) yes; $K_{sp} = 1.1 \times 10^{-10}$
 62. (a) 52.6 kJ (b) 6×10^{-10}
 64. (a) 105 kJ (b) 104 kJ/mol
 66. (a) -7.43 kJ (b) 0.15
 68. 6.9×10^{-4}
 70. 35.3 kJ/mol
 72. 130.4 kJ
 74. (a) $\Delta G^\circ = 201.3 \text{ kJ}$ (nonspontaneous)
 (b) $\Delta G^\circ = -98.9 \text{ kJ}$
 76. $\text{C}_6\text{H}_{12}\text{O}_6(s) + 6\text{O}_2(g) + 80\text{ADP} + 80\text{HPO}_4^{2-}(aq) +$
 $160\text{H}^{+}(aq) \longrightarrow 80\text{ATP} + 86\text{H}_2\text{O} + 6\text{CO}_2(g)$
 78. 510 K = 238°C
 80. ΔG for overall reaction is -2016 kJ
 82. 4.4×10^{-3}
 84. (a) False
 (b) False
 (c) False
 (d) False
 86. (a) 0 K (b) 1 (c) larger
 88. (a) Entropy decreases because $S^\circ_{\text{gas}} > S^\circ_{\text{solid}}$ or S°_{liq}
 (b) ΔS° is the difference between entropy of products and reactants.
 (c) A solid has fewer options for placement of particles, i.e., more orderly.
 90. (a) Increase in T decreases ΔG° (b) yes (c) no
 (d) $\approx 350 \text{ K} = 77^\circ\text{C}$ (e) 7.6×10^{-3}
 92. (a) LT (b) LT (c) MI
 93. 0.2827 kJ/mol
 94. $P_{\text{H}_2} = P_{\text{I}_2} = 0.07 \text{ atm}$ $P_{\text{HI}} = 0.46 \text{ atm}$
 95. (a) 6.00 kJ (b) 0 (c) 0.0220 kJ/K
 (d) 0.43 kJ (e) -0.45 kJ

96. (a) 4.2 kJ (b) $\approx 5.2 \times 10^2$ g
 97. 1430 K
 98. (1) $\Delta G^\circ = 146 - 0.1104 T$; becomes spontaneous above 1050°C
 (2) $\Delta G^\circ = 168.6 - 0.0758 T$; becomes spontaneous above 1950°C
 99. -0.10 kJ/mol · K
 100. 26.7 kJ
 101. 464 K
 102. 0.2598 kJ/mol

Chapter 17

2. (a) $\text{CH}_3\text{OH}(aq) + \text{H}_2\text{O} \longrightarrow \text{CO}_2(g) + 6e^- + 6\text{H}^+(aq)$
 (b) $\text{NO}_3^-(aq) + 8e^- + 10\text{H}^+ \longrightarrow \text{NH}_4^+(aq) + 3\text{H}_2\text{O}$
 (c) $\text{Fe}^{3+}(aq) + 3e^- \longrightarrow \text{Fe}(s)$
 (d) $\text{V}^{2+}(aq) + 6\text{OH}^-(aq) \longrightarrow \text{VO}_3^-(aq) + 3e^- + 3\text{H}_2\text{O}$
 4. (a) $2\text{H}^+(aq) + \text{H}_2\text{O}_2(aq) + 2\text{Ni}^{2+}(aq) \longrightarrow 2\text{Ni}^{3+}(aq) + 2\text{H}_2\text{O}$
 (b) $14\text{H}^+(aq) + \text{Cr}_2\text{O}_7^{2-}(aq) + 3\text{Sn}^{2+}(aq) \longrightarrow 2\text{Cr}^{3+}(aq) + 3\text{Sn}^{4+}(aq) + 7\text{H}_2\text{O}$
 6. (a) $\text{P}_4(s) + 12\text{Cl}^-(aq) + 12\text{H}^+(aq) \longrightarrow 4\text{PH}_3(g) + 6\text{Cl}_2(g)$
 (b) $2\text{MnO}_4^-(aq) + 6\text{H}^+(aq) + 5\text{NO}_2^-(aq) \longrightarrow 2\text{Mn}^{2+}(aq) + 3\text{H}_2\text{O} + 5\text{NO}_3^-(aq)$
 (c) $3\text{HBrO}_3(aq) + 2\text{Bi}(s) \longrightarrow 3\text{HBrO}_2(aq) + \text{Bi}_2\text{O}_3(s)$
 (d) $2\text{CrO}_4^{2-}(aq) + 3\text{SO}_3^{2-}(aq) + 10\text{H}^+(aq) \longrightarrow 2\text{Cr}^{3+}(aq) + 3\text{SO}_4^{2-}(aq) + 5\text{H}_2\text{O}$
 8. (a) $3\text{Ca}(s) + 8\text{H}_2\text{O} + 2\text{VO}_4^{3-}(aq) \longrightarrow 3\text{Ca}^{2+}(aq) + 2\text{V}^{2+}(aq) + 16\text{OH}^-(aq)$
 (b) $\text{C}_2\text{H}_4(g) + 10\text{H}_2\text{O} + 6\text{BiO}_3^-(aq) \longrightarrow 2\text{CO}_2(g) + 6\text{Bi}^{3+}(aq) + 24\text{OH}^-(aq)$
 (c) $2\text{H}_2\text{O} + 2\text{PbO}_2(s) \longrightarrow 2\text{Pb}^{2+}(aq) + \text{O}_2(g) + 4\text{OH}^-(aq)$
 (d) $16\text{Cl}^-(aq) + 9\text{H}_2\text{O} + 3\text{IO}_3^-(aq) \longrightarrow 8\text{Cl}_2(g) + \text{I}_3^-(aq) + 18\text{OH}^-(aq)$
 10. (a) $2\text{NO}(g) + 5\text{H}_2(g) \longrightarrow 2\text{NH}_3(g) + 2\text{H}_2\text{O}(g)$
 (b) $\text{H}_2\text{O}_2(aq) + 2\text{ClO}^-(aq) + 2\text{H}^+(aq) \longrightarrow \text{O}_2(g) + \text{Cl}_2(g) + 2\text{H}_2\text{O}$
 (c) $\text{Zn}(s) + 2\text{VO}^{2+}(aq) + 4\text{H}^+(aq) \longrightarrow \text{Zn}^{2+}(aq) + 2\text{V}^{3+}(aq) + 2\text{H}_2\text{O}$
 12. (a) $3\text{Cd}(s) + 2\text{Sb}^{3+}(aq) \longrightarrow 3\text{Cd}^{2+}(aq) + 2\text{Sb}(s)$
 (b) $2\text{Cu}^+(aq) + \text{Mg}^{2+}(aq) \longrightarrow 2\text{Cu}^{2+}(aq) + \text{Mg}(s)$
 (c) $2\text{Cr}^{3+}(aq) + \text{ClO}_3^-(aq) + 4\text{H}_2\text{O} \longrightarrow \text{Cr}_2\text{O}_7^{2-}(aq) + \text{Cl}^-(aq) + 8\text{H}^+(aq)$
 14. (a) Sn anode, Ag cathode; e^- move from Sn to Ag. Anions move to Sn and cations to Ag.
 (b) Pt both anode and cathode. Anode has H_2 gas and H^+ ; cathode has chloride ions, Hg and Hg_2Cl_2 . e^- move from anode to cathode. Anions move to the anode; cations move to the cathode.
 (c) Pb anode and PbO_2 cathode. e^- move from Pb to PbO_2 . Anions move to Pb; cations to PbO_2 .
 16. (a) anode to cathode
 (b) Pt
 (c) $\text{MnO}_4^-(aq) + 8\text{H}^+(aq) + 5e^- \longrightarrow \text{Mn}^{2+}(aq) + 4\text{H}_2\text{O}$
 18. anode: $2\text{I}^-(aq) \longrightarrow \text{I}_2(s) + 2e^-$
 cathode: $\text{Br}_2(l) + 2e^- \longrightarrow 2\text{Br}^-(aq)$
 overall: $\text{Br}_2(l) + 2\text{I}^-(aq) \longrightarrow 2\text{Br}^-(aq) + \text{I}_2(s)$
 cell notation: $\text{Pt} \mid \text{I}^- \mid \text{I}_2 \parallel \text{Br}_2, \text{Br}^- \mid \text{Pt}$

20. (a) Br^- (b) Ni (c) Hg_2^{2+}
 22. $\text{K}^+ < \text{Mn}^{2+} < \text{S} < \text{Cl}_2 < \text{Co}^{3+}$
 24. oxidizing agents: $\text{Fe}^{2+} < \text{Ni}^{2+} < \text{H}^+ < \text{Cu}^+$
 reducing agents: $\text{Fe}^{2+} < \text{Cu}^+ < \text{Zn}$
 both oxidizing and reducing agents: $\text{Cu}^+, \text{Fe}^{2+}$
 26. (a) Co^{2+} (b) Mn (c) Co^{3+} (d) Mn^{2+}
 (e) yes (f) no (g) $\text{Co}^{3+}, \text{Fe}^{3+}$ (h) Cd, Pb, Mn
 28. (a) O_2 (b) Na, Ca (c) Ca, Ba, K
 30. (a) 2.305 V (b) 1.83 V (c) -0.846 V
 32. (a) 0.562 V (b) 0.534 V
 34. (a) -0.645 V (b) 2.02 V (c) 0.743 V
 36. (a) -0.300 V (b) $+1.377$ V (c) $+0.213$ V; same
 38. a
 40. (1) $2\text{Co}^{3+}(aq) + 2\text{I}^-(aq) \longrightarrow 2\text{Co}^{2+}(aq) + \text{I}_2(s)$
 $E^\circ = 1.419$ V
 (2) $6\text{Co}^{3+}(aq) + 2\text{Cr}^{3+}(aq) + 7\text{H}_2\text{O} \longrightarrow 6\text{Co}^{2+}(aq) + 14\text{H}^+(aq) + \text{Cr}_2\text{O}_7^{2-}(aq)$ $E^\circ = 0.623$ V
 (3) $\text{Cr}_2\text{O}_7^{2-}(aq) + 14\text{H}^+(aq) + 6\text{I}^-(aq) \longrightarrow 3\text{I}_2(s) + 2\text{Cr}^{3+}(aq) + 7\text{H}_2\text{O}$ $E^\circ = 0.796$ V
 42. (a) Nitrate will oxidize Cu to Cu^{2+} but not Au to Au^{3+} .
 (b) no product
 (c) Both acidic and basic mediums will work.
 44. (a) no reaction
 (b) $\text{MnO}_2(s) + 4\text{H}^+(aq) + 2\text{Hg}(l) \longrightarrow \text{Mn}^{2+}(aq) + 2\text{H}_2\text{O} + \text{Hg}_2^{2+}(aq)$ $E^\circ = +0.433$ V
 (c) no reaction
 46. Na and Pb
 48. (a) no reaction
 (b) no reaction
 (c) $2\text{Cr}^{2+}(aq) + \text{S}(s) + 2\text{H}^+(aq) \longrightarrow 2\text{Cr}^{3+}(aq) + \text{H}_2\text{S}(aq)$
 50. (a) $\Delta G^\circ = 15.9$ kJ; $E^\circ = -0.041$ V
 (b) $\Delta G^\circ = -45.2$ kJ; $K = 8.3 \times 10^7$
 (c) $E^\circ = 0.015$ V; $K = 10$
 52. (a) -104 kJ (b) -208 kJ (c) -312 kJ
 54. $E^\circ = 0.054$ V; $\Delta G^\circ = -52$ kJ; $K = 1.3 \times 10^9$
 56. (a) -444.8 kJ (b) -1059 kJ (c) 325.3 kJ
 58. (a) 1×10^{19} (b) 1×10^{18}
 60. 1.57×10^{25}
 62. 0.29 V
 64. (a) 0.152 V (b) $E = 0.152 - \frac{0.0257}{2} \ln \frac{[\text{Mn}^{2+}]}{[\text{Br}^-]^2[\text{H}^+]^4}$
 (c) -0.221 V
 66. (a) 0.305 V
 (b) $E = 0.305 - \frac{0.0257}{6} \ln \frac{(P_{\text{NO}})^2[\text{OH}^-]^8}{[\text{S}^{2-}]^3[\text{NO}_3^-]^2}$
 (c) 0.299 V
 68. (a) 0.319 V (b) -0.369 V
 70. 1.2
 72. $[\text{H}^+] = 8 \times 10^{-7}$ M
 74. (a) yes; $E^\circ = 0.899$ V (b) yes; $E = 0.534$ V
 (c) no; $E = -0.058$ V (d) 7.51
 76. (a) 0.127 V (b) 1.6×10^{-3} M (c) 1.6×10^{-5}
 78. (a) $1.37 \times 10^{23} e^-$ (b) 2.20×10^4 C
 (c) 2.30 g H_2 ; 8.08 g Cl_2
 80. (a) 7.3×10^3 C (b) Cu
 82. (a) 5.92 g (b) 6.91 min
 84. (a) 8.4×10^7 J (b) \$2.1
 86. 0.550 g Cd; 0.810 g Ni_2O_3
 88. (a) -1.596 V (b) 1.0 g

90. 96 g
 92. 0.896 V
 94. no ($E = -0.400$ V)
 96. c
 98. b
 100. (a) (1) $2\text{Tl}(s) + \text{Tl}^{3+}(aq) \longrightarrow 3\text{Tl}^{+}(aq)$
 (2) $2\text{Tl}(s) + \text{Tl}^{3+}(aq) \longrightarrow 3\text{Tl}^{+}(aq)$
 (3) $2\text{Tl}(s) + \text{Tl}^{3+}(aq) \longrightarrow 3\text{Tl}^{+}(aq)$
 (b) (1) 1.62 V (2) 0.54 V (3) 1.08 V
 (c) (1) -313 kJ (2) -313 kJ (3) -313 kJ
 (d) ΔG° is a state property; E° is not.
 102. $Y > X > Z$
 103. $\approx 31.8\%$ Sn and 68.2% Cu
 104. 2.007 V
 105. (a) 0.621 V (b) increases; decreases
 (c) 1×10^{-21}
 (d) $[\text{Zn}^{2+}] = 2.0$ M; $[\text{Sn}^{2+}] = 2 \times 10^{-21}$ M
 106. (a) 1.12×10^5 J; 0.38×10^5 J; 1.50×10^5 J
 (b) -0.389 V
 107. 0.414 V
 108. 12 days
 109. 79% for Zn; 21% for Sn

Chapter 18

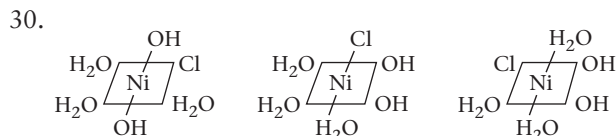
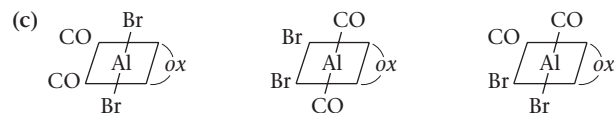
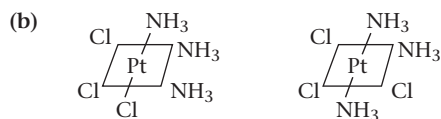
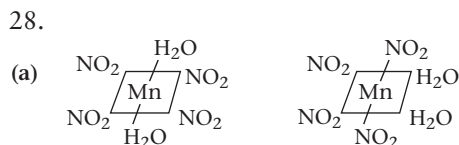
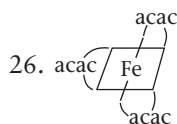
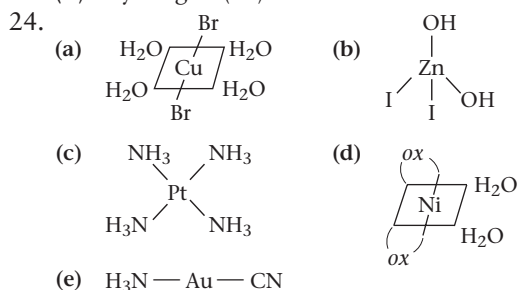
2. (a) $^{28}_{14}\text{Si}$ (b) ^6_3Li (c) $^{23}_{11}\text{Na}$
 4. (a) Ni (b) Se (c) Cd
 6. $^{54}_{24}\text{Cr} \longrightarrow ^0_0e + ^{54}_{23}\text{V}$
 8. (a) Th-231 (b) Pa-231
 10. (a) $^{56}_{26}\text{Fe} \longrightarrow ^{56}_{25}\text{Mn} + ^0_1e$
 (b) $^{228}_{88}\text{Ra} \longrightarrow ^{228}_{89}\text{Ac} + ^0_{-1}e$
 (c) $^{236}_{95}\text{Am} \longrightarrow ^{232}_{93}\text{Np} + ^4_2\text{He}$
 12. (a) $^{230}_{90}\text{Th} \longrightarrow ^4_2\text{He} + ^{226}_{88}\text{Ra}$
 (b) $^{210}_{82}\text{Pb} \longrightarrow ^0_{-1}e + ^{210}_{83}\text{Bi}$
 (c) $^{235}_{92}\text{U} + ^1_0n \longrightarrow ^{140}_{54}\text{Ba} + 3^1_0n + ^{93}_{36}\text{Kr}$
 (d) $^{37}_{18}\text{Ar} + ^0_{-1}e \longrightarrow ^{37}_{17}\text{Cl}$
 14. (a) $^{272}_{111}\text{Rg}$
 (b) $^{260}_{105}\text{Db}$
 16. The product ($^{282}_{114}\text{Z}$) is the same.
 18. (a) $^{54}_{26}\text{Fe} + ^4_2\text{He} \longrightarrow 2^1_1\text{H} + ^{56}_{26}\text{Fe}$
 (b) $^{96}_{42}\text{Mo} + ^1_0n \longrightarrow ^1_0n + ^{97}_{43}\text{Tc}$
 (c) $^{40}_{18}\text{Ar} + ^4_2\text{He} \longrightarrow ^{43}_{19}\text{K} + ^1_1\text{H}$
 (d) $^{31}_{16}\text{S} + ^1_0n \longrightarrow ^1_1\text{H} + ^{31}_{15}\text{P}$
 20. (a) $^{78}_{35}\text{Br}$ (b) $^{59}_{26}\text{Fe}$ (c) ^4_2He (d) $^{24}_{11}\text{Na}$
 22. 5.25×10^{12} atoms
 24. 1.25×10^{-5} Ci
 26. 5.6×10^4 Ci
 28. 5.74×10^3 Ci
 30. 5.1×10^{-14} g
 32. 7.3×10^7 β -particles; 3.3×10^{-5} Ci
 34. (a) 8.0 days (b) 22 atoms
 36. No. The canvas is about 235 years old, which means it was used around 1775.
 38. 9.2×10^3 yr
 40. 8.5 years
 42. 4.3×10^9 yr

44. (a) $^{90}_{38}\text{Sr} \longrightarrow 2^0_{-1}e + ^{90}_{40}\text{Zr}$
 (b) -0.0034 g/mol
 (c) 2.21×10^4 kJ
 46. (a) 0.24992 g/mol (b) 2.25×10^{10} kJ/mol
 48. Ca-40
 50. fusion
 52. 1.19×10^{-2}
 54. (a) 16% (b) 18 mg
 56. 8.4×10^{-11} g
 58. 2.5×10^3 counts/min/mL
 60. 2.60 Ci
 62. 6.5×10^2 mL
 64. $2\text{C}_2\text{O}_4^{2-}/\text{Cr}^{3+}$
 66. 38 mL
 68. 2.42×10^{-3} nm
 70. (a) Alpha particles (He nuclei) attracted to negative pole; beta particles (electrons) attracted to positive pole.
 (b) Can follow path of C-11 in organic compounds in brain, using radiation counter.
 (c) Neutrons produced can continue fission reaction.
 72. $t_{1/2} = 3.3$ hours
 74. 99.8% remains after one year. Decay is slow.
 76. 5.8×10^{-19} mol/L
 77. (a) 2.5×10^{-9} g (b) 5.5×10^{-3} kJ
 (c) 73 rem
 78. (a) 1×10^{-13} J (b) 6×10^6 m/s
 79. (a) -5.72×10^8 kJ/g (b) -1.3×10^{28} kJ
 (c) 1.8×10^{-11}
 80. 8.3×10^{-6} atm
 81. 3×10^6 yr
 82. 4.3×10^{-29}

Chapter 19

2. (a) $en = 0$; $\text{SCN} = -1$, $\text{OH} = -1$
 (b) +3
 (c) $\text{Mg}[\text{Cd}(en)(\text{SCN})_2(\text{OH})_2]$
 4. (a) $\text{Pt}(\text{NH}_3)_2(\text{C}_2\text{O}_4)$ (b) $\text{Pt}(\text{NH}_3)_2(\text{SCN})\text{Br}$
 (c) $\text{Pt}(en)(\text{NO}_2)_2$
 6. (a) 6 (b) 4 (c) 6 (d) 2
 8. (a) 3 (b) 2 (c) 2 (d) 3
 10. (a) $[\text{Fe}(\text{H}_2\text{O})_6]_2(\text{CO}_3)_3$
 (b) $\text{Ba}[\text{Pt}(\text{OH})_3\text{Br}_3]_2$
 (c) $\text{Ba}[\text{V}(en)\text{Cl}_4]$
 (d) $[\text{Au}(\text{CN})_2]_2\text{CO}_3$
 12. (a) $\text{Pt}(\text{NH}_3)_6^{4+}$ (b) $\text{Ag}(\text{CN})_2^-$
 (c) $\text{Zn}(\text{C}_2\text{O}_4)_2^{2-}$ (d) $\text{Cd}(\text{CN})_4^{2-}$
 14. 28.4%
 16. one
 18. (a) $[\text{Cr}(\text{NH}_3)_2(\text{H}_2\text{O})_4]\text{Cl}_2$ (b) $[\text{Cd}(\text{Cl})_4(\text{SO}_4)^{3-}]$
 (c) $\text{Na}_2[\text{Ni}(\text{OH})_4]$ (d) $[\text{Fe}(\text{Br})_2(en)_2]^+$
 20. (a) sodium tetrahydroxoaluminate(III)
 (b) diaquadioxalatocobaltate(III)
 (c) triamminetrichloroiridium(III)
 (d) diamminedibromoethylenediaminechromium(III) sulfate
 22. (a) hexaaquairon(III)
 (b) amminetribromoplatinate(II)

- (c) tetrachloroethylenediaminevanadate(II)
(d) dicyanogold(III)

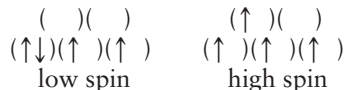


32. (a) $[\text{Kr}]4\text{d}^{10}$
(b) $[\text{Ar}]3\text{d}^6$
(c) $[\text{Xe}]4\text{f}^{14}5\text{d}^8$
(d) $[\text{Ar}]3\text{d}^5$
(e) $[\text{Ar}]3\text{d}^7$

34. (a) $[\text{Kr}] (\uparrow\downarrow)(\uparrow\downarrow)(\uparrow\downarrow)(\uparrow\downarrow)(\uparrow\downarrow)$ no unpaired electrons
(b) $[\text{Ar}] (\uparrow\downarrow)(\uparrow)(\uparrow)(\uparrow)(\uparrow)$ 4 unpaired electrons
(c) $[\text{Xe}]4\text{f}^{14} (\uparrow\downarrow)(\uparrow\downarrow)(\uparrow\downarrow)(\uparrow)(\uparrow)$ 2 unpaired electrons
(d) $[\text{Ar}] (\uparrow)(\uparrow)(\uparrow)(\uparrow)(\uparrow)$ 5 unpaired electrons
(e) $[\text{Ar}] (\uparrow\downarrow)(\uparrow\downarrow)(\uparrow)(\uparrow)(\uparrow)$ 3 unpaired electrons

36. (a) for both high and low spin: $(\uparrow\downarrow)(\uparrow\downarrow)(\uparrow\downarrow)(\uparrow\downarrow)(\uparrow\downarrow)$
(b) for low spin: $(\uparrow)(\uparrow)(\uparrow)(\uparrow)(\uparrow)$ for high spin: $(\uparrow)(\uparrow)(\uparrow)(\uparrow)(\uparrow)$

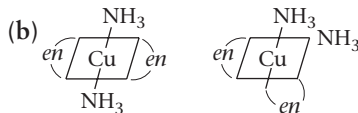
38. Mn^{3+} contains four 3d electrons, so it can form



Mn^{4+} , with only three 3d electrons, cannot do this.

40. NH_3 has a large Δ_o ; low spin; no unpaired electrons.
 F^- has a small Δ_o ; high spin; unpaired electrons present.
42. (a) 4 (b) 4 (c) 0 (d) 4 (e) 2
44. $4.60 \times 10^2 \text{ nm}$
46. $\approx 500 \text{ nm}$; green

48. (a) $\text{CoN}_6\text{H}_{18}\text{Cl}_3$
(b) $\text{Co}(\text{NH}_3)_6\text{Cl}_3(\text{s}) \rightleftharpoons \text{Co}(\text{NH}_3)_6^{3+}(\text{aq}) + 3\text{Cl}^-(\text{aq})$
50. (a) 6, not 5 (b) shorter, not longer
(c) true (d) eight, not seven
51. 0.92 g
52. $[\text{Pt}(\text{NH}_3)_4] [\text{PtCl}_4]$ or $[\text{Pt}(\text{NH}_3)_3\text{Cl}] [\text{Pt}(\text{NH}_3)\text{Cl}_3]$
53. (a) $\text{CuC}_4\text{H}_{22}\text{N}_6\text{SO}_4$



54. red-violet

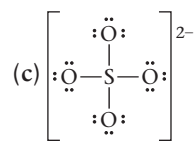
Chapter 20

2. $2\text{Al}_2\text{O}_3(\text{l}) \longrightarrow 4\text{Al}(\text{l}) + 3\text{O}_2(\text{g})$; 2.91 g
4. $\text{Cu}_2\text{S}(\text{s}) + \text{O}_2(\text{g}) \longrightarrow 2\text{Cu}(\text{s}) + \text{SO}_2(\text{g})$
6. -211.9 kJ
8. (a) $\text{Fe}_2\text{O}_3(\text{s}) + 3\text{CO}(\text{g}) \longrightarrow 2\text{Fe}(\text{l}) + 3\text{CO}_2(\text{g})$
(b) $\text{C}(\text{s}) + \text{O}_2(\text{g}) \longrightarrow \text{CO}_2(\text{g})$
10. $2.5 \times 10^3 \text{ kWh}$
12. $1.7 \times 10^6 \text{ L}$
14. (a) potassium nitride, K_3N
(b) potassium iodide, KI
(c) potassium hydroxide, KOH
(d) potassium hydride, KH
(e) potassium sulfide, K_2S
16. (a) $\text{Na}_2\text{O}_2(\text{s}) + 2\text{H}_2\text{O} \longrightarrow 2\text{Na}^+(\text{aq}) + 2\text{OH}^-(\text{aq}) + \text{H}_2\text{O}_2(\text{aq})$
sodium and hydroxide ions, hydrogen peroxide
(b) $2\text{Ca}(\text{s}) + \text{O}_2(\text{g}) \longrightarrow 2\text{CaO}(\text{s})$; calcium oxide
(c) $\text{Rb}(\text{s}) + \text{O}_2(\text{g}) \longrightarrow \text{RbO}_2(\text{s})$; rubidium superoxide
(d) $\text{SrH}_2(\text{s}) + 2\text{H}_2\text{O} \longrightarrow \text{Sr}^{2+}(\text{aq}) + 2\text{OH}^-(\text{aq}) + 2\text{H}_2(\text{g})$
strontium and hydroxide ions, hydrogen gas
18. 0.126 g
20. (a) $\text{Co}(\text{s}) + 2\text{H}^+(\text{aq}) \longrightarrow \text{Co}^{2+}(\text{aq}) + \text{H}_2(\text{g})$
(b) $3\text{Cu}(\text{s}) + 2\text{NO}_3^-(\text{aq}) + 8\text{H}^+(\text{aq}) \longrightarrow 3\text{Cu}^{2+}(\text{aq}) + 2\text{NO}(\text{g}) + 4\text{H}_2\text{O}$
(c) $\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 6\text{e}^- + 14\text{H}^+(\text{aq}) \longrightarrow 2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}$
22. $3\text{Cd}(\text{s}) + 12\text{Cl}^-(\text{aq}) + 2\text{NO}_3^-(\text{aq}) + 8\text{H}^+(\text{aq}) \longrightarrow 3\text{CdCl}_4^{2-}(\text{aq}) + 2\text{NO}(\text{g}) + 4\text{H}_2\text{O}$
24. (a) $\text{Fe}(\text{s}) + 3\text{NO}_3^-(\text{aq}) + 6\text{H}^+(\text{aq}) \longrightarrow \text{Fe}^{3+}(\text{aq}) + 3\text{NO}_2(\text{g}) + 3\text{H}_2\text{O}$
(b) $4\text{Cr}(\text{OH})_3(\text{s}) + 3\text{O}_2(\text{g}) + 8\text{OH}^-(\text{aq}) \longrightarrow 4\text{CrO}_4^{2-}(\text{aq}) + 10\text{H}_2\text{O}$
26. (a) Cd ($E^\circ = 1.366 \text{ V}$) (b) Cr ($E^\circ = 1.708 \text{ V}$)
(c) Co ($E^\circ = 1.246 \text{ V}$) (d) Ag ($E^\circ = 0.165 \text{ V}$)
(e) no reaction
28. (a) 0.724 V (b) 0.942 V
30. (a) 9×10^9 (b) $2 \times 10^{-4} \text{ M}$
32. 208 g
34. 6.7
36. 53.8% Zn, 46.2% Cu
38. $2\text{Ag}_2\text{S}(\text{s}) + 8\text{CN}^-(\text{aq}) + 3\text{O}_2(\text{g}) + 2\text{H}_2\text{O} \longrightarrow 4\text{Ag}(\text{CN})_2^-(\text{aq}) + 2\text{SO}_2(\text{g}) + 4\text{OH}^-(\text{aq})$
 $2\text{Ag}(\text{CN})_2^-(\text{aq}) + \text{Zn}(\text{s}) \longrightarrow \text{Zn}(\text{CN})_4^{2-}(\text{aq}) + 2\text{Ag}(\text{s})$
40. (a) Cr^{2+} (b) Au^+ (c) Co^{2+} (d) Mn^{2+}
41. 2% BaO_2

42. (a) $\text{Fe}(\text{OH})_3(\text{s}) + 3\text{H}_2\text{C}_2\text{O}_4(\text{aq}) \longrightarrow \text{Fe}(\text{C}_2\text{O}_4)_3^{3-}(\text{aq}) + 3\text{H}_2\text{O} + 3\text{H}^+(\text{aq})$
 (b) 0.28 L
 43. 2.80%
 44. $2.83 \times 10^3 \text{ K}$
 45. $\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 2\text{OH}^-(\text{aq}) \longrightarrow 2\text{CrO}_4^{2-}(\text{aq}) + \text{H}_2\text{O}$
 $2\text{Ag}^+(\text{aq}) + \text{CrO}_4^{2-}(\text{aq}) \longrightarrow \text{Ag}_2\text{CrO}_4(\text{s})$
 $\text{Ag}_2\text{CrO}_4(\text{s}) + 4\text{NH}_3(\text{aq}) \longrightarrow 2\text{Ag}(\text{NH}_3)_2^+(\text{aq}) + \text{CrO}_4^{2-}(\text{aq})$
 $2\text{Ag}(\text{NH}_3)_2^+(\text{aq}) + 4\text{H}^+(\text{aq}) + \text{CrO}_4^{2-}(\text{aq}) \longrightarrow \text{Ag}_2\text{CrO}_4(\text{s}) + 4\text{NH}_4^+(\text{aq})$

Chapter 21

2. (a) bromic acid (b) potassium hypoiodite
 (c) sodium chlorite (d) sodium perbromate
 4. (a) KBrO_2 (b) CaBr_2
 (c) NaIO_4 (d) $\text{Mg}(\text{ClO})_2$
 6. (a) NO_3^- (b) SO_4^{2-} (c) ClO_4^-
 8. (a) H_2SO_3 (b) HClO (c) H_3PO_3
 10. (a) NaN_3 (b) H_2SO_3
 (c) N_2H_4 (d) NaH_2PO_4
 12. (a) H_2S (b) N_2H_4 (c) PH_3
 14. (a) NH_3 , N_2H_4 (b) HNO_3
 (c) HNO_2 (d) HNO_3
 16. (a) $2\text{I}^-(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) + 4\text{H}^+(\text{aq}) \longrightarrow \text{I}_2(\text{s}) + \text{SO}_2(\text{g}) + 2\text{H}_2\text{O}$
 (b) $2\text{I}^-(\text{aq}) + \text{Cl}_2(\text{g}) \longrightarrow \text{I}_2(\text{s}) + 2\text{Cl}^-(\text{aq})$
 18. (a) $3\text{HClO}(\text{aq}) \longrightarrow \text{Cl}_2(\text{g}) + \text{HClO}_2(\text{g}) + \text{H}_2\text{O}$
 (b) $2\text{ClO}_3^-(\text{aq}) \longrightarrow \text{ClO}_4^-(\text{aq}) + \text{ClO}_2^-(\text{aq})$
 20. (a) $\text{Cl}_2(\text{g}) + 2\text{Br}^-(\text{aq}) \longrightarrow 2\text{Cl}^-(\text{aq}) + \text{Br}_2(\text{l})$
 (b) NR (c) NR (d) NR
 22. (a) $\text{Pb}(\text{N}_3)_2(\text{s}) \longrightarrow 3\text{N}_2(\text{g}) + \text{Pb}(\text{s})$
 (b) $2\text{O}_3(\text{g}) \longrightarrow 3\text{O}_2(\text{g})$
 (c) $2\text{H}_2\text{S}(\text{g}) + \text{O}_2(\text{g}) \longrightarrow 2\text{S}(\text{s}) + 2\text{H}_2\text{O}$
 24. (a) $\text{Cd}^{2+}(\text{aq}) + \text{H}_2\text{S}(\text{aq}) \longrightarrow \text{CdS}(\text{s}) + 2\text{H}^+(\text{aq})$
 (b) $\text{H}_2\text{S}(\text{aq}) + \text{OH}^-(\text{aq}) \longrightarrow \text{H}_2\text{O} + \text{HS}^-(\text{aq})$
 (c) $2\text{H}_2\text{S}(\text{aq}) + \text{O}_2(\text{g}) \longrightarrow 2\text{H}_2\text{O} + 2\text{S}(\text{s})$
 26. (a) $2\text{H}^+(\text{aq}) + \text{CaCO}_3(\text{s}) \longrightarrow \text{CO}_2(\text{g}) + \text{H}_2\text{O} + \text{Ca}^{2+}(\text{aq})$
 (b) $\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \longrightarrow \text{H}_2\text{O}$
 (c) $\text{Cu}(\text{s}) + 4\text{H}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \longrightarrow \text{Cu}^{2+}(\text{aq}) + 2\text{H}_2\text{O} + \text{SO}_2(\text{g})$
 28. (a) $\text{Cl}-\ddot{\text{O}}-\ddot{\text{O}}-\ddot{\text{Cl}}$ (b) $\ddot{\text{O}}-\text{N}\equiv\text{N}$
 (c) $\text{P} \begin{array}{c} \diagup \text{P} \diagdown \\ \diagdown \text{P} \diagup \end{array}$ (d) $\text{N}\equiv\text{N}$
 30. a and b
 32. (a) $\left[\begin{array}{c} \ddot{\text{O}}-\text{N}=\ddot{\text{O}} \\ \vdots \\ \ddot{\text{O}} \end{array} \right]^-$ (b) $\left[\begin{array}{c} \ddot{\text{O}} \\ \vdots \\ \text{H}-\ddot{\text{O}}-\text{S}-\ddot{\text{O}} \\ \vdots \\ \ddot{\text{O}} \end{array} \right]^-$
 (c) $\left[\begin{array}{c} \ddot{\text{O}} \\ \vdots \\ \text{H}-\ddot{\text{O}}-\text{P}-\ddot{\text{O}}-\text{H} \\ \vdots \\ \ddot{\text{O}} \end{array} \right]^-$
 34. (a) $\begin{array}{c} \ddot{\text{O}}-\text{N}-\ddot{\text{O}}-\text{N}-\ddot{\text{O}} \\ \parallel \quad \parallel \\ \text{:O:} \quad \text{:O:} \end{array}$ (b) $\text{H}-\ddot{\text{O}}-\text{N}=\ddot{\text{O}}:$

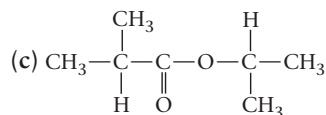
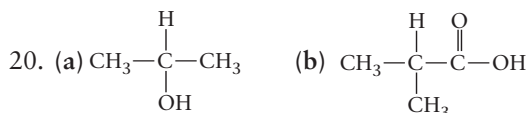
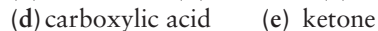
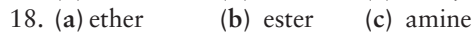
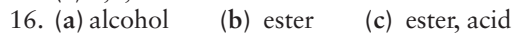
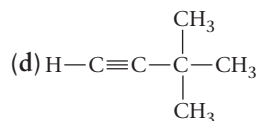
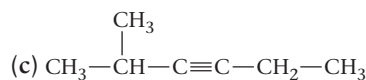
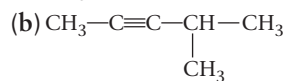
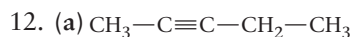
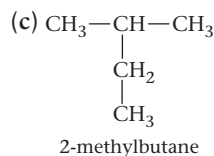
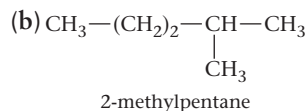
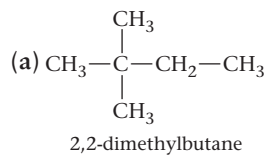


36. 14.3 L
 38. 0.204 M
 40. $7.7 \times 10^4 \text{ L}$; $1.5 \times 10^5 \text{ g}$
 42. 12 L; 3.53
 44. 4.28, 0.10 M
 46. 1.9×10^{-3}
 48. 0.012 g/100 mL
 50. yes; 0 K
 52. (a) yes (b) 2×10^{16}
 54. 510 K
 56. $2.26 \times 10^5 \text{ g}$
 58. 27.4 kg
 60. b, c, d
 62. 4.6
 64. (a) dispersion (b) dispersion, dipole
 (c) dispersion, H—bonds (d) dispersion, H—bonds
 (e) no intermolecular forces; not a molecule
 66. (a) +3 (b) +4 (c) +5 (d) -3
 68. (a) HClO (b) S, KClO_3
 (c) NH_3 , NaClO (d) HF
 70. (a) See text pages 540–541. (b) has an unpaired electron
 (c) H^+ is a reactant. (d) C is a product.
 71. density of sulfur; depth of deposit, purity of S
 72. no
 73. 1.30%
 74. Assume reaction is $\text{NaN}_3(\text{s}) \longrightarrow \text{Na}(\text{s}) + \frac{3}{2}\text{N}_2(\text{g})$
 Assume 25°C , 1 atm pressure; mass of NaN_3 is 35 g.

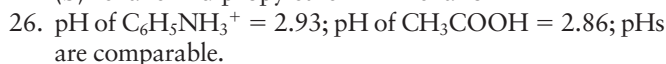
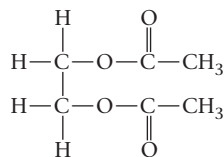
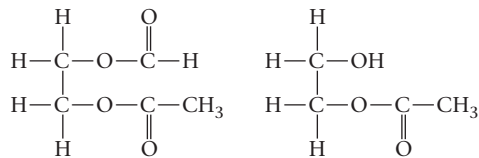
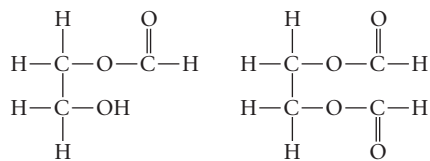
Chapter 22

2. (a) alkene (b) alkyne (c) alkane
 4. (a) C_9H_{16} (b) $\text{C}_{22}\text{H}_{44}$ (c) $\text{C}_{10}\text{H}_{22}$
 6. (a) 2-methyloctane (b) 2,2-dimethylpropane
 (c) 2,2,4-trimethylpentane
 (d) 2,5-dimethylheptane
 8. $\begin{array}{c} \text{CH}_3 \quad \text{H} \\ | \quad | \\ \text{CH}_3-\text{C}-\text{CH}_2-\text{C}-\text{CH}_3 \\ | \quad | \\ \text{CH}_3 \quad \text{CH}_3 \end{array}$
 (a) $\begin{array}{c} \text{CH}_3 \\ | \\ \text{CH}_3-\text{C}-\text{CH}_3 \\ | \\ \text{CH}_3 \end{array}$
 (b) $\begin{array}{c} \text{CH}_3 \\ | \\ \text{CH}_3-\text{C}-\text{CH}_3 \\ | \\ \text{CH}_3 \end{array}$
 (c) $\begin{array}{c} \text{H} \\ | \\ \text{CH}_3-(\text{CH}_2)_2-\text{C}-(\text{CH}_2)_3-\text{CH}_3 \\ | \\ \text{CH}_3-\text{C}-\text{CH}_3 \\ | \\ \text{H} \end{array}$
 (d) $\begin{array}{c} \text{CH}_3 \quad \text{H} \quad \text{CH}_3 \\ | \quad | \quad | \\ \text{CH}_3-\text{C}-\text{C}-\text{C}-(\text{CH}_2)_2-\text{CH}_3 \\ | \quad | \quad | \\ \text{H} \quad \text{CH}_3 \quad \text{H} \end{array}$

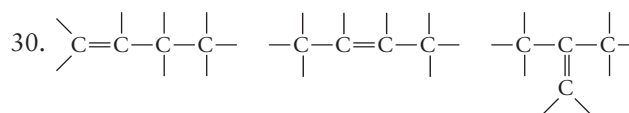
10.



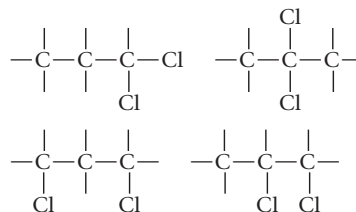
22.



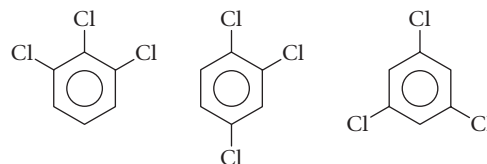
28. 0.73



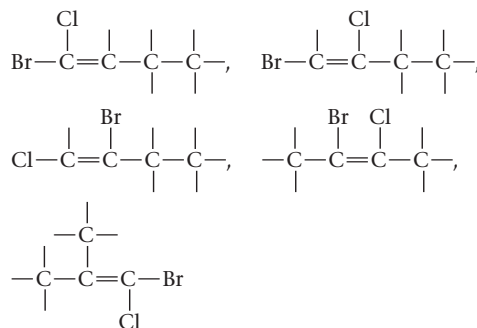
32.



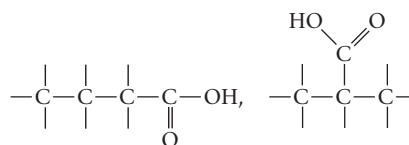
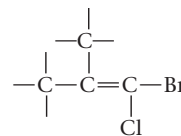
34.



36.



38.

40. All of the compounds in Problem 36 show *cis-trans* isomerism exceptwhere there are two $-\text{CH}_3$ groups attached to the same carbon.

42. b, c

44. c and d

46. (a) —center carbon (b) none

(c) —carbon atom at right

48. (a) addition (b) elimination (c) condensation

50. (a) 2,3-dichloro-2-methylbutane

(b) 2,3-diodo-2-methylbutane

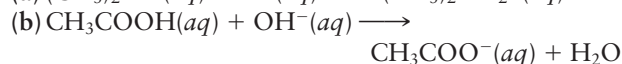
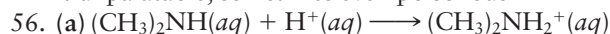
52. Three pairs of electrons spread around the ring

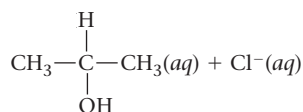
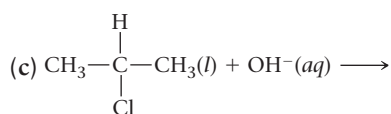
54. (a) no multiple bonds

(b) sodium salt of a long-chain carboxylic acid

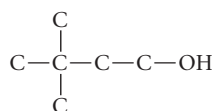
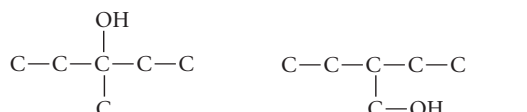
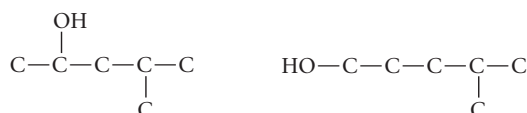
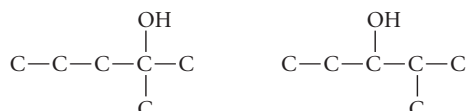
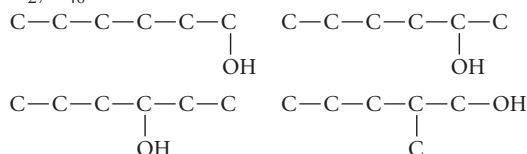
(c) twice the volume of alcohol present

(d) ethanol with additives (mainly methanol) that make it unpalatable, sometimes even poisonous





58. $\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}$ $\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}$


$$60. \text{ClCH}_2\text{COOH}(aq) + (\text{CH}_3)_3\text{N}(aq) \longrightarrow \text{ClCH}_2\text{COO}^-(aq) + (\text{CH}_3)_3\text{NH}^+(aq)$$

$$K = 8.8 \times 10^6; 3.4 \times 10^{-5} M$$

Chapter 23

2. (a)

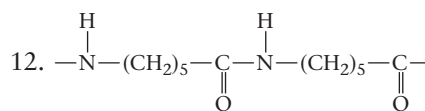
$$\begin{array}{ccccccc} & \text{F} & & \text{F} & & \text{F} & & \text{F} \\ & | & & | & & | & & | \\ - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - \\ & | & & | & & | & & | \\ & \text{E} & & \text{E} & & \text{E} & & \text{E} \end{array}$$

(b) 2.5×10^6 g/mol
(c) 24.02% C, 75.98% F

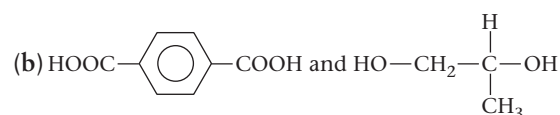
4. 

$$\text{(b) } \text{CH}_3 - \underset{\text{H}}{\underset{|}{\text{C}}} = \underset{\text{H}}{\underset{|}{\text{C}}} - \text{CH}_3$$

10.

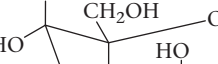


14. (a) $\text{H}_2\text{N}-\text{CH}_2-\text{CH}_2-\text{NH}_2$ and $\text{HOOC}-\text{CH}_2-\text{COOH}$



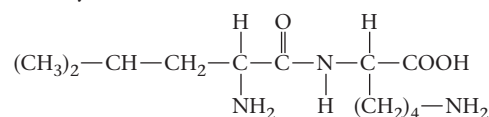
16. $\text{C}_{12}\text{H}_{22}\text{O}_{11}(aq) + \text{H}_2\text{O} \longrightarrow 2\text{C}_6\text{H}_{12}\text{O}_6(aq)$

18. (a) 44.44% C, 6.22% H, 49.34% O (b) 6.2×10^2

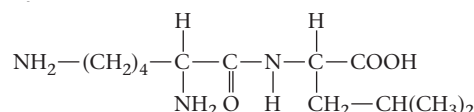
20. 

22. 9; 10

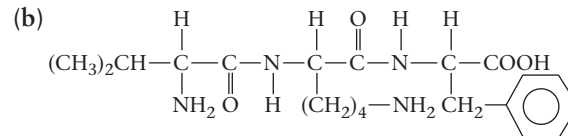
24. Leu-Lys:



Lys-Leu:

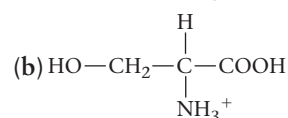
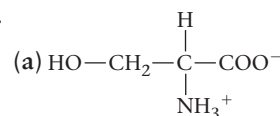


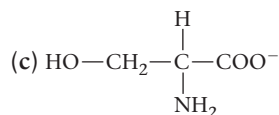
26. (a) 6



Val-Lys-Phe

28.





30. (a) 2.29 (b) 9.74 (c) 6.0

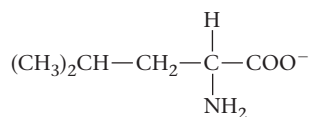
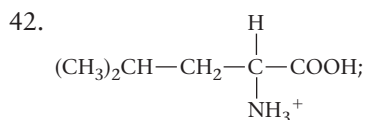
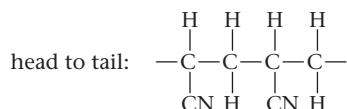
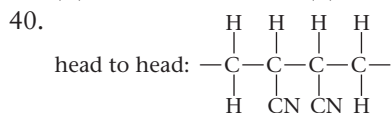
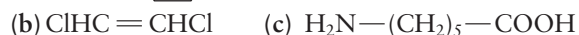
32. Ala-Phe-Leu-Met-Val-Ala

34. Double bond for addition; two functional groups for condensation

36. (a) Linear has straight chain with no branches.

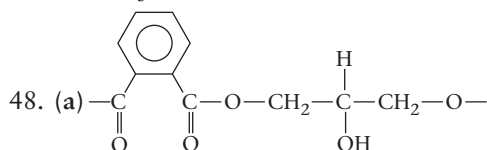
(b) See page 585

(c) See page 585



44. $1.59 \times 10^4 \text{ g/mol}$

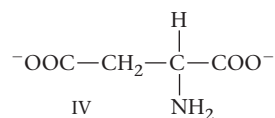
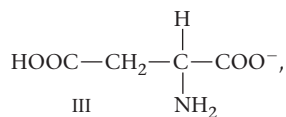
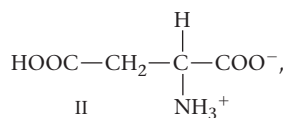
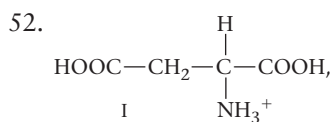
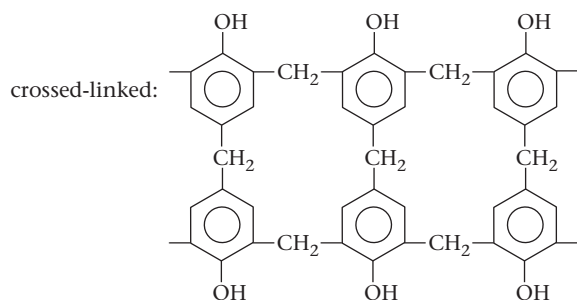
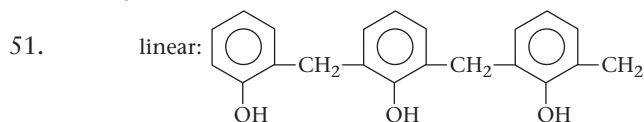
46. -214 kJ



(b) Orthophthalic acid condenses with OH groups in two adjacent chains.

49. 63.68% C, 9.80% H, 14.14% O, 12.38% N

50. -17 kJ



I, pH < 2.10; II, pH 2.10–3.85; III, pH 3.85–9.82;

IV, pH > 9.82

Note: Boldface terms are defined in the context used in the text; italic locators indicate figures; t indicates a table.

A

A. *See* Mass number

Abbreviated electron configuration Brief notation in which only those electrons beyond the preceding noble gas are shown. The abbreviated electron configuration of the Fe atom is $[\text{Ar}]4s^23d^6$, 140, 140t

Absolute temperature, 98, 116

Acetaldehyde, 280, 287

Acetate ion, 376

Acetates, 390t

Acetic acid

acid-base titration, 376–377, 377

buffers, 366t

equilibrium constant, 340t

and fermentation, 560

freezing point and boiling point constants, 264t

household products, 340

as an organic acid, 357t

percent ionization of, 343

and titrations, 84, 85

and vinegar, 563

Acetone, 561, 562

Acetylene

as an alkyne, 555–556, 555

as a binary compound, 45

free energies of formation, 417

multiple bonds, 158, 173, 181

percent abundance, 4t

sigma and pi bonds, 182–183, 183

Acetylsalicylic acid (ASA), 52–53, 52

Acid An aqueous solution in which $[\text{H}^+]$ is greater than 10^{-7} M , 45–48

alternative definitions of, 356t

Brønsted-Lowry acid-base model, 331–332

flowchart for determining, 47

ion product of water, 333

names of, 45–48

pH and pOH, 333–338

as a proton donor, 332

strength of and molecular structure, 347–348

transition metals, reactions with, 517–519

weak acids and their equilibrium constants, 339–348

Acid-base indicators, 80, 85, 338, 338, 371–373, 371, 372, 373t, 384b

Acid-base model. *See* Brønsted-Lowry acid-base model

Acid-base properties, 352–355, 353t, 359d

Acid-base reactions, 80–86, 83t, 94a–94c, 384

Acid-base solutions, equilibria in

acid-base indicators, 371–373, 384b

acid-base titration, 371–382, 384b–384c

buffers, 360–371, 384–384b

Acid-base titrations Procedures used to determine the concentration of an acid or base. The volume of a solution of an acid (or base) of known molarity required to react with a known volume of base (or acid) is measured, 85, 371–374, 374

characteristics of, 381t

strong acid-strong base, 374–376

strong acid-weak base, 379–380

titration of diprotic acids, 380–382

weak acid-strong base, 376–379

Acid equilibrium constant (K_a) The equilibrium constant for the ionization of a weak acid, 339–343, 351–352, 352t, 364, 372

Acidic ion Ion that forms H^+ ions in water. The ammonium ion is acidic because of the reaction, $\text{NH}_4^+(\text{aq}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{NH}_3(\text{aq})$, 339

Acidic oxide, 537

Acidic solution An aqueous solution with a pH less than 7, 80, 92, 111, 338, 353, 432, 441, 520–522

Acid indigestion, 93

Acidosis, 336

Acid rain, 382–383

Acrylic resins, 577t

Acrylonitrile, 577t

Actinides Elements 89 (Ac) through 102 (No) in the periodic table, 142

Actinium, 142

Activated complex An unstable high-energy species that must be formed before the reaction can occur, 291–292

Activation energy The minimum energy that must be possessed by a pair of molecules if collision is to result in reaction, 290, 291–293, 292, 294, 295–296, 297, 298

Activity (A) Rate of radioactive decay; number of atoms decaying per unit time, 473–475

Addition polymer Polymer produced by a monomer, usually a derivative of ethylene, adding to itself; no other product is formed, 577–580

Addition reactions Reactions in which a small molecule (e.g., H_2) is directly inserted into a double or triple bond, 572

Adenosine triphosphate (ATP), 426–427, 426

ADP (adenosine diphosphate), 426–427, 426

Advanced CANDU, 482

Agriculture, arsenic use in, 20

Air, composition of, 95

Airport security, 7

Alanine, 589t, 592

Alanylglycine, 592

Albinism, 594

Alcohol dehydrogenase, 523

Alcoholic beverages, 560

Alcohols Compounds containing an $-\text{OH}$ group attached to a hydrocarbon chain. The simplest example is CH_3OH , 37, 256t, 558–561, 559t, 560t

Aldehydes Compounds containing the carbonyl group $-\text{CHO}$ bonded to two hydrocarbons, 559t, 561–562, 562

Aleve, 571

Alkali halides, 242

Alkali metals Metals in Group 1 of the periodic table, 33–34, 513

flame tests, 404

hydrogen, reaction with, 514

oxygen, reaction with, 514–516

and the periodic table, 507

reactions of, 513t

water, reaction with, 514

Alkaline dry cell, 459

Alkaline earth metals Metals in Group 2 of the periodic table, 34, 513

hydrogen, reaction with, 514

oxygen, reaction with, 514–516

and the periodic table, 507

reactions of, 513t

water, reaction with, 514

Alkaloids, 358

Alkanes Hydrocarbons containing only single carbon-carbon bonds. The simplest example is methane, CH_4 , 548–553, 548, 550t, 560t

Alkenes Hydrocarbons containing one carbon-carbon double bond. The simplest alkene is C_2H_4 , 553–555, 572, 573

Alkyl group A hydrocarbon functional group based on an alkane, 550–551, 550t, 559

Alkynes Hydrocarbons containing one carbon-carbon triple bond. Example: $\text{HC}\equiv\text{CH}$, 554, 555–556

Allotrope One of two or more forms of an element in the same physical state. Graphite and diamond are allotropes of carbon; O_2 and O_3 are allotropes of oxygen, 545

Alloy, 3

Almonds, 562

Alpha particle A helium nucleus; He^{2+} ion, 467, 468, 469t

Alpha particle emission, 467

Aluminium, 60–61

Aluminium nitrate, 352

Aluminum, 3–4, 90

and acid rain, 383

acting as a weak acid, 353

electrolysis of, 509

metallurgy, 509–510

not in the human body, 35

percent abundance, 4t

and specific heat, 190

Aluminum hydroxide, 542

Aluminum salts, 340

Am-241, 472

Americium, 470t

Amine An amine can be considered to be a derivative of ammonia in which one or more hydrogen atoms have been replaced by hydrocarbon groups, 37, 81, 357–358, 357t, 559t, 565–566

α -amino acids Compounds that have both an NH_2 group and a COOH group attached to the same carbon atom, 588–592, 589t

Ammonia

acid-base titration, 379–380

and amines, 357

base equilibrium constant, 349

as a binary compound, 45

boiling point, 229

buffers, 365–366

complexes of cations with, 401t

complexes with, 489t

complex formation, 401

composition of complex ions, 488

as condensable gas, 223t

dissolving precipitates, 402

and entropy, 409–410, 409

equilibrium constant, 318

Haber process, 328–329, 329t

hybrid orbital, 180

in Lewis acid-base model, 355–356

molecular formula for, 36

molecular geometry, 169–170, 169

and molecular speed, 116

and nitric acid, 542

overview of, 530–531

reaction rate, 275

standard molecular entropies, 410

structural formula for, 36, 36

synthesis of, 327

as a weak base, 82

and weak bases, 81

Ammonium, 339

Ammonium chloride, 423

Ammonium dichromate, 521, 522

Ammonium ion, 340t, 353, 355, 366, 366t, 380, 380

Ammonium nitrate, 197, 410, 526

Amount, 96. *See also* Mass; Mole

Ampere (A) Rate of flow of electric current such that one coulomb passes a given point in one second, 453, 453t

Amphetamine, 571

Amphiprotic species Capable of acting as either a Brønsted-Lowry acid or base, 332, 333

Amplitude (Ψ) Height of a standing wave, 125, 133

Anesthetic, 561

Aniline, 557

Animals, and coloration, 153

- Anions** Ions with a negative charge. Examples include Cl^- and OH^- , 37–38
compounds of silicon, 234
ionic radius, 150, 150
and ionic solid dissolved in water, 56
and ionic solids, 235
in names of compounds, 43–44
with noble-gas structures, 41, 146
polyprotic weak acids, 346
in salt solutions, 352, 353t
selective precipitation, 396
standard molecular entropies, 411t
as weak bases, 348
as weak bases or spectator ions, 353
- Anode** Electrode at which oxidation occurs and toward which anions move, 430, 435, 436–437, 452, 453
- Anode half-cell, 436
- Antacids, 93, 93t
- Anthracene, 558
- Antifreeze, 264, 561
- Antimony, 27–28, 34, 68, 69–70
- Aqua regia, 519
- Aqueous solution, reactions in
acid-base reactions, 80–86
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- Archaeology, 472
- Arenes. *See* Aromatic hydrocarbons
- Arginine, 589t, 593
- Argon, 34, 139, 184, 185, 223t
- Arlington National Cemetery, 596
- Armbruster, Peter, 470
- Aromatic hydrocarbons** Hydrocarbons containing one or more benzene rings, 556–558, 575a
- Arrhenius, Svante, 80, 87, 331–332
- Arrhenius acid** Species that, upon addition to water, increases $[\text{H}^+]$, 80, 81
- Arrhenius base** Species that, upon addition to water, increases $[\text{OH}^-]$, 80, 81
- Arrhenius equation** Equation that expresses the temperature dependence of the rate constant: $(E_a/R)/(1/T_1 - 1/T_2)$, 294–296, 294, 327, 356t
- Arsenic, 20, 31–32, 545–546
- Arsenic poison, 545
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- Art restoration, 504
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- Asbestos, 234
- Asparagine, 589t
- Aspartame, 298, 586t
- Aspartase, 298
- Aspartic acid, 589t
- Aspirin, 52–53, 52, 342, 342, 357
- Assay, 252
- Astaxanthin, 153, 153
- Asymmetric synthesis, 571
- Atherosclerosis, 573
- Atmosphere (atm)** Unit of pressure equal to 101.325 kPa; equivalent to the pressure exerted by a column of mercury 760 mm high, 97, 424
- Atmospheric pressure, 96–97
- ATP (adenosine triphosphate), 426–427, 426
- Atom** Smallest particle of an element that retains the chemical properties of that element, 22–23
in atomic theory, 23
components of, 23–26, 50a
electron configuration in, 138–143
masses of individual atoms, 31–32
with noble-gas structures, 146
number of in unit cells, 239
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periodic trends in the properties of, 148–152, 154c
quantitative properties of, 26–32, 50a
relative size of parent atom and its ions, 150, 150
- Atom balance, 77
- Atomic bomb, 480–481, 480
- Atomic mass** Average mass of an atom compared to that of another element, based upon the C-12 scale, 28, 50a–50b, 87
- Atomic mass units (amu)** The units used to express atomic masses; 1/12 of the mass of a carbon-12 atom, 28
- Atomic nucleus, 25–26
- Atomic number (Z)** Number of protons in the nucleus of an atom, 26, 466
- Atomic orbital model. *See* Valence bond model
- Atomic orbitals, 138, 156, 178–184, 186b
- Atomic radius** One half of the distance of closest approach between two nuclei in the ordinary form of an element, 148–150, 148, 149, 239–240, 239
- Atomic spectrum** Diagram showing the wavelength at which light is emitted by excited electrons in an atom, 129–130, 130t, 154a
- Atomic theory** Dalton's theory of the atomic nature of matter, 22–23, 23, 24, 50–50a
- Atomic weights, 28. *See also* Atomic mass
- Attractive forces, 121
- Aurora borealis, 125
- Average speed of gas molecules** $u = \left(\frac{3RT}{MM}\right)^{1/2}$, 115–117
- Average translational kinetic energy, 115
- Avogadro, Amadeo, 109
- Avogadro's law, 99, 109
- Avogadro's number** (N_A) 6.022×10^{23} ; the number of units in a mole, 31–32, 52, 54, 65, 109, 115
- B**
- Baking powder, 340
- Baking soda, 52
- Ball-and-stick model, 36, 161
- Balmer series, 129, 132
- Bar** Unit of pressure = 10^5 Pa = 1.013 atm, 97
- Barium hydroxide, 81t, 336
- Barium ion, 397
- Barium sulfate, 390, 393
- Barometer, 96, 96
- Bartlett, Neil, 184
- Base** Compound that dissolves in water to give a solution in which $[\text{OH}^-]$ is greater than 10^{-7} M
acid-base reactions, 80–86
alternative definitions of, 356t
Brønsted-Lowry acid-base model, 331–332
ion product of water, 333
pH and pOH, 333–338
as a proton acceptor, 332
weak bases and their equilibrium constants, 348–352
- Base equilibrium constant** (K_b) The equilibrium constant for the ionization of a weak base, 349, 351–352, 352t
- Basic anhydrides, 515
- Basic ion** An anion that forms OH^- ions in water; the CO_3^{2-} ion is basic because of the reaction $\text{CO}_3^{2-}(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{HCO}_3^-(\text{aq}) + \text{OH}^-(\text{aq})$, 348
- Basic solution** An aqueous solution with a pH greater than 7 (at 25°C), 80, 84, 334, 338, 432, 441, 520, 522, 542
- Bauxite ore, 509–510
- Becquerel, Henri, 473
- Bell jar experiment, 264–265, 264
- Belt of stability, 466, 466
- Bends, 259
- Bent molecule** Molecule containing three atoms in which the bond angle is less than 180° ; examples include H_2O and SO_2 , 166
- Benzaldehyde, 562
- Benzedrine, 571
- Benzene
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- Beryllium fluoride, 163, 164, 167, 175–176, 176, 179
- Berzelius, Jöns, 49, 87, 109
- Beta particle emission, 467–468
- Beta particles** High speed energy electrons emitted by the nucleus during radioactive decay or fission, 467, 468, 468, 469t
- Bimolecular, 299
- Binary ionic compounds, 46
- Binary molecular compounds, 44–45
- Binding energy** Energy equivalent of the mass defect; measure of nuclear stability, 478–480, 480
- Biologically important elements, 35, 35
- Bjerrum, Niels, 130
- Blassie, Michael, 596
- Bleach, 277
- “Blind stagger,” 546
- Blister copper, 511–512
- Blood, 370, 503
- Blood pressure, measurement of, 122
- Blood sugar, 585
- Body-centered cubic cell (BCC)** A cubic unit cell with an atom at each corner and one at the center, 238–239, 238, 239t
- Bohr, Niels, 130
- Bohr model** Model of the hydrogen atom developed by Niels Bohr; it predicts that the electronic energy is $-R_H/n^2$, where R_H is the Rydberg constant and n is the principal quantum number, 130–132
- Boiling curve, 262
- Boiling point** Temperature at which the vapor pressure of a liquid equals the applied pressure, leading to the formation of vapor bubbles, 16, 221–222
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of molecular substances, 226–227
of nonpolar molecular substances, 227
of polar molecules, 228, 228t
and vapor pressure, 221–222, 221
of water, 221–222, 229, 230
- Boiling point constants, 264t
- Boiling point elevation** (ΔT_b) Increase in the boiling point caused by addition of a nonvolatile solute, 261–264
- Boltzmann, Ludwig, 114
- Bombardment reactions, 469–471, 470t
- Bomb calorimeter** Device used to measure heat flow, in which a reaction is carried out within a sealed metal container, 193–195, 194
- Bonaparte, Napoleon, 20, 545–546
- Bond angle** The angle between two covalent bonds, 166, 169–170, 180, 548
- Bonded atoms, 169
- Bond energy. *See* Bond enthalpy
- Bond enthalpy** The enthalpy change (kJ/mol) when a particular type of bond is broken in the gas state, 207–209, 208t, 208
- Bond polarity. *See* Polarity
- Boric acid, 164, 356
- Boron, 143–144, 179
- Boron trifluoride, 163, 164, 167, 168, 531
- Boyle, Robert, 338
- Boyle's law** Relation stating that at constant T and n , the pressure of a gas is inversely proportional to its volume, 99, 218

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 Branched polyethylene, 578, 578
 Brass, 6
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 percent abundance, 4t
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Brønsted-Lowry acid A species that donates a proton in an acid-base reaction; in the reaction $\text{HB}(aq) + \text{A}^-(aq) \rightleftharpoons \text{HA}(aq) + \text{B}^-(aq)$, HB is a Brønsted-Lowry acid, 332, 336, 347, 351, 352t, 531, 590
Brønsted-Lowry acid-base model, 374, 379
 ion product of water, 333
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 with weak acids, 339
Brønsted-Lowry base A species that accepts a proton in an acid-base reaction; in the reaction $\text{HB}(aq) + \text{A}^-(aq) \rightleftharpoons \text{HA}(aq) + \text{B}^-(aq)$, A^- is a Brønsted-Lowry base, 332, 336, 351, 352t, 531, 590
Buffer A system whose pH changes only slightly when strong acid or base is added. A buffer ordinarily consists of a weak acid and its conjugate base, present in roughly equal amounts
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 determination of H^+ in, 362–364
 at different pH values, 366t
 effect of, 361
 effect of added H^+ or OH^- , 368–370
 introduction to, 360–362
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Buffer capacity Amount of strong acid or base that can be added to a buffer without causing a drastic change in pH, 370–371
 Buffer range, 370–371
 Butadiene polymer, 428
 Butane, 549, 549, 550, 550t, 552, 560t
 Butanol, 256t
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 Calcium hydride, 351
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 Calcium oxide, 510
 Calcium propionate, 563
 Calcium silicate, 510
 Califormium, 470t
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Calorimeter Device used to measure heat flow, 192–195, 197
 Calorimetry, 192–195, 215a–215b
 Calvin, Melvin, 165
 Camphor, 264t
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Carbohydrates Large biological molecules made up of carbon, hydrogen and oxygen, 583–587, 597a
Carbon. *See also* Organic chemistry
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 in iron and steel production, 509–510
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Carbon-12 scale Atomic mass scale where the C-12 isotope is assigned a mass of exactly 12 amu, 28
 Carbon-14, 475
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 Carbon tetrachloride, 176, 176, 226
Carbonyl group The group $\begin{array}{c} \diagup \\ \text{C} \\ \parallel \\ \text{O} \end{array}$ found in aldehydes and ketones, 561
Carboxylic acids Organic compounds containing the $\begin{array}{c} \text{—C—OH} \\ \parallel \\ \text{O} \end{array}$ group, 356–358, 559t, 562–565
 Carotenoids, 153
 Carothers, Wallace, 582
 Carrier gas, 6
 Carus, Titus Lucretius, 576
 Catalase, 298
 Catalysis, 296–298, 297, 305f
Catalyst A substance that increases the rate of a reaction without being consumed by it, 296–298
 Catalytic converter, 297, 297
Cathode Electrode at which reduction occurs and toward which cations move, 430, 435, 436–437, 452, 453
 Cathode half-cell, 436
 Cathode ray, 23, 24
Cations Ions with a positive charge, such as Na^+ , 37
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 of transition and post-transition metals, 42
 transition metal cations, 146–148
 of transition metals, equilibria between, 519–521
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 as weak acids or spectator ions, 353
 Cellulose, 587, 587
Cell voltage A measurement of the current flow in an electrochemical cell, 439
 Celsius, Anders, 8
Celsius ($^{\circ}\text{C}$) Unit of temperature based on there being 100° between the freezing and boiling points of water, 8–9, 8
Centi Metric prefix indicating a multiple of 10^{-2} , 7t
Central atom Atom at the center of a molecule, to which two or more atoms are bonded. C is the central atom in CH_4 , 158, 488
 Ceres (god), 48
 Cerium (IV) oxide, 141
 Cesium, 152, 242, 481
 Cesium chloride, 242
 CFCs (Chlorofluorocarbons), 303
 Chadwick, James, 473
 Chain reaction, 481
 Chalcocite, 38, 511
 Charge balance, 77
 Charged particle, 470
Charles's and Gay-Lussac's law Relation stating that at constant P and n , the volume of a gas is directly proportional to its absolute temperature, 99, 99
Chelates Compounds that have a metal cation bonded at two or more points to nonmetal anions or molecules, 490, 490, 503–504
Chemical equation Expression that describes the nature and relative amounts of reactants and products in a reaction, 63–65. *See also* Equations
Chemical kinetics Study of reaction rates, 87, 274, 292. *See also* Reaction rate
Chemical properties Properties of a substance that are observed during a chemical reaction, 15–16, 16
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Chiral center Carbon atom bonded to four different groups, 569–571, 584, 588
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- Chlorine trifluoride, 165
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 Chromium(III) nitrate, 147
 Chromium(III) oxide, 521
 Chromium(III) salts, 520
 Chromium-oxygen compounds, 24
 Cinnamaldehyde, 562
 Cinnabar, 4, 511
 Cinnamon, 562
Cis isomer Geometric isomer in which two like groups are relatively close to another (e.g., a, a), 495–497, 496, 497, 567–568
- 
- Citric acid, 340, 357t
 Clapeyron, B. P. E., 220
 Clathrates, 71
 Clausius, Rudolph, 114, 220, 409
Clausius-Clapeyron equation An equation expressing the temperature dependence of vapor pressure: $\ln(P_2/P_1) = \Delta H_{\text{vap}}(1/T_1 - 1/T_2)/R$, 220, 295, 327
 Claussen, Walter, 72
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 Cobalt-60, 471, 471
 Cobalt chloride, 71
 Cobalt(II) chloride, 147
 Cobalt(II) oxide, 516
Coefficient rule Rule which states that when the coefficients of a chemical equation are multiplied by a number n , the equilibrium constant is raised to the n th power, 311 312t
 Coefficients, 64, 65, 67
Coffee-cup calorimeter Calorimeter made of nested coffee cups in which essentially all of the heat given off by a reaction is absorbed by a known amount of water, 192–193, 192, 197
 Coke, 509–510
 Cold pack, 197
 Coleridge, Samuel Taylor, 246
 Collagen, 595
Colligative properties Physical properties of a solution that primarily depend on the concentration rather than the kind of solute particle. Vapor pressure lowering is a colligative property; color is not.
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 lithium-ion (Li-ion) batteries, 460–461
 primary (nonrechargeable) voltaic cells, 458–459
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 storage (rechargeable) voltaic cells, 459–460
Common ion effect The reduction in the solubility of a salt in a solution that contains either an anion or a cation common with that salt, 393–394
 Complex anions, 492–493
 Complex cations, 492
 Complex formation, 386, 401–403, 402
Complex ion An ion containing a central metal atom bonded to two or more ligands. The species $\text{Ag}(\text{NH}_3)_2^+$ and $\text{Zn}(\text{H}_2\text{O})_4^{2+}$ are complex ions.
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 formation constants, 386t
 geometry of, 491t, 494–497, 505a
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 ligands, 490
 naming, 492–493, 505a
 precipitate formation, 394–398
 solubility, 388–394
Compound Substance containing more than one element, 3, 4–5, 23, 42–43, 50c, 411t
Concentration A measure of the relative amounts of solute and solvent in a solution; may be expressed as molarity, mole fraction, etc., 54
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 and time, 276, 277
 Condensable gas, 223t
 Condensation, 217, 222, 264–265, 264
Condensation polymer A polymer formed from monomer units by splitting out a small unit, most often a water molecule, 580–583
Condensation reactions Reactions in which two molecules combine to produce a larger molecule and a small molecule (e.g., H_2O), 572
 Condensed ring structures, 558
Condensed structural formula Formula of a molecule which indicates the functional group present (e.g., CH_3COOH for acetic acid), 36
Conductivity The relative ease with which a sample transmits electricity. Because a much larger electrical current will flow through an aluminum rod at a given voltage than through a glass rod of the same shape, aluminum is a better electrical conductor than glass, 40, 40, 226, 233, 235, 236
 Coniine, 358
Conjugate acid The acid formed by adding a proton to a base; NH_4^+ is the conjugate acid of NH_3 , 332, 352t
Conjugate base The base formed by removing a proton from an acid; NH_3 is the conjugate base of NH_4^+ , 332, 339, 340t, 352t, 365
 Conservation of mass, law of, 24
 Constant composition, law of, 24
 Contact process, 543
 Continuous visible spectra, 129
 Control rods, 482, 482
 Conversion-factor approach, 198
Conversion factor A ratio, numerically equal to 1, by which a quantity can be converted from one set of units to another, 12–14
 Conversions, 53–54, 54, 251–254
 Coordinate covalent bonds, 488
Coordination compounds Compounds in which there are complex ions. Examples include $[\text{Cu}(\text{NH}_3)_4]\text{Cl}_2$ and $\text{K}_4[\text{Fe}(\text{CN})_6]$, 487, 488–489, 492–493, 498, 498, 505a
Coordination number The number of bonds from the central metal to the ligands in a complex ion, 488, 491, 491t, 494–495, 494
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 colors of copper complexes, 488
 conductivity, 236
 and electrolysis, 511–512
 electron configuration, 143
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 Copper carbonate, 207
 Copper(II), 490, 490
 Copper(II) chloride, 494
 Copper(II) salt, 488
 Copper(II) sulfate, 147
 Copper(I) sulfide, 511–512
 Copper nails, 52
 Copper sulfate, 6, 71, 127, 226, 247, 444, 444
 Copper tetramine, 489, 492
Core electrons Electrons in an inner, complete level, 150, 157
 Cosby, Bill, 409
Coulomb (C) A unit of quantity of electricity; $9.648 \times 10^4 \text{ C} = 1 \text{ mol } e^-$, 453, 453t
 Coulomb's law of electrostatic attraction, 130
Coupled reactions Two reactions that add to give a third, 425–427, 429d
Covalent bond A chemical link between two atoms produced by sharing electrons in the region between the atoms, 35, 36, 36
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 Lewis structures, 156–166, 157t
 molecular geometry, 166–174
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 polarity of molecules, 174–178
 valence bond model, 178–179
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Critical pressure The pressure at the critical temperature; the highest vapor pressure that a liquid can have, 222–223
Critical temperature The highest temperature at which a substance can exhibit liquid-vapor equilibrium. Above that temperature, liquid cannot exist, 222–223, 222, 223t
 Crosslinking, 427, 428
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 Crustacyanin, 153, 153
 Crutzen, Paul, 303
 Cryolite, 509
 Crystal field energy, 505a–505b
Crystal field model Electrostatic model of the bonding in complex ions. The only effect of the ligands is to change the relative energies of the d orbitals of the central metal atom, 498
Crystal field splitting energy The difference in energy between the two sets of d orbitals in a complex ion, 500–502, 500
 Crystalization, 243
 Crystal structures, 238–243, 245c
 Cubic cell units, 238–239, 238, 239t
 Cucumber, 266, 266

- Curie, Irene. *See* Joliot-Curie, Irène
 Curie, Marie, 241, 467, 473
 Curie, Pierre, 473
Curies (unit) (Ci) Units of radiation corresponding to the radioactive decay of 3.700×10^{10} atoms/s, 474
 Curiosity (Mars rover), 63, 63
 Curium, 470t
 Cyalume light, 293
 Cyanide, 494
 Cyanide process, 512–513, 512
Cycloalkanes Saturated hydrocarbons containing closed rings. General formula C_nH_{2n} , 553, 553
 Cyclohexane, 264t, 553
 Cyclopentane, 553
 Cysteine, 589t
 Cystic fibrosis, 452
- D**
 Dalton, John, 22–23, 23, 24, 109, 111, 258
Dalton's law A relation stating that the total pressure of a gas mixture is the sum of the partial pressures of its components, 111
 Davy, Humphry, 458
 De Broglie, Louis, 132
 Debye, Peter, 271
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 Deci, 7t
 Decomposition rate, 277, 278, 278, 280, 285, 285t, 297, 298
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 Denatured alcohol, 560
Density The ratio of the mass of a substance to its volume, 16–18, 18, 103–105, 105, 225, 226, 234
 Deoxyribonucleic acid (DNA), 595–596, 595
Deposition The phase transition from the vapor phase to the solid phase, without passing through the liquid phase, 225
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 Dexedrine, 571
Diamagnetic A term indicating that a substance does not contain unpaired electrons and so is not attracted into a magnetic field, 144
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 and temperature, 326–328, 326
 in writing and balancing equations, 63–64
 Dinitrogen trioxide, 535
Dipole Species in which there is a separation of charge (i.e., a positive pole at one point and a negative pole at a different point), 174–176
Dipole forces Attractive forces between polar molecules, 228–229, 228
 Dipole moment, 175
 Diprotic acids, 346, 380–382, 381
Disaccharides The carbohydrates formed when two monosaccharides undergo a condensation reaction, 584
Dispersion force An attractive force between molecules that arises because of the presence of temporary dipoles, 227, 227, 550
Disproportionation A reaction in which a species undergoes oxidation and reduction simultaneously, 519, 532, 532
 Distillation, 6, 7
 DNA fingerprinting, 595–596, 595
 Dogs, 161
 D orbitals, 498–499, 499, 500, 501
Double bond Two shared electron pairs between two bonded atoms, 158
 Double helix model, 595–596, 596
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 Dry cells, 458–459
 Dry cleaning industry, 244
 Dry ice. *See* Carbon dioxide
 Dubnium, 470t
 Ductility, 236
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- E**
 E° . *See* Standard cell voltage
 E°_{ox} . *See* Standard oxidation voltage
 E°_{red} . *See* Standard reduction voltage
 Eckberg, Anders, 49
E. coli, 472
 EDTA (Ethylenediaminetetraacetate) ion, 504, 504
Effective nuclear charge Positive charge felt by the outermost electrons in an atom; approximately equal to the atomic number minus the number of electrons in inner, complete levels, 150
Efflorescence Loss of water by a hydrate, 71
Effusion Movement of gas molecules through a pinhole or capillary, 117–119, 119
 Einstein, Albert, 127
 Elastomers, 427–428
Electrical neutrality The principle that, in any compound, the total positive charge must equal the total negative charge, 41, 436–437, 452, 517
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 Electric field, 23, 24, 175, 175
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 oxidation–reduction reactions, 431–435, 464–464a
 standard cell voltage and standard free energy change, 443–446, 464c
 standard voltages, 439–446, 464a–464c
 voltaic cells, 435–439, 464a
Electrodes Anodes or cathodes in an electrochemical cell, 430, 452
Electrolysis Passage of a direct electric current through a liquid containing ions, producing chemical changes at the electrodes.
 and chloride ores, 507, 508
 and copper, 511–512
 to decompose water, 407
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 and Faraday, 458
 and fluorine and chlorine, 530
 and oxides, 509
 of potassium iodide, 456
 of sodium chloride, 457
 of water, 108
 of water solution, 456t
 Electrolyte, 40, 81, 269–271
Electrolytic cell A cell in which the flow of electrical energy from an external source causes a redox reaction to occur, 430, 452–456, 453, 464d–464e
 Electrolytic copper, 512
 Electromagnetic spectrum, 126, 126
 Electron cloud, 133, 227
Electron configuration An expression giving the population of electrons in each sublevel.
 The electron configuration of the Li atom is $1s^2 2s^1$, 124, 138–145, 141
 Electron-deficient molecules, 163–164
 Electron density, 155–156, 156
Electronegativity A property of an atom that increases with its tendency to attract electrons to a bond, 152, 152t
 Electronic level capacities, 137, 137t
 Electron-pair bond, 165, 179
 Electron-pair geometry, 169
Electron-pair repulsion The principle used to predict molecular geometry. Electron pairs around a central atom tend to orient themselves to be as far apart as possible, 166
 Electron pairs, in Lewis acid–base model, 355–356
Electrons Negatively charged components of an atom, found outside the nucleus.
 atomic orbitals, 138
 atomic spectra, 129–130
 electron arrangements in monatomic ions, 145–148
 electron configuration in atoms, 138–143
 hydrogen atom, 130–133
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 periodic trends in the properties of atoms, 148–152
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 quantum mechanical model, 132–133
 quantum numbers, 133–137
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Electron-sea model A model of metallic bonding in which cations act as fixed points in a mobile “sea” of electrons, 236
Electron spin The property of an electron described by the quantum number m_s , which can be $+1/2$ or $-1/2$, 135, 135
 Electroplating, 455, 456
Element A substance whose atoms are all chemically the same, containing a definite number of protons, 3
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 chemical reactivity, 526–529
 definition of, 2–4
 occurrence and preparation, 529–530
 with percentage abundances, 4t
 and the periodic table, 50b
 and physical state at room temperature, 37
 standard molecular entropies, 411t
 and their preparation, 526–530
 Elementary oxygen, 164
Elementary steps The individual steps that constitute a reaction mechanism, 299
Elements of Chemistry (Lavoisier), 15
Elimination reactions Reactions in which a reactant loses an atom or groups of atoms to form a double bond, 572
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Enantiomers Optical isomers, 569–571
Endothermic A process in which heat is absorbed by a system; ΔH is positive for an endothermic reaction, 189, 190, 196, 196, 197, 208, 257, 326–328, 407–408
End point The point during a titration at which the indicator changes color, 371, 373t
Energy A property of a system which can be altered only by exchanging heat or work with the surroundings, 127, 127, 187, 209–212, 210t, 214t
 Energy balance, 211, 213–214

- Energy change (ΔE), 211–213, 461, 476–480
 Energy diagram, 196
 Energy factor, 407–408
 Energy input, 213
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 Energy output, 213–214
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Enthalpy (H) A property of a system that reflects its capacity to exchange heat (q) with the surroundings; defined so that $\Delta H = q$ for a constant-pressure process, 195–196, 211–212, 413
Enthalpy change (ΔH) The difference in enthalpy between products and reactants.
 and energy change, 211–213
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 rules of thermochemistry, 198–200
 in transition-state model, 291–293
Enthalpy of formation (ΔH_f°) When one mole of a species is formed from the elements, 202
 calculation of, 202–207
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 exothermic reactions, 202
 relation with enthalpy change, 206
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Entropy (S) A property of a system related to its degree of order; highly ordered systems have low entropy
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 overview of, 409–410
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Entropy change (ΔS) The difference in entropy between products and reactants, 409
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 net ionic equation, 76–78, 83
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Equilibrium A state of dynamic balance in which rates of forward and reverse reactions are equal; the system does not change with time.
 changes in conditions, effect of, 323–328
 compression or expansion, 325–326
 gaseous species, adding or removing, 323–325
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 between a solid and its liquid, 223
 between a solid and its vapor, 223
 and spontaneous reactions, 407
 and sublimation, 225
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 vapor pressure, 222
Equilibrium constant (K) A number characteristic of an equilibrium system at a particular temperature. For the system $\text{A(g)} + 2\text{B(aq)} \rightleftharpoons 2\text{C(g)}$ the expression for K is $(P_{\text{C}})^2/(P_{\text{A}})[\text{B}]^2$.
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 Equilibrium constant expression, 310–315, 330a–330b
 Equilibrium curve, 395
 Equilibrium partial pressures, 320–323
Equivalence point The point during a titration when reaction is complete; equivalent quantities of the two reactants have been used, 84–85, 371, 374, 380–381
 Essential metal ions, 523t
Esters Organic compounds containing the —C—O— functional group, 559t,
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 Ethane, 223t, 548, 550t
 Ethanol, 191t, 553, 560, 560t. *See also* Ethyl alcohol
 Ethene, 554. *See also* Ethylene
Ethers Organic compounds containing the —O— functional group, 558–561, 559t, 560t
 Ethyl alcohol, 37, 61, 223t, 226, 255, 256t, 262, 560. *See also* Ethanol
 Ethyl butyrate, 564t
 Ethylene, 158, 174, 181, 182–183, 183, 554, 554, 577t. *See also* Ethene
 Ethylenediamine, 490, 490, 497, 497
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 Ethylene glycol, 255, 255, 264, 561, 581
 Ethyl ether, as liquid, 223t
 Ethyl formate, 564, 564t
 Ethyl group, 550t
 Ethyl methyl ether, 560t
 Europium oxide, 141
 Evaporation, 217, 219, 264–265, 264
Excited state An electronic state that has a higher energy than the ground state, 131
Exothermic Describes a process in which heat is evolved by a system; H is negative for an exothermic reaction, 189, 190, 196, 196, 197, 202, 208, 407, 414
Expanded octets More than four electron pairs about a central atom, 164–166, 167, 172
Experimental yield The amount of product actually obtained in a reaction, 70–71
 Exponential notation, 11
Extensive properties Properties of a substance which depend upon the amount of sample; volume is an extensive property, 15–16, 16
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Face-centered cubic cell (FCC) A cubic unit cell with atoms at each corner and one at the center of each face, 238, 238, 239t
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 Fahrenheit scale, 8–9, 8
 Faraday, Michael, 71, 458, 556
Faraday constant The constant that gives the number of coulombs equivalent to one mole of electrons; 96480 C/mol e^- , 446
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 Fermentation, 15t, 560
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 Fertilizer, 66–67, 67, 545
Filtration A process for separating a solid-liquid mixture by passing it through a barrier with fine pores, such as filter paper, 6
 Final and initial state problems, 100–102
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First law of thermodynamics The statement that the change in energy, ΔE , of a system is the sum of the heat flow into the system, q , and the work done on the system, w , 209–213, 215d
First-order reaction A reaction whose rate depends upon reactant concentration raised to the first power, 283–287, 284, 288t, 305c–305d
 First quantum number (n), 134
Fission The splitting of a heavy nucleus by a neutron into two lighter nuclei, accompanied by the release of energy, 480–483, 480
 Fission process, 480–481
Five percent rule The empirical rule that the approximation $a = a - x$ if $x \leq 0.05a$, 345
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 Fluorite, 238
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 Forensic toxicology, 545–546
Formal charge The charge that an atom would have if the bonding electrons in a molecule were equally shared, 162–163, 186–186a
 Formaldehyde, 561, 562
Formation constant (K_f) Equilibrium constant for the formation of a complex ion from the corresponding cation and ligands, 385–388, 386t, 405
 Formic acid, 340t
 Fourth quantum number (m_l), 135
 Franklin, Rosalind, 595
 Frasch, Herman, 529
Frasch process The process used to extract native sulfur from underground deposits, 529, 529
Free energy (G) A thermodynamic quantity, defined as the difference between the enthalpy and the product of the absolute temperature and entropy of a system, 413–415, 414
Free energy change (ΔG) The difference in free energy between products and reactants, 414, 424–427, 429c–429d
Free energy of formation ΔG for the formation of a species from the elements, 413–415, 461
 Free radicals, 163, 485
 Freezing curve, 262
Freezing point The temperature at which the solid and liquid phases of a substance are at equilibrium, 223, 225
 Freezing point constants, 264t
Freezing point lowering The decrease in the freezing point of a liquid caused by adding a solute, 262–264, 268, 270t
 Freon, 303
Frequency (ν) The number of complete wave cycles per unit time, 125–127, 125
 Frost, Robert, 187

- Fructose, 586t
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 Fuel cells, 461–463, 461
 Fuel rods, 481
Functional group A small group of atoms in an organic molecule that gives the molecule its characteristic chemical properties.
 alcohols and ethers, 558–561
 aldehydes and ketones, 561–562
 amines, 565–566
 carboxylic acids and esters, 562–565
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Fusion A reaction between small atomic nuclei to form a larger one, releasing energy in the process, 480, 483–484, 486b
- G**
G. See Free energy
 Gadolinium oxide, 141
 Galactose, 586t
Gamma radiation High-energy photons emitted by radioactive nuclei, 467, 468, 468, 469t, 471, 471
Gas The physical phase of matter without a fixed shape or volume, 2, 3
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 comparison of solids, liquids, and gases, 216–217
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 stoichiometry of gaseous reactions, 105–110, 123b–123c
 volume, amount, and temperature, 96
 Gas chromatography (GC), 6
Gas constant (R) The constant that appears in the ideal gas law; $R = 0.0821 \text{ L} \cdot \text{atm/mol} \cdot \text{K} = 8.31 \text{ J/mol} \cdot \text{K}$, 99–100, 100t
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Gaviscon, 93t
Gay-Lussac, Joseph, 108
GC (Gas chromatography), 6
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Geometric isomerism A type of isomerism that arises when two species have the same molecular formulas but different geometric structures, 494, 495–497, 567–569
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- Gibbs, J. Willard**, 413, 415
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Gibbs-Helmholtz equation The relation $\Delta G = \Delta H - T\Delta S$, 414–415, 418–420
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Graham, Thomas, 117
Graham's law The rate of effusion of a gas is inversely proportional to the square root of its molar mass, 117–119
Grain alcohol, 560. *See also* Ethyl alcohol
Gram, 52–54, 73–73a
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Graphite, 233–234, 233
Gray arsenic, 545
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Ground state The lowest allowed energy state of a species, 131, 138
Group, functional. *See* Functional group
Group 1, 507, 513, 515. *See also* Alkali metals
Group 2, 507, 513, 514, 515. *See also* Alkaline earth metals
Group I Cation group in qualitative analysis, 403–404
Group II Cation group in qualitative analysis, 403–404, 403
Group III Cation group in qualitative analysis, 404, 404
Group IV Cation group in qualitative analysis, 404
Groups Vertical columns of the periodic table, 33–34, 140, 140t
- H**
H. See Enthalpy
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Haber, Clara, 329
Haber, Fritz, 328–329
Haber process An industrial process used to make ammonia from the elements, 328–329, 329t, 530–531
Hahn, Otto, 480
Half-cell Half of an electrochemical cell, at which oxidation or reduction occurs, 436
Half-equations Equations written to describe half-reactions of oxidation or reduction, 87, 431–435, 432
Half-life The time required to convert half of the original amount of reactant to product, 285–287, 290
Half-neutralization, 377
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Hall, Charles, 3–4, 509
Halogens Elements of Group 17, 34, 164, 227t, 528, 530, 538t
Hatchett, Charles, 49
HDL (High-density) cholesterol, 573–574
Head-to-head, tail-to-tail polymer, 579
Head-to-tail polymer, 579
- Heartburn**, 93
Heat A form of energy that flows between two samples because of their difference in temperature, 5–6, 187, 209–211, 210t
Heat capacity The amount of heat required to raise the temperature one degree Celsius, 190
Heat content. *See* Enthalpy
Heat flow (q) The amount of heat flowing into a system (+) or out of it (–)
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Henry, William, 258
Henry's law At low to moderate pressures, gas solubility is directly proportional to pressure, 258, 258, 259
Heptane, 550t, 553
Heptanol, 256t
Héroult, Paul, 3–4, 509
Herschel, William, 48
Hertz (Hz) A unit of frequency; one cycle per second, 125
Hess, Germain, 200
Hess's law The heat flow in a reaction that is the sum of two other reactions is equal to the sum of the heat flows in those two reactions, 200–201, 200, 206, 425
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Hexacyanoferrate(III), 493
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Hexamminecobalt(III) chloride, 388, 388
Hexane, 61, 255, 550t
Hexanol, 256t
High-density (HDL) cholesterol, 573–574
Highly toxic elements, 35, 35
High-spin complexes Any complex that, for a particular metal cation, has the largest possible number of unpaired electrons, 500, 501
High-temperature fuel cells, 462
Hindenburg explosion, 105
Histidine, 589t
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 Horace, 1
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 Household solutions, 80
 Hubble Space Telescope, 48
 Human body, energy balance in, 213–214
 Hund, Friedrich, 144
Hund's rule Ordinarily, electrons will not pair in an orbital until all orbitals of equal energy contain one electron, 144, 498
Hybridization Mixing of two or more orbitals or structures, 178–184, 186b
Hybrid orbital An orbital made from a mixture of individual atomic orbitals. An sp^2 orbital is formed by mixing an s with two p orbitals, 179–181, 179, 180t
Hydrates Compounds containing bound water such as $BaCl_2 \cdot H_2O$, 71–72
Hydration Reaction with water, 572
 Hydrazine, 45, 63–64, 65, 531
Hydride A compound of hydrogen, specifically one containing H^- ions, 460
 Hydride ion–water reaction, 351
 Hydriodic acid, 81t
 Hydrobromic acid, 81t
Hydrocarbon An organic compound containing only carbon and hydrogen atoms, 227t, 255, 411, 548, 553
 Hydrochloric acid
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Hydrogen bond An attractive force between molecules found when a hydrogen atom is bonded to N, O, or F, 229–232, 229t, 231, 255
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Hydronium ion The H_3O^+ ion characteristic of acidic water solutions, 332, 374, 379
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 Ideal gases, 120t
Ideal gas law A relation between pressure, volume, temperature, and amount for any gas at moderate pressures: $PV = nRT$, 98–100, 98
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 and gas mixtures, 110–114
 and law of combining volumes, 108
 and real gases, 120–121
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Ideal geometry The geometry a molecule would have if the effect of unshared pairs were neglected, 167
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 Induced dipole, 227
 Induced radioactivity, 473
 Industrial ethanol, 560
 Inert gases, 34
Infrared (IR) radiation Light having a wavelength greater than about 700 nm, 127
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 Insoluble carbonate, 93
 Instantaneous rate, 277
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 Insulin, 241
Intensive properties Properties of a substance which are independent of the amount of sample; density is an intensive property, 15–16, 16
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Intermolecular forces The forces between molecules, 226
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 Iodine chloride, 228, 228
 Ion concentrations, 451–452
 Ionic atmosphere, 271, 271
Ionic bonds The electrostatic forces of attraction between oppositely charged ions in ionic compounds, 39
Ionic compound Any compound made up of cations and anions, 39
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 Ionic crystals, 242–243, 242
Ionic radius The radius assigned to a monatomic ion, 149, 150–151
Ionic solids Any compound made up of cations and anions. (Also sometimes referred to as *ionic compounds*), 232, 232, 235, 245c
Ionization energy The energy that must be absorbed to remove an electron from a species, 151–152, 151
 Ion pair, 271
Ion product constant (Q) The product of the concentration of dissociated ions of a salt (raised to the power of their coefficients) at a particular point in time, 395
Ion product constant of water (K_w) The product $[H^+][OH^-] = 1.0 \times 10^{-14}$ at 25°C, 333
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 Iron(II) sulfate, 147
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 Iron production, 509–510, 509
 Isobutyl formate, 564t
Isoelectric point The pH at which an amino acid does not migrate in an electric field, 591
 Isoelectronic, 146
 Isoleucine, 589t
 Isomerism in organic compounds, 566–571, 575b–575c
Isomers Any species with the same formula as another species but having different properties. Structural and geometric isomers are possible, 162, 495–497

- Isooctane, 553
 Isopentyl acetate, 564t
 Isopropyl group, 550t
Isotope An atom having the same number of protons as another atom but with different numbers of neutrons, 27–28, 50a
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- J**
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 Jewelry, 512
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Joule (J) The base SI unit of energy, a joule is equal to the kinetic energy of a two-kilogram mass moving at a speed of one meter per second, 127, 189, 453, 453t, 478
 Jung, Carl, 360
- K**
K. See Equilibrium constant
K_a. See Acid equilibrium constant
K_b. See Base equilibrium constant
K-electron capture The natural radioactive process in which an inner electron (*n* = 1) enters the nucleus, converting a proton to a neutron, 468, 469t
Kelvin (K) The scale obtained by taking the lowest attainable temperature to be 0 K; the size of degree is the same as °C, 9, 96
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Ketones Compounds containing the carbonyl group —C=O bonded to two hydrocarbons, 559t, 561–562
K_f. See Formation constant
Kilo The prefix indicating a multiple of 1000, 7t
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 Kilojoules, 127, 189, 478
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Kinetic theory A model of molecular motion used to explain many of the properties of gases
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Le Châtelier's principle When a system at equilibrium is disturbed it responds in such a way as to partially counteract that change, 323, 325, 326, 363, 393
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Lewis acid A species that accepts an electron pair in an acid-base reaction, 355–356
 Lewis acid-base model, 355–356, 356t
Lewis base A species that donates an electron pair in an acid-base reaction, 355–356, 490, 531
Lewis structure An electronic structure of a molecule or ion in which electrons are shown by dashes or dots (electron pairs), 156–166, 385, 535, 535
 of atoms commonly forming covalent bonds, 157t
 definition of, 157
 of ethylenediamine molecule, 490
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 of oxoacids and oxoanions, 538
 resonance forms, 160–162
 writing, 158–160
 Libby, Willard, 165, 475
 Lichens, 503
 Life processes, kinetics of, 292
Ligands Molecules or anions bonded to the central metal in a complex ion, 488, 490, 499, 499, 503
 Light, 125–129, 154a
 Light, speed of (*c*), 476–480
 Light absorption, 501
 Light water reactors, 481–482
 Limestone, 510, 534, 534. See also Calcium carbonate
Limiting reactant The least abundant reactant based on the equation for a reaction; dictates the maximum amount of product that can be formed, 67–70
 Linear functions, 219–220
Linear molecule A triatomic molecule in which the bond angle is 180°; examples include BeF₂ and CO₂, 166
 Linear polyethylene, 578, 578
 Line emission spectra, 129
 Liquid propane, 552
 Liquid scintillation counter, 473
Liquid The physical phase of matter that has a fixed volume but is not rigid in shape, 3
 boiling point, 221–222
 comparison of solids, liquids, and gases, 216–217
 and critical temperature, 222–223, 223t
 critical temperature and pressure, 222–223
 definition of, 2
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 Lithium-6, 479
 Lithium chlorate (LiClO₃), 75
 Lithium chloride, 242, 242
 Lithium hydroxide, 81t, 336
 Lithium-Ion (Li-Ion) batteries, 460–461
 Livingston, James D., 487
 Lobsters, 153
 Lockyer, Norman, 49
- London forces, 227
 Low-density (LDL) cholesterol, 573–574
 Lowry, Thomas, 332
Low-spin complexes Any complex that, for a particular metal ion, has the smallest possible number of unpaired electrons, 500, 500, 501
 Lucite, 577t
Luster The characteristic shiny appearance of a metal surface, 236
 Lye. See Sodium hydroxide
 Lysine, 589t, 593
- M**
 Maalox, 93t
 Manganese(II) chloride, 147
 Magic numbers, 466
 Magnesium, 70–71
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 percent abundance, 4t
 reactions with water, 514
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 thermite reaction, 204
 Magnesium iodide, 70–71
 Magnesium ion, 396–397
 Magnesium oxide, 202
 Magnesium sulfate, 270–271, 270t
 Magnus, Albertus, 20
Main-group elements Elements in one of the groups numbered 1 to 2 or 13 to 18 of the periodic table, 33
 Malic acid, 357t
Malleability The ability to be shaped, as by pounding with a hammer; characteristic of metals, 236
 Maltase, 298
 Maltose, 298, 585–586, 586t
 Manganese, 4t, 236, 519, 520t
 Manganese dioxide, 458, 532, 532
 Manometer, 96, 97, 122
 Maple syrup, 272
 Marcet, Jane, 458
 Mars rover Curiosity, 63, 63
 Mass, 8, 13t, 16, 17, 31–32, 54
 Mass, change in (Δm), 476–480
Mass defect The difference between the mass of a nucleus and the sum of the masses of the neutrons and protons of which it is composed, 479
 Mass-energy relations, 476–480, 486b
Mass number (A) An integer equal to the sum of the number of protons and neutrons in an atomic nucleus, 27–28
Mass percent 100 times the ratio of the mass of a component to the total mass of a sample, 249–250, 251
 Mass relations
 from equations, 65–67
 experimental yield and percent yield, 70–71
 limiting reactant and theoretical yield, 67–70
 molecular formula from simplest formula, 62–63
 mole-mass relations in, 73c–73d
 percent composition, 58–59
 simplest formula, 60–62
 writing and balancing chemical equations, 63–65
 Mass spectrometry, 7, 28–29, 29
 Masteron, William L., 272
 Matter, 1–7, 3, 15–20, 21a
 Maxwell, James, 114, 119, 415
Maxwell distribution A relation describing the way in which molecular speeds or energies are shared among gas molecules, 119
 Mayer, Maria, 467
 Measurements
 conversion of units, 12–14
 instruments and units, 8–9
 introduction to, 7
 uncertainties in, 9–12, 10
 Medicine, 20, 471
 Mega, 7t

- Meitner, Lise, 480
- Melting point** The temperature at which the solid and liquid phases of a substance are in equilibrium with each other, 16, 223, 225–226, 226, 228, 233, 235–236
- Membrane, 265–266
- Mendeleev, Dmitri, 34, 184
- Mendelevium, 142
- Mercury, 3, 4t, 4, 9, 18, 96–97, 96, 236, 520t
- Mercury (god), 48, 48
- Mercury cell, 459
- Mercury(II) oxide, 15–16, 459
- Mercury sulfide (HgS), 75
- Metabolic energy, 213–214
- Metal alloys, 246
- Metal cations, 339, 523t
- Metal ions, 505a–505b
- Metallic iron, 58–59
- Metalloids** Elements such as Si or B that have properties intermediate between those of metals and nonmetals, 34, 34
- Metallurgy** The science and processes of extracting metals from their ores, 506
- chloride ores, 507–508
 - native metals, 512–513
 - oxide ores, 509–510
 - sulfide ores, 511–512
- Metals** Substances having the characteristics luster, malleability, and high electrical conductivity, 34–35
- alkali and alkaline earth metals, reactions of, 513–516, 524a
 - and cations, 37
 - crystal structures, 238–241
 - diagram of, 232
 - metallic solids, 232, 236–237, 245c
 - metallurgy, 506–513, 524–524a
 - in nutrition, 522–523
 - and the periodic table, 507
 - structure and properties of, 237t
 - transition metals, 516–522, 524a
- Methane, 4, 168, 169
- applications of, 552
 - as a binary compound, 45
 - bond angle, 548
 - deviation from ideal gas behavior, 121–122, 121
 - free energies of formation, 417
 - hybrid orbital, 180
 - molecular formula for, 36
 - nomenclature, 550t
 - as permanent gas, 223t
 - reaction with oxygen, 211, 211
 - structural formula for, 36, 36
- Methane hydrate, 71, 72, 72
- Methanol, 153, 559. *See also* Methyl alcohol
- Methionine, 589t
- Methylacetylene, 555, 555
- Methyl alcohol, 162–163, 255, 256t. *See also* Methanol
- Methylamine, 81, 82, 565
- Methyl butyrate, 564t
- Methyl group, 550t
- Methyl methacrylate, 577t
- Methyl red, 372, 373, 373t, 374, 376, 377, 379, 380, 380
- Metric system** A measuring system where all units of a particular type (e.g., volume) are related to one another by powers of ten, 7, 7t
- Metric ton, 8
- Micro, 7t
- Microstates, 409
- Milk of magnesia, 515
- Milli** The prefix on a metric unit indicating a multiple of 10^{-3} , 7t
- Millimeters of mercury (mm Hg)** A unit of pressure: 1 atm = 760 mm Hg, 97
- Milton, John, 430
- Mirror images, 569
- Mixture** Two or more substances combined so that each substance retains its chemical identity, 3, 5–6
- Models, for reaction rates, 289–293
- Mode of decay, 467–469
- Moissan, Henri, 530
- Molal boiling point constant, 263
- Molal freezing point constant, 263
- Molality (m)** A concentration unit defined as the number of moles of solute per kilogram of solvent, 250–253, 252, 263
- Molar heat capacity, 190
- Molarity (M)** A concentration unit defined to be the number of moles of solute per liter of solution, 54–58, 247–248, 251–253, 252, 424
- Molar mass** The mass in grams of one mole of a substance, 52, 54
- boiling point, effect on, 227t
 - colligative properties, determination from, 267–269
 - and dispersion forces, 227
 - and effusion, 117, 119
 - and gases, 96, 103–105
 - and molecular speed, 116
 - molecular speed, relation to, 116
 - and standard molecular entropies, 411
- Molar volume, 100, 121–122
- Mole** A collection of 6.022×10^{23} items. The mass in grams of one mole of a substance is numerically equal to its formula mass, 51–58, 54, 73–73a, 100–103
- Mole fraction (X)** A concentration unit defined as the number of moles of a component divided by the total number of moles, 112–114, 123c–123d, 249, 251
- Mole ratio, 59, 108–109
- Molecular collisions, 290
- Molecular compounds, 50c–50d, 60
- Molecular formula** A formula in which the number of atoms of each type in a molecule is indicated as a subscript after the symbol of the atom, 36, 62–63
- Molecular geometry** The shape of a molecule, describing the relative positions of atoms, 166–174, 168, 170t, 172, 186a
- Molecular hydrates, 71–72
- Molecular liquids, 226
- Molecular model, 114, 114
- Molecular orbitals, 164
- Molecular speeds, 116, 119–120
- Molecular structure, of rubbery materials, 427–428
- Molecular substance** A substance composed of discrete molecules such as H_2 or CH_4 , 36
- dipole forces, 228–229
 - dispersion force, 227
 - effect of molar mass on boiling points, 227t
 - hydrogen bonds, 229–232
 - liquid, 226–232
 - in solids, liquids, and gases, 217
 - structure and properties of, 237t
- Molecule** An aggregate of atoms that is the fundamental building block in all gases and many solids and liquids; held together by covalent bonds between the atoms, 35–37, 50b–50c, 174–178, 186b, 216–217, 348
- Mole-mass conversions, 66, 73–73a
- Molina, Mario, 303
- Monatomic anions, 43
- Monatomic cations, 43
- Monatomic ions, 39, 145–148, 154c
- Monoatomic ion, 88, 146
- Monomers** Small molecules that join with other monomers to form a polymer, 576
- Monosaccharides** Carbohydrates that cannot be broken down into a simple sugar, 583
- Monounsaturated fats, 574, 574
- Morphine, 358
- Moss, 503
- Multiple bond** A double or triple bond, 171, 181–182
- Multiple proportions, law of, 24, 24
- Muscular activity, 214
- Mylanta, 93t
- N**
- n.* *See* Mole
- N_A . *See* Avogadro's number
- Naming, complex ions and coordination compounds, 492–493
- Nano** The prefix on a metric unit indicating a multiple of 10^{-9} , 7t
- Naphthalene, 4, 264t, 558
- Naproxen, 571
- Native metals, 512–513
- Natural gas pipelines, 71–72, 552
- Natural logarithm, 219–220
- Natural radioactivity, 467
- Neon, 34, 34, 146, 184
- Neptune (god), 49
- Neptunium, 470, 470t
- Nernst, Walther, 449
- Nernst equation** An equation relating cell voltage E to the standard voltage E° and the ionic concentrations and/or pressures of reactants and products at 25°C: $E = E^\circ - (0.0257/m)(\ln Q)$, 449–451
- Net ionic equation** A chemical equation for a reaction involving ions in which only those species that actually react are included, 76–78, 83
- Network covalent** Having a structure in which all the atoms are linked by a network of covalent bonds, 232–234, 232, 237t, 245c
- Neutral complexes, 492
- Neutralization** A reaction between a strong acid and base to form a neutral solution, 82, 374, 399
- Neutral solution** A water solution with a pH of 7 (at 25°C), 333, 334
- Neutral species, 88
- Neutron activation analysis, 471–472
- Neutron** A particle in an atomic nucleus with zero charge and a mass of approximately 1 amu, 25–26, 25t, 469, 473
- Neutron bombardment, 470, 470t
- Neutron-to-proton ratio (n/p^+), 466, 466
- Newman, John Henry Cardinal, 51
- Newton, Isaac, 5, 129, 465
- Newton's law of motion, 130
- Nickel, 4t, 444, 444, 501, 518, 527
- Nickel-based batteries, 460
- Nickel-cadmium (Nicaid) batteries, 460
- Nickel chloride, 76, 76
- Nickel hydroxide, 76
- Nickel(II) oxide, 517
- Nickel(II) salt, 437
- Nickel(II) sulfate, 147
- Nickel-metal hydride batteries, 460
- Nickel nitrate, 236
- Nitric acid
- and acid rain, 382
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- Nitric oxide, 45, 163–164, 536
- Nitrogen
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 - equilibrium constant, 318
 - equilibrium partial pressures of, 320
 - in fertilizer, 66–67, 67
 - hydrogen bonds, 229–230
 - occurrence and preparation, 529
 - oxoanions of, 44t
 - percent abundance, 4t
 - as permanent gas, 223t
 - properties of, 526t
 - reactivity of, 526
 - as a reducing agent, 531
 - single bonds, 158
- Nitrogen dioxide
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- Nitrogen oxides, 535
 Nitronium ion, 382
 Nitrous acid, 339, 340t, 539
 Nitrous oxide, 45, 297, 536
 Nobelium, 142
 Nobel Peace Prize, 178
 Nobel Prize in chemistry, 87, 142, 178, 241, 303, 329, 473, 498, 530, 571
 Nobel Prize in medicine, 595
 Nobel Prize in physics, 130, 467, 473
Noble gases Elements in group 18 at the far right of the periodic table, 34, 41, 146, 146, 184–185, 227t
 Noble-gas structures, 41, 156
 Nonelectrolytes, 40, 260–269
 Nonmetal oxides, 535–537, 535t
Nonmetals Elements in the upper right part of the periodic table that do not show metallic properties, 34–35
 and anions, 37–38
 elements and their preparation, 526–530
 hydrogen compounds of, 530–534, 530t
 introduction to, 525
 oxoacids and oxoanions, 537–545, 546a–546c
 oxoacids of, 538t
 oxygen compounds of, 534–537
 and the periodic table, 526
 properties of, 526t
- Nonpolar bond** A covalent bond in which the electrons are equally shared by two atoms, so there are no positive and negative ends, 174
Nonpolar molecule A molecule in which there is no separation of charge and hence no positive and negative poles, 174–178, 228t
 Nonspontaneous reactions, 407, 414, 425
 Nonstoichiometric nickel(II) oxide, 517
 Nonstoichiometric oxides, 517
 Nonuniform mixtures. *See* Heterogeneous mixture
Normal boiling point The temperature at which the vapor pressure equals 1 atm, 221
 Novocaine hydrochloride, 358
 Noyori, Ryoji, 571
 Nuclear accidents, 482
 Nuclear binding energy, 478–480
Nuclear equations Symbolic representations of processes that show how the structure of an atomic nucleus is altered, 465
 Nuclear fission. *See* Fission
 Nuclear fusion. *See* Fusion
 Nuclear masses on the C scale, 477t
 Nuclear radiation, 468
 Nuclear reactions
 mass-energy relations, 476–480, 486b
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 nuclear fusion, 483–484, 486b
 nuclear stability, 465–467, 486
 radioactive decay, rate of, 473–476, 486a–486b
 radioactivity, 467–472, 486–486a
 Nuclear reactors, 481–483, 482
 Nuclear stability, 465–467, 479–480, 480, 486
Nuclear symbol A symbol giving the atomic number and mass number of a nucleus. Example: $^{12}_6\text{C}$, 27, 50a
Nucleon Either protons or neutrons, 466
 Nucleotides, 595
Nucleus The small, dense, positively charged region at the center of the atom, 25–26
 Nutrition, essential metals in, 522–523. *See also* Carbohydrates; Proteins; Vitamins
 Nyholm, R. S., 167
 Nylon, 582–583, 583
- O**
 Octahedral complexes, 499–501
Octahedron A figure with eight sides and six vertices, 168, 495, 495, 496, 497, 500, 503
 Octane, 226, 550t
 Octane number, 552–553
Octet rule Bonded atoms (except H) tend to have a share in eight valence electrons, 156–166, 186
 Octyl acetate, 564t
 Odd electron, 163
 Oil, 255. *See also* Petroleum
 Omeprazole, 93
 1-Propanol, 560t
 “On the Equilibrium of Heterogeneous Substances” (Gibbs), 415
 “On the Influence of Carbon Dioxide in the Air on the Temperature of the Ground” (Arrhenius), 87
 Opium poppy, 358
 Oppenheimer, J. Robert, 480
Optical isomers Isomers which rotate the plane of plane-polarized light, 569–571, 569
Orbital Region of space in which there is a high probability of finding an electron within an atom, 124, 133, 135
Orbital diagrams Sketches showing electron populations of atomic orbitals; electron spins are indicated by up and down arrows, 124, 143–145, 144, 154b–154c
Order of reaction An exponent to which the concentration of a reactant must be raised to give the observed dependence of rate upon concentration, 278–282
Ores Natural mineral deposits from which metal can be extracted profitably
 chloride, 507–508
 gold content of, 512
 oxide, 509–510
 principal, 506, 507
 sulfide, 511–512, 511
 Organic acids, 356–358, 357t
 Organic bases, 356–358
 Organic chemistry. *See also* Carbon
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 isomerism in organic compounds, 566–571
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 Organic material, age of, 475–476, 476
 Organic polymers
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 introduction to, 576
 proteins, 587–595, 597a
 synthetic addition polymers, 577–580, 577t, 597–597a
 synthetic condensation polymers, 580–583, 597a
 Organic reactions, 571–573, 575c
 Orientation of polar molecules, 175
 Ortega y Gasset, José, 307
Osmosis A process by which a solvent moves through a semipermeable membrane from a region where its vapor pressure is high to one where it is low, 264, 265, 266
Osmotic pressure The pressure that must be applied to a solution to prevent osmosis, 264–267, 265, 268, 272
 Osteoporosis, 522
 Ostwald, Wilhelm, 87, 542
 Oxalate anion, 490, 490
 Oxalic acid, 346, 346t, 357t
Oxidation A half-reaction in which there is an increase in oxidation number, 89–90, 431–433, 517t, 518
Oxidation number A number that is assigned to an element in a molecule or ion to reflect, qualitatively, its state of oxidation, 88–92, 90, 431, 432
 Oxidation-reduction reactions. *See* Redox reaction
- Oxide ores, 509–510
 Oxides, molecular structure of, 535–536, 546a–546b
Oxidizing agent A species that accepts electrons in a redox reaction, 90–91, 431, 440–442, 464a–464b, 512, 521–522, 527–529, 540
Oxoacids Acids containing oxygen, such as HNO_3 or H_2SO_4 , 46, 347–348
 acid strength, 538–540
 equilibrium constants for, 538t
 introduction to, 537–538
 Lewis structures of, 538
 nitric acid, 542–543
 of nonmetals, 538t
 oxidation and strength reduction, 540–541
 phosphoric acid, 545
 sulfuric acid, 543–544
Oxoanions Anions containing oxygen, such as NO_3^- , or SO_4^{2-} , 42, 43, 44t, 521–522, 537–538, 538
 Oxyacetylene torch, 556
 Oxygen
 in acetic acid, 62
 in acids, 46
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 formal charge, 163
 hydrogen bonds, 229–230
 in a magnetic field, 164
 nonmetal compounds, 534–537
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 as permanent gas, 223t
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 reactions with transition metals, 516–517, 516t
 reaction with methane, 211, 211
 single bonds, 158
 solubility, 257
 as a terminal atom, 164
 transition metals, reactions with, 516–517
 in white crystal, 60–61
 Oxyhemoglobin, 503
 Ozone, 126–127, 302–303, 303
 Ozone hole, 303, 303
- P**
P. See Pressure
 Paired electrons, 144
 Palladium, 17, 297
Paramagnetic Showing magnetic properties caused by the presence of unpaired electrons, 144, 499
Partial pressure The part of the total pressure in a gas mixture that can be attributed to a particular component. The partial pressure of a component may be found by multiplying the total pressure by the mole fraction, 110–114, 123c–123d, 306–310, 308, 315, 318
 Particles, 54
 Particle scattering experiment, 25, 26
 Particle volume, 121–122
 Partner-exchange reactions, 76
Parts per billion (ppb) For liquids and solids, the number of grams of solute per billion grams of sample, 249–250
Parts per million (ppm) For liquids and solids, the number of grams of solute per million grams of sample, 249–250
Pascal (Pa) An SI unit of pressure; the pressure exerted by the force of 1 newton on an area of 1 square meter, 97
 Pascal, Blaise, 406
 Pasteur, Louis, 571

- Pauli, Wolfgang, 135
- Pauli exclusion principle** A principle which states that no two electrons in the atom can have four identical quantum numbers, 135–137
- Pauling, Linus, 152, 178
- p*-Dichlorobenzene, 264t
- PEM (Proton-exchange membrane), 461–462
- Penicillin, 241
- Pentaamminechlorochromium(III), 492
- Pentaamminechlorocobalt (III) Chloride, 388, 388
- Pentane, 255, 550t, 551
- Pentanol, 256t
- Pentyl propionate, 564t
- Peptide linkage** The —C—N— group found in $\begin{array}{c} \text{O} \quad \text{H} \\ \parallel \quad | \\ \text{—C—N—} \end{array}$
- polypeptides, including proteins, 592
- Percent composition** Mass percents of the elements in a compound, 58–59
- Percent ionization** For a weak acid HB, % ionization = $100 \times [\text{H}^+]/[\text{HB}]_0$, 342, 343
- Percent yield** A quantity equal to $100 \times (\text{actual yield/theoretical yield})$, 70–71, 70
- Perchlorate ion, 540
- Perchloric acid, 81t
- Perchloroethylene (PERC), 244
- Periodic function** A physical or chemical property of elements that varies periodically with atomic number, 148
- Periodic table** An arrangement of the elements in rows and columns according to atomic numbers such that elements with similar chemical properties fall in the same column, 30, 33–35, 33, 50b
- atomic orbitals, 138
- atomic spectra, 129–130
- electron arrangements in monatomic ions, 145–148
- electron configuration from, 142–143
- electron configuration in atoms, 138–143
- and electron configurations, 141
- filling of sublevels, 140–142
- Greek and Roman gods, 48
- hydrogen atom, 130–133
- introduction to, 124–125
- light, 125–129
- and metals, 507
- and nonmetals, 526
- orbital diagrams of atoms, 143–145
- periodic trends in the properties of atoms, 148–152
- photon energies, 127–129
- quantum numbers, 133–137
- Periods** Horizontal rows of elements in the periodic table, 33–34
- Permanent gas, 222–223, 223t
- Permanganate ion, 431, 522
- Peroxide** A compound containing the peroxide ion, O_2^{2-} , 514
- PET (Positron emission tomography), 471
- Petroleum, 255, 552–553
- Petroleum distillation, 552
- pH** Defined as $-\log_{10} [\text{H}^+]$
- measurement of, 338
- overview of, 333–336
- relationship with $[\text{H}^+]$, 334, 334
- of some common materials, 334t
- of strong acids and strong bases, 336–338
- Phase diagram** A graph of pressure vs. temperature showing the conditions for equilibrium between phases, 223–226, 243, 245a–245b
- Phenanthrene, 558
- Phenol, 557
- Phenolphthalein, 85, 371–373, 372, 373t, 374, 376, 376, 377, 379, 380, 514
- Phenylalanine, 589t
- Phillips, 93t
- pH meter, 338, 338, 452, 452
- Phosphates, 390t
- Phosphine, 45
- Phosphoric acid, 340t, 346t, 537, 537, 545
- Phosphorus, 4t, 67, 164, 180, 526t, 536, 537
- Phosphorus-30, 470
- Phosphorus pentachloride, 165, 180
- Phosphorus pentafluoride, 168, 168
- Photochemistry, 165
- Photon energies, 127–129, 154a
- Photons** Any individual particle of radiant energy, 127–129
- pH paper, 338
- Physical properties** Properties such as melting point or density which can be determined without changing the chemical identity of a substance, 16, 16
- Piazzi, Guiseppe, 48–49
- Pi bond** (π) A bond in which electrons are concentrated in orbitals located off the internuclear axis; in a double bond there is one pi bond, in a triple bond there are two, 182–184, 186b
- Pico, 7t
- Pig iron, 509, 510
- Pipet, 8
- pK_a** Defined as $-\log_{10} K_a$, where K_a is the ionization constant of a weak acid, 341
- pK_b** Defined as $-\log_{10} K_b$, where K_b is the ionization constant of a weak base, 349
- Planck, Max, 127
- Planck's constant, 127
- Platinum, 297, 297, 489t
- Platinum electrode, 437, 437
- Platinum(II), 489
- Platinum-rhodium catalyst, 542
- Plexiglas, 577t
- Pluto (god), 49
- Plutonium, 470t
- pOH** Defined as $\text{pOH} = -\log_{10} [\text{OH}^-]$, 333–336, 359a–359b
- Poison gas, 329, 528
- Polar bond** A chemical bond that has positive and negative ends; characteristic of all bonds between unlike atoms, 174
- Polarimeter, 569
- Polarity, 174, 176, 186b, 229
- Polar molecule** A molecule in which there is a separation of charge and hence positive and negative poles, 174–178, 228, 228t
- Polonium, 473
- Polyacrylonitrile (PAN), 577t
- Polyamide** A compound formed when a diamine reacts with a dicarboxylic acid, 582–583
- Polyatomic ions, 39, 41t, 42–43, 42, 56–57, 88
- Polyester** A large molecule made up of ester units, 581
- Polyethylene, 577–579, 577t
- Poly(ethylene terephthalate) (PET), 581
- Polymers** Huge molecules made up of many small units linked together chemically. *See also*
- Organic polymers
- carbohydrates, 583–587, 597a
- introduction to, 576
- proteins, 587–595, 597a
- synthetic addition polymers, 577–580, 577t, 597–597a
- synthetic condensation polymers, 580–583, 597a
- Polypeptide** A compound containing two or more α -amino acid residues, 592–593
- Polypropylene, 577t
- Polyprotic acid** An acid containing more than one ionizable H atom. Examples include H_2SO_4 and H_3PO_4 , 346–347, 346t, 359c
- Polysaccharides** Carbohydrates made up of sugar molecules bonded together, 584
- Polystyrene, 577t
- Polyunsaturated fats, 574, 574
- Polyvinyl chloride (PVC), 457, 577t, 579–580
- Poodle, 161
- Pope, Alexander, 124
- P orbitals, 138, 138
- Positive ion bombardment, 470t
- Positron** Identical to an electron except that it has a charge of +1 rather than –1, 468
- Positron emission, 468, 469t
- Positron emission tomography (PET), 471
- Post-transition metals** Lower members of periodic groups 13, 14, and 15, such as Pb and Bi, 33, 42, 44
- Potassium, 4t, 34, 67, 139
- Potassium carbonate, 352
- Potassium chromate, 56, 252, 394–395
- Potassium dichromate, 42, 57–58, 147
- Potassium ferricyanide, 493
- Potassium fluoride, 530
- Potassium hexacyanoferrate(III), 493
- Potassium hydroxide, 81t, 336
- Potassium iodide solution, 456
- Potassium nitrate, 42
- Potassium permanganate, 42, 127, 127, 278, 522
- Potassium superoxide, 515
- Pounds per square inch (psi), 96
- Povidone-iodine, 528–529
- Powell, H. M., 166
- Precipitate** A solid that forms when two solutions are mixed, 76, 76
- Precipitate formation, 394–398, 405a–405b
- Precipitates, dissolving, 399–403, 402, 405b–405c
- Precipitation reaction** Formation of an insoluble solid when two electrolyte solutions are mixed
- net ionic equations, 76–78
- solubility of ionic compounds, 75–76
- stoichiometry, 78–80
- Prefixes, Greek, 44–45, 45t
- Prefixes, metric, 7t
- Pressure** (*P*) Force per unit area, 223
- and boiling point, 221–222
- effect of on gaseous equilibria, 326t
- and gases, 96–98
- in gas law calculations, 100–103, 104
- and gas laws, 211–212
- and Haber process, 329t
- in ideal gas law, 99, 99
- and kinetic theory of gases, 114–115
- and melting point, 225, 226
- reaction spontaneity, effect on, 421–424, 429c
- and real gases, 121
- solubility, effect on, 257–259, 259
- vapor pressure, 218–219
- Prevacid, 93
- Priestly, Joseph, 5
- Prilosec, 93
- Primary (nonrechargeable) voltaic cells, 458–459
- Primary structure** For a protein, it is the linear sequence of amino acids in the polypeptide chain, 593–594
- Principal energy level** The energy level designated by the quantum number, *n*, 134
- Principal ores, 507
- Probability, 408
- Product** A substance formed as a result of a reaction; appears on the right side of an equation, 37, 63, 65, 68, 198, 204, 209
- Proline, 589t
- Propane, 223, 223t, 548, 550, 550t, 560t
- Propane gas, 552
- Propanol, 256t
- Propene, 554
- Propylamine, 230
- Propylene, 60, 577t
- Propyl group, 550t
- Proteins** Large molecules made up of several amino acids, 587
- acid-base properties of amino acids, 589–592
- α -amino acids, 588–589
- polypeptides, 592–593
- primary structure, 593–594
- secondary and tertiary structure, 594–595
- Proton** The nucleus of the hydrogen atom, the H^+ ion, 25–26, 25t
- Proton-exchange membrane (PEM), 461–462
- Proton pump inhibitors, 93, 93
- Prune, 266, 266
- Pure substances, 2, 3
- PVC (Polyvinyl chloride), 457, 577t, 579–580
- Pyrite, 382
- Q**
- q.* *See* Heat flow
- Q.* *See* Reaction quotient

Quadratic formula The formula used to obtain the two roots of the quadratic equation $ax^2 + bx + c = 0$. The formula is $x = (-b \pm \sqrt{b^2 - 4ac})/2a$, 322

Qualitative analysis The determination of the nature of the species present in a sample; most often applied to cations, 403–404

Quantum mechanical model, 132–133

Quantum mechanics, 130, 132–133

Quantum numbers Numbers used to describe energy levels available to electrons in atoms; there are four such numbers
first (n), 133–134, 136t, 137, 138
fourth (m_l), 134, 135, 136, 136t
permissible values, 136t
second (ℓ), 133–135, 136t, 137
third (m_l), 133–134, 135, 136t

Quartz, 234, 234

Quinic acid, 357t

R

R. See Gas constant

Racemic mixture Mixture containing equal numbers of two enantiomers of a substance, 570

Radiation exposure, 485, 485t, 485

Radioactive decay, 285, 469t, 473–476, 486a–486b

Radioactive waste, disposal of, 482–483

Radioactivity The ability possessed by some natural and synthetic isotopes to undergo nuclear transformation to other isotopes
applications, 471–472
biological effects of, 485
bombardment reactions, 469–471
mode of decay, 467–469

Radium, 473

Radon, 185

Radon-222, 485, 485

Rads, 485

Ramsay, William, 184

Randall, Merle, 165

Randomness factor, 408–409, 408

Random polymer, 579

Raoult, François, 260

Raoult's law A relation between the vapor pressure (P) of a component of a solution and that of the pure component (P°) at the same temperature; $P_1 = X_1P_1^\circ$, where X is the mole fraction, 260–261, 260

Rate constant The proportionality constant in the rate equation for a reaction, 278, 280, 284, 291t

Rate-determining step The slowest step in a multi-step mechanism, 299–300

Rate expression A mathematical relationship describing the dependence of reaction rate upon the concentration(s) of reactant(s), 278, 283, 300–302

Rayleigh, Lord, 184

Reactant The starting material in a reaction;
appears on the left side of an equation, 37
bond enthalpy, 209
in chemical equations, 63, 65, 68
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order of reaction with more than one, 280–282
order of reaction with single, 278–280
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in thermite reactions, 204

Reactant concentration

first-order reactions, 283–287

and reaction rate, 277–282

second-order reaction, 287–289

and time, 283–289

zero-order reaction, 287–289

Reacting species A species that takes part in a reaction. When hydrochloric acid reacts with NaOH, the reacting species is the H^+ ion, 83, 83, 85, 381, 459

Reaction

direction of, 318–320, 330b–330c

extent of, 320–323, 330c–330d

spontaneity of, 406–428

Reaction energy diagram, 292

Reaction mechanism A sequence of steps that occurs during the course of a reaction, 298, 305f

elementary steps, 299

intermediates, elimination of, 300–302

rate expression, deduced from proposed mechanism, 300

reaction plot for, 300

slow steps, 299–300

Reaction order, 289

Reaction plot, 300

Reaction quotient (Q) An expression with the same form as K but involving concentrations and pressures at a particular point in time rather than equilibrium partial pressures or concentrations, 318–320, 421–422, 449

Reaction rate The ratio of the change in concentration of a species divided by the time interval over which the change occurs.

activation energy, 290–291

activation energy diagrams, 291–292

Arrhenius equation, 294

catalysis, 296–298, 305f

collision model, 290–291

and concentration, 277–282, 278, 305a

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order of, 305b–305c

order of with a single reactant, 278–280

order of with more than one reactant, 280–282

rate expression and rate constant, 278

reactant concentration and time, 283–289

reaction mechanism, 298–302, 305f

second-order reaction, 305d–305e

and temperature, 293–296, 293, 305e–305f

and time, 305b–305e

transition-state model, 291–292

two-point equation relating k and T , 295–296

zero-order reaction, 305d–305e

Real gases, 120–122, 120t, 123d

Reciprocal rule The equilibrium constant for a reaction is the reciprocal of that for the same reaction in the reverse direction, 311, 312t, 314, 374, 376

Red cabbage, 371

Redox reaction A reaction involving oxidation and reduction

balancing half-equations, 431–433

balancing redox equations, 433–435

and copper, 511

definition of, 431

in electrochemistry, 431–435

half-reactions, 88

introduction to, 87–88, 87

oxidation number, 88–92

spontaneity of, 443–446

stoichiometric calculations, 91–92

terminology and concepts, 431

zinc-copper(II) voltaic cell, 435, 436

Redox titration, 92

Reducing agent A species that furnishes electrons to another in a redox reaction, 91, 431, 440–442, 464a–464b, 509, 531, 540

Reduction A half-reaction in which a species decreases in oxidation number, 88, 89, 431, 431–433, 520t

Relative masses, 28

Rems, 485

Resonance A model used to rationalize the properties of a species for which a single Lewis structure is inadequate; resonance forms differ only in the distribution of electrons, 160–162

Resonance forms, 160–162, 186–186a

Resonance hybrids, 160

Reverse osmosis, 243, 265

Rhodium, 297, 297

Roasting A metallurgical process in which a sulfide ore is heated in air, forming either the free metal or the metal oxide, 511

Rock candy, 20

Rolands, 93t

Roman numerals, 44

Rose, Heinrich, 49

Rowland, F. Sherwood, 303

Rubber bands, 428

Rubber elasticity, 427–428

Rubidium, 481

Rubidium-90, 481

Rule of multiple equilibria A rule which states that a reaction can be expressed as the sum of two or more reactions, K for the overall reaction is the product of the equilibrium constants of the individual reactions, 311, 312t

Rust, 413

Rutherford, Ernest, 23, 23, 25, 26

Rutherfordium, 470t

S

S. See Entropy

Saccharin, 586t

Salt An ionic solid containing any cation other than H^+ and any anion other than OH^- or O^{2-} , 352–355, 354

Salt bridge A U-tube containing a salt solution; used to bridge the gap between two halves of a voltaic cell, 436, 437–439

Salt solutions, acid-base properties of, 352–355, 359d

Samarium, 481

Sand, 234

Sap, 272

Saturated fats, 574, 574

Saturated hydrocarbons Alkanes; hydrocarbons in which all the carbon-carbon bonds are single, 548–553

Saturated solution A solution in equilibrium with undissolved solute, 19

Scandium, 38, 39, 139

Schrödinger, Erwin, 133

SCUBA divers, 259, 259

Seaborg, Glenn, 142, 165, 470

Seaborgium, 470t

Seawater, 6

Secondary structure The three-dimensional form of segments of a protein- α -helix, 594–595

Second law of thermodynamics A basic law of nature, one form of which states that all spontaneous processes occur with an increase in entropy, 413

Second-order reaction A reaction whose rate depends on the second power of reactant concentration, 287–289, 288t, 291t, 305d–305e

Second quantum number (ℓ), 134–135

Selective precipitation Separation of ions in solution by adding a reagent which, at a given concentration, precipitates one of the ions, leaving the other(s) in solution, 396–398, 403, 405b

Selene (god), 49

Selenium, 35, 539, 545–546

Semiconductors, 517

Semipermeable membrane, 265–266

Sequester, 504

Serine, 589t

Sharpless, K. Barry, 571

Shield, John, 525

Shroud of Turin, 476, 476

SI (International System of Units), 9

Sickle cell anemia, 594

Side of cell (s), 239, 239

Sidgwick, N. V., 166

Sigma bond (σ) A chemical bond in which electron density on the internuclear axis is high, as with all single bonds. In a multiple bond, one and only one of the electron pairs forms a sigma bond, 182–184, 186b

- Significant figures** Meaningful digits in a measured quantity, 9–12, 21a–21b
- Silicate lattices, 235
- Silicon, 2, 4t, 35, 234
- Silicon dioxide, 509
- Silver, 4t, 34, 236, 388
- Silver chloride, 395, 398, 399, 402, 416, 416, 452
- Silver (I) oxide, 516
- Silver nitrate, 402
- Silver phosphate, 399
- Simple cubic cell (SC)** A unit cell in which there are atoms at each corner of a cube, 238, 238, 239t
- Simple organic compounds, 61
- Simplest formula** A formula of a compound which gives the simplest atom ratio of the elements present. The simplest formula for hydrogen peroxide is HO, 60–63, 60
- Single bond** A pair of electrons shared between two bonded atoms, 158
- Single proton emission computer tomography (SPECT scans), 471
- Slag, 510
- Smog, 535–536, 535
- Smoke detectors, 472, 472
- Soap, 563
- Soda water, 6
- Sodium, 5, 5
- applications of, 563
 - and cations, 37
 - in ionic compounds, 41
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- Sodium carbonate, 64–65, 76–77, 77, 533
- Sodium chloride, 5, 5
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 - electrolysis of, 457, 457, 507, 508
 - freezing point lowering, 270t
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 - vs. sodium hydride, 514
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- Sodium cyanide, 512
- Sodium fluoride, 348
- Sodium hydride, 514, 514
- Sodium hydrogen carbonate, 559
- Sodium hydroxide
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 - precipitation of iron(III) hydroxide, 78
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 - titration of with hydrogen chloride, 85
 - titration of with vinegar, 84
- Sodium iodide, 298
- Sodium ion, 396–397
- Sodium lactate, 363–364
- Sodium nitrate, 256–257
- Sodium peroxide, 515
- Solid** The physical phase of matter that has a fixed shape and volume, 2
- in classification of matter, 3
 - comparison of solids, liquids, and gases, 216–217
 - crystal structures, 238–243
 - intermolecular forces, 217
 - ionic solids, 232, 235
 - mass and volume of, 17
 - melting point, 225–226, 226
 - metallic solids, 232, 236–237
 - network covalent, 232–234
 - weighing, 8
- Solid deuterium oxide, 27
- Solid oxide fuel cell (SOFC), 462–463
- Solubility** The amount of a solute that can be dissolved in a given mass of solvent at a specified temperature
- of alcohols, 256t
 - complex ion, 388–394, 405–405a
 - of hydrocarbons, 255, 255
 - of ionic compounds, 75–76, 75, 256
 - of ionic solids, 235
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 - of molecular substances, 226
 - of network covalent solids, 233
 - overview of, 18–20
 - of oxygen, 257
 - pressure, effect of, 257–259, 259
 - principles of, 255–259
 - solute-solvent interactions, 255–256
 - of sucrose, 19
 - temperature, effect of, 256–257
 - of vitamins, 255
- Solubility chart, 75
- Solubility product constant (K_{sp})** The equilibrium constant for the reaction by which a slightly soluble ionic solid dissolves in water
- at 25°C, 390t
 - and the common ion effect, 393–394
 - and the equilibrium concentrations of ions, 389–390
 - expression of, 388–389
 - and precipitate formation, 395–396
 - and sulfide minerals, 392
 - and water solubility, 390–393
- Solute** The solution component present in smaller amount than the solvent, 246
- Solute-solvent interactions, 255–256
- Solution** A homogeneous mixture containing a solvent and one or more solutes
- in classification of matter, 3
 - colligative properties of electrolytes, 269–271
 - colligative properties of nonelectrolytes, 260–269
 - concentration units, 246–254
 - definition of, 5
 - moles in, 54–58, 73a
 - solubility, principles of, 255–259
- Solution stoichiometry, 78
- Solvent** A substance, usually a liquid, which is the major component of a solution, 246
- s orbitals, 138
- Sørensen, Søren, 333–334
- Soybeans, 503
- Space filling model, 36
- Specific gravity, 252
- Specific heat** The amount of heat required to raise the temperature of one gram of a substance by 1°C, 190, 190, 191t
- Specific heat capacity, 190
- Specific ion electrode, 452
- Spectator ions** Ions that, although present, takes no part in reactions, 77, 82, 85, 353, 381
- Spectrochemical series, 503, 503
- Spectrum, 129. *See also* Atomic spectrum
- Sphygmomanometer, 122
- Splitting energy. *See* Crystal field splitting energy
- Spontaneous change, 408
- Spontaneous processes** Processes that can occur by themselves without input of work from outside; $\Delta G < 0$ for a spontaneous process at constant T and P
- additivity of free energy changes, 425–427, 429d
 - coupled reactions, 425–427, 429d
 - effect of enthalpy and entropy on, 413
 - energy factor, 407–408
 - entropy, 409–413
 - free energy (G), 413–415, 414
 - free energy change and the equilibrium constant, 424–425
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 - randomness factor, 408–409
 - redox reactions, 443–446
 - spontaneous processes, 407–409
 - and standard entropy change, 413
 - standard free energy change (ΔG°), 415–419
 - and temperature, 420–421, 420t
 - temperature, pressure, and concentration, effect of, 419–424, 429b–429c
- Square planar** The geometry of a species in which four groups are located at the corners of a square, surrounding the central atom, 494, 494, 495
- Square pyramids** Pyramids that have a square as their base, 168
- Stability constant. *See* Formation constant (K_f)
- Stained glass, 545, 545
- Stainless steel, 190
- Standard cell voltage (E°)** The voltage of a cell in which all species are in their standard states (1 atm for gases, 1 M for ions in solution), 439, 446–448, 448t, 464b–464c
- Standard conditions, 415–416
- Standard enthalpy, 202
- Standard enthalpy change (ΔH°)** The enthalpy change at 1 atm, 1M, at a specified temperature, usually 25°C, 202, 327, 416
- Standard entropy change (ΔS°)** The entropy change at 1 atm, 1 M, at a specified temperature, usually 25°C, 410–411, 412, 413
- Standard free energy change (ΔG°)** ΔG when reactants and products are in their standard states, 415–416, 446
- calculation of at other temperatures, 418–419
 - and the equilibrium constant, 424–425
 - free energies of formation, 417–418
 - relation to standard cell voltage, 448t
- Standard free energy of formation (ΔG_f°)** Defined as the free energy change per mole when a compound is formed from the elements in their stable states at 1 atm, 417–418
- Standard molar entropy (S°)** Entropy of a substance in its standard state (per mole), 410–411, 411t
- Standard oxidation voltage (ΔE_{ox}°)** The voltage associated with an oxidation half-reaction when all gases are at 1 atm and all aqueous solutes are at 1 M, 439–440, 442–443
- Standard potential** Identical with the standard reduction voltage, 440, 441t
- Standard reduction voltage (ΔE_{red}°)** The voltage associated with a reduction half-reaction when all gases are at 1 atm and all aqueous solutions are at 1 M, 439–440, 442–443
- Standard solution, 84
- Standard temperature and pressure (STP)** Conditions of 0°C, 1 atm, 100
- Standard voltages, 439
- calculation of, 442–443
 - oxidizing and reducing agents, strength of, 440–442
 - spontaneity of redox reactions, 443–446
- Starch, 586–587, 587
- State** A condition of a system at fixed temperature, pressure, and chemical composition, 188
- State properties** Properties of a system whose values are fixed when its temperature, pressure, and composition are specified, 188, 196, 206, 211, 409, 413–414
- Steam, molecule density, 216, 217t
- Stearic acid, 563
- Steel production, 509–510, 509

- Steric factor, 291, 294
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 Stoichiometric nickel (II) oxide, 517
 Stoichiometric ratios, 65, 66
Stoichiometry Relationships between amounts (grams, moles) of reactants and products
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 for redox reactions in water solutions, 91–92
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 writing and balancing chemical equations, 63–65
 Storage (rechargeable) voltaic cells, 459–460
 Stratosphere, 302–303
Strong acid A species that is completely ionized to H^+ ions in dilute water solution, 81t
 acid-base titration, 374–376, 379–380, 380, 381t
 and acid rain, 383
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 and buffers, 370
 definition of, 80–81
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 ionization of, 336
 pH of, 336–338
 redox reactions, 87
 strong base, reactions with, 82, 83t
 weak base, reactions with, 82, 83t
 zinc, reactions with, 89
Strong base A species that is completely ionized to OH^- ions in dilute water solution, 81t
 acid-base titration, 374, 374–379, 377, 381t
 Arrhenius and, 87
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 Strontium, 472
 Strontium-90, 481
 Strontium chromate, 288–289, 388, 388, 394–395, 394, 423–424, 423, 515
 Strontium hydroxide, 81t, 336
Structural formula A formula showing the arrangement of bonded atoms in a molecule, 36, 548
Structural isomers Two or more species having the same molecular formula but different structural formulas. Examples: C_2H_5OH and CH_3-O-CH_3 , 549–550
 Styrene, 577t
 Styrene polymer, 428
 Subatomic particles, 25t
 Sublevel energies, 138–140
Sublevels Subdivisions of an energy level, designated as an s, p, d, or f sublevel, 134–135, 135t, 137–142, 137t, 139
Sublimation The phase transition from the solid phase to the vapor phase, without passing through the liquid phase, 225, 225
 Subscripts, 59, 64
 Substances, 15–20, 19, 21c–21e
Substitution reactions Reactions in which a group of atoms or molecule is replaced by a different atom or group, 573
Successive approximations A technique used to solve quadratic or higher-order equations. A first, approximate answer is refined to obtain a more nearly exact solution, 345
 Sucralose, 586t
 Sucrose, 18–20, 585–586, 586t
 Suffixes, 44–45
 Sugar, 52. *See also* Sucrose
 Sulfates, 390t
 Sulfide ores, 511–512, 511
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 Sulfur dioxide, 160, 161, 223t, 382–383, 536, 543–544
 Sulfur hexafluoride, 165, 168, 168, 180
 Sulfuric acid, 46, 81t, 382, 543–544, 544
 Sulfurous acid, 340t, 346t
 Sulfur trioxide, 536–537, 543
 Sully-Prudhomme, 385
 Superconductivity, 517, 517
 Supercritical carbon dioxide, 243–244
 Supercritical fluid, 223
Superoxide A compound containing the O_2 ion, 514, 515
 Superphosphate of lime, 545
Supersaturated solution A solution containing more solute than allowed at equilibrium; unstable to addition of solute, 19, 20
 Surface tension, 217, 217
 Surpass, 93t
Surroundings Everything outside the system being studied, 188
Symbol A one- or two-letter abbreviation for the name of an element, 2
 Synthesis gas, 559
 Synthetic addition polymers, 577–580, 597–597a
 Synthetic condensation polymers, 580–583, 597a
 Syphilis, 20
System The sample of matter under observation, 188, 188
 T
 T. *See* Temperature
 Tachenius, Otto, 331
 Talc, 234
 Tantalum, 49
 Tantalus (god), 49
 Tartaric acid, 357t
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 Terephthalic acid, 581
 Terminal atoms, 164
 Termolecular, 299
 Terra (god), 48
Tertiary structure A three-dimensional conformation of a protein showing the folding of the secondary structure, 594–595
 Tetraamminecopper(II) chloride, 493
 Tetraamminezinc(II) ion, 494
 Tetraaquacopper(II), 492
 Tetraaquazinc(II) ion, 340t
 Tetrachlorocuprate(II), 493
 Tetraethyllead, 553
 Tetrafluoroethylene, 577t
Tetrahedron A figure of four triangular faces with eight edges and four vertices, 168, 494, 494, 536
 Tetrahydroxozincate(II), 492
Theoretical yield The amount of product obtained from the complete conversion of the limiting reactant, 67–70
Thermal conductivity The ability to conduct heat, 236
 Thermite reaction, 204, 204
Thermochemical equation A chemical equation in which the value of ΔH is specified, 196–202, 215b–215c
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Thermodynamics The study of heat and work effects in physical and chemical changes, 406, 415, 546b–546c
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Thermodynamics and the Free Energy of Chemical Substances (Lewis/Randall), 165
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 The Thinker (Rodin), 504, 504
Third law of thermodynamics A natural law that states that the entropy of a perfectly ordered, pure crystalline solid is 0 at 0 K, 410
 Third quantum number (m_l), 135
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 Threonine, 589t
 Time, 276, 277, 283–289, 305b–305e
 Tincture of iodine, 528
 Titanic, 5
 Titanium, 4t
 Titans (gods), 48
Titration A process in which one reagent is added to another with which it reacts; an indicator is used to determine the point at which equivalent quantities of the two reagents have been added, 84–86, 84, 85
 Titration curve, 381
 Toluene, 414, 557
 Tomb of the Unknown Soldier, 596
 Top Care, 93t
 Torr, 97
 Torricelli, Evangelista, 96
 Toxic elements, 35, 35
Trans isomer A geometric isomer in which two identical groups are as far apart as possible (e.g., a b), 495–497, 496, 497,

 567–569
 Transition metal cations, 56–57, 56, 146–148, 455, 498–499, 523t

- Transition metals** Metals in the central groups (3–12) of the 4th, 5th, and 6th periods of the periodic table, 33, 42, 141
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- Transition-state model**, 291–292, 291t
- Transplants**, 244
- Transuranium elements**, 470, 470t
- Trichloroacetic acid**, 563
- Triglycerides**, 574
- Trigonal bipyramid** A solid with five vertices; may be regarded as two pyramids fused through a base that is an equilateral triangle, 168
- Trigonal planar** The geometry of an AX₃ molecule where A is at the center of the equilateral triangle formed by three X atoms, 167
- Trigonal pyramid** The geometry of an AX₃E molecule in which atom A lies directly above the center of an equilateral triangle formed by three X atoms, 169
- Trimethylamine**, 230
- Triple bond** Three electron pairs shared between two bonded atoms, 158
- Triple point** The temperature and pressure at which the solid, liquid, and vapor phase of a substance can coexist in equilibrium, 224, 225
- Triprotic acids**, 346
- Tris(ethylenediamine)chromium(III)**, 492
- Tris(ethylenediamine)iron(III) phosphate**, 493
- Troposphere**, 302
- Trypsin**, 593
- Tryptophan**, 589t
- Tums**, 93t
- Tungsten**, 236
- 2-methylpropane**, 549, 549, 550–551
- Tyrosine**, 589t
- U**
- UAVs** (Unmanned autonomous vehicles), 461
- Ultraviolet (UV) radiation** Light with a wavelength less than 400 nm but greater than 10 nm, 126–127, 302–303
- Uniform mixtures.** *See* Homogeneous mixtures
- Unimolecular**, 299
- Unit cell** The smallest unit of a crystal that, repeated again and again, generates the whole crystal, 238–239
- Units, conversion of**, 12–14, 21b–21c
- Units of measurement**, 8–9
- Unmanned autonomous vehicles (UAVs)**, 461
- Unpaired electrons**, 144, 164
- Unreactive gases.** *See* Noble gases
- Unsaturated hydrocarbons**, 553–556
- Unsaturated solution** A solution that contains less solute than the equilibrium (saturated) value, 19
- Unshared electron pair** A pair of electrons that “belongs” to a single atom and is not involved in bonding. Also called a *lone pair*, 157, 171, 172, 173
- Unstable isotopes**, 467
- Uranium**, 26, 27, 118–119, 142, 287, 473
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- Uranium-238**, 467, 480, 485
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- Uranium hexafluoride**, 118–119, 480–481
- Uranus (god)**, 48, 49
- Uranus (planet)**, 48
- Urey, Harold**, 165
- Uuo-294**, 470
- V**
- V. See** Volume
- Valence and the Structure of Atoms and Molecules** (Lewis), 165
- Valence bond model** Model of the electronic structure of molecules in which electrons are assigned to orbitals, pure or hybridized, of individual atoms, 178, 498
- Valence electrons** Electrons in the outermost principal energy level. For a main-group element, the number of valence electrons is given by the last digit of the group number, 156, 157, 162–163, 498
- Valine**, 589t
- Vanadium oxide**, 543
- Vanilla beans**, 562
- Vanillin**, 562
- Van’t Hoff, Jacobus**, 87, 327
- Van’t Hoff equation**, 327
- Van’t Hoff factor**, 269
- Vapor**, 217
- Vaporization (ΔH_{vap})**, 199
- Vapor pressure** The pressure exerted by a vapor when it is in equilibrium with a liquid, 111–112, 218–222, 218, 220, 221, 225, 260–261
- Vapor pressure lowering**, 260–261, 262–263, 262, 269
- Vinegar**, 84, 340, 563
- Vinyl chloride**, 577t, 579–580
- Vitamin B-12**, 241
- Vitamin C**, 62–63
- Vitamins**, 255, 256
- Volt (V)** A unit of electric potential: 1 V = 1 J/C, 440, 453t
- Voltage**, 448–452, 464c–464d
- Voltaic (galvanic) cell** A device in which a spontaneous reaction produces electrical energy, 430, 435–439, 464a
- Volume (V)**
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relations between length and mass units, 13t
uncertainties in measurement of, 10, 12
units of, 8, 8
and vapor pressure, 218
- Volume ratio**, 108–109
- Von Hofer, Ludwig**, 48
- VSEPR model** Valence Shell Electron Pair Repulsion model, used to predict molecular geometry; states that electron pairs around a central atom tend to be as far apart as possible, 156, 166–167, 167, 169–171, 173, 180, 494, 548
- Vulcanized**, 427
- W**
- w. See** Work
- Water**, 4
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- Water purification**, 60–61
- Water softeners**, 234
- Water solubility**, 390–393
- Watras, Stanley**, 485
- Watson, James**, 595
- Watt (W)**, 453t
- Wave function**, 133–134
- Wavelength (λ)** A characteristic property of a wave related to its color and equal to the length of a full wave, 125–127, 125, 127t, 127
- Weak acid** An acid that is only partially dissociated to H⁺ ions in water
acid-base titration, 374, 376–379, 377, 381t
Arrhenius and, 87
and buffers, 360, 364–365
carboxylic acids, 563
definition of, 80–81
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H⁺ in a water solution of, 343–346
household products, 340
ionization of, 342
polyprotic acids, 346–347
strong base, reactions with, 82, 83t
and their equilibrium constants, 339–343, 359b–359c
- Weak base** A base that is only partially dissociated to form OH[−] ions in water
acid-base titration, 374, 379–380, 380, 381t
Arrhenius and, 87
definition of, 81
household products, 348
OH[−] in a water solution of, 349–350
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- Weight, units of**, 8
- Welding**, 556
- Werner, Alfred**, 498
- White crystal**, 60–61
- Whitman, Walt**, 506
- WHO (World Health Organization)**, 546
- Wilkins, Maurice**, 595
- Wine, fermentation of**, 15t, 560
- Women**, 241, 467, 470, 473
- Wood alcohol.** *See* Methyl alcohol
- Work (w)** Any form of energy except heat exchanged between system and surroundings; includes expansion work and electrical work, 209–210, 210t, 211
- Work effect**, 211
- World Health Organization (WHO)**, 546
- World War II**, 480
- X**
- X. See** Mole fraction
- Xanthoprotein**, 543
- Xenon**, 184–185
- Xenon difluoride**, 184
- Xenon hexafluoride**, 184
- Xenon tetrafluoride**, 165, 171, 171
- Xenon trioxide**, 184
- X-ray diffraction**, 241, 242
- Y**
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- Yttrium**, 39
- Yttrium oxide**, 141
- Yucca Mountain, Nevada**, 482–483

Z

Z. *See* Atomic number

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

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Zinc-hydrogen-ion voltaic cell, 439

Zinc hydroxide, 399, 401, 492

Zinc(II) cation, 488

Zinc-manganese dry cell, 458, 458

Zinc salts, 339

Zwitterion Form of an amino acid in which there is a separation of charge between the nitrogen atom of the NH_2 group (+) and one of the oxygen atoms of the COOH group (–), 590–591