Units, Constants, and Reference Data

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 = 10^3 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 ($kg \cdot m/s^2$) 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 m^3. 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 m^3. The density of water is commonly expressed as 1.00 g/cm^3, 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

	$\Delta H_f°$ (kJ/mol)	$S°$ (kJ/K·mol)	$\Delta G_f°$ (kJ/mol) at 25°C
$Ag(s)$	0.0	+0.0426	0.0
$Ag^+(aq)$	+105.6	+0.0727	+77.1
$AgBr(s)$	−100.4	+0.1071	−96.9
$AgCl(s)$	−127.1	+0.0962	−109.8
$AgI(s)$	−61.8	+0.1155	−66.2
$AgNO_3(s)$	−124.4	+0.1409	−33.4
$Ag_2O(s)$	−31.0	+0.1213	−11.2
$Al(s)$	0.0	+0.0283	0.0
$Al^{3+}(aq)$	−531.0	−0.3217	−485.0
$Al_2O_3(s)$	−1675.7	+0.0509	−1582.3
$Ba(s)$	0.0	+0.0628	0.0
$Ba^{2+}(aq)$	−537.6	+0.0096	−560.8
$BaCl_2(s)$	−858.6	+0.1237	−810.4
$BaCO_3(s)$	−1216.3	+0.1121	−1137.6
$BaO(s)$	−553.5	+0.0704	−525.1
$BaSO_4(s)$	−1473.2	+0.1322	−1362.3
$Br_2(l)$	0.0	+0.1522	0.0
$Br^-(aq)$	−121.6	+0.0824	−104.0
$C(s)$	0.0	+0.0057	0.0
$CCl_4(l)$	−135.4	+0.2164	−65.3
$CHCl_3(l)$	−134.5	+0.2017	−73.7
$CH_4(g)$	−74.8	+0.1862	−50.7
$C_2H_2(g)$	+226.7	+0.2008	+209.2
$C_2H_4(g)$	+52.3	+0.2195	+68.1
$C_2H_6(g)$	−84.7	+0.2295	−32.9
$C_3H_8(g)$	−103.8	+0.2699	−23.5
$CH_3OH(l)$	−238.7	+0.1268	−166.3
$C_2H_5OH(l)$	−277.7	+0.1607	−174.9
$CO(g)$	−110.5	+0.1976	−137.2
$CO_2(g)$	−393.5	+0.2136	−394.4
$CO_3^{2-}(aq)$	−677.1	−0.0569	−527.8
$Ca(s)$	0.0	+0.0414	0.0
$Ca^{2+}(aq)$	−542.8	−0.0531	−553.6
$CaCl_2(s)$	−795.8	+0.1046	−748.1
$CaCO_3(s)$	−1206.9	+0.0929	−1128.8
$CaO(s)$	−635.1	+0.0398	−604.0
$Ca(OH)_2(s)$	−986.1	+0.0834	−898.5
$CaSO_4(s)$	−1434.1	+0.1067	−1321.8
$Cd(s)$	0.0	+0.0518	0.0
$Cd^{2+}(aq)$	−75.9	−0.0732	−77.6
$CdCl_2(s)$	−391.5	+0.1153	−344.0
$CdO(s)$	−258.2	+0.0548	−228.4
$Cl_2(g)$	0.0	+0.2230	0.0
$Cl^-(aq)$	−167.2	+0.0565	−131.2
$ClO_3^-(aq)$	−104.0	+0.1623	−8.0
$ClO_4^-(aq)$	−129.3	+0.1820	−8.5
$Cr(s)$	0.0	+0.0238	0.0
$CrO_4^{2-}(aq)$	−881.2	+0.0502	−727.8
$Cr_2O_3(s)$	−1139.7	+0.0812	−1058.1
$Cr_2O_7^{2-}(aq)$	−1490.3	+0.2619	−1301.1
$Cu(s)$	0.0	+0.0332	0.0
$Cu^+(aq)$	+71.7	+0.0406	+50.0
$Cu^{2+}(aq)$	+64.8	−0.0996	+65.5
$CuO(s)$	−157.3	+0.0426	−129.7
$Cu_2O(s)$	−168.6	+0.0931	−146.0
$CuS(s)$	−53.1	+0.0665	−53.6
$Cu_2S(s)$	−79.5	+0.1209	−86.2
$CuSO_4(s)$	−771.4	+0.1076	−661.9
$F_2(g)$	0.0	+0.2027	0.0
$F^-(aq)$	−332.6	−0.0138	−278.8
$Fe(s)$	0.0	+0.0273	0.0
$Fe^{2+}(aq)$	−89.1	−0.1377	−78.9
$Fe^{3+}(aq)$	−48.5	−0.3159	−4.7
$Fe(OH)_3(s)$	−823.0	+0.1067	−696.6
$Fe_2O_3(s)$	−824.2	+0.0874	−742.2
$Fe_3O_4(s)$	−1118.4	+0.1464	−1015.5
$H_2(g)$	0.0	+0.1306	0.0
$H^+(aq)$	0.0	0.0000	0.0
$HBr(g)$	−36.4	+0.1986	−53.4
$HCl(g)$	−92.3	+0.1868	−95.3
$HCO_3^-(aq)$	−692.0	+0.0912	−586.8
$HF(g)$	−271.1	+0.1737	−273.2
$HI(g)$	+26.5	+0.2065	+1.7
$HNO_3(l)$	−174.1	+0.1556	−80.8
$H_2O(g)$	−241.8	+0.1887	−228.6
$H_2O(l)$	−285.8	+0.0699	−237.2
$H_2O_2(l)$	−187.8	+0.1096	−120.4
$H_2PO_4^-(aq)$	−1296.3	+0.0904	−1130.3
$HPO_4^{2-}(aq)$	−1292.1	−0.0335	−1089.2
$H_2S(g)$	−20.6	+0.2057	−33.6
$H_2SO_4(l)$	−814.0	+0.1569	−690.1
$HSO_4^-(aq)$	−887.3	+0.1318	−755.9
$Hg(l)$	0.0	+0.0760	0.0
$Hg^{2+}(aq)$	+171.1	−0.0322	+164.4
$HgO(s)$	−90.8	+0.0703	−58.6
$I_2(s)$	0.0	+0.1161	0.0
$I^-(aq)$	−55.2	+0.1113	−51.6
$K(s)$	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
$K^+(aq)$	−252.4	+0.1025	−283.3
$KBr(s)$	−393.8	+0.0959	−380.7
$KCl(s)$	−436.7	+0.0826	−409.1
$KClO_3(s)$	−397.7	+0.1431	−296.3
$KClO_4(s)$	−432.8	+0.1510	−303.2
$KNO_3(s)$	−494.6	+0.1330	−394.9
$Mg(s)$	0.0	+0.0327	0.0
$Mg^{2+}(aq)$	−466.8	−0.1381	−454.8
$MgCl_2(s)$	−641.3	+0.0896	−591.8
$MgCO_3(s)$	−1095.8	+0.0657	−1012.1
$MgO(s)$	−601.7	+0.0269	−569.4
$Mg(OH)_2(s)$	−924.5	+0.0632	−833.6
$MgSO_4(s)$	−1284.9	+0.0916	−1170.7
$Mn(s)$	0.0	+0.0320	0.0
$Mn^{2+}(aq)$	−220.8	−0.0736	−228.1
$MnO(s)$	−385.2	+0.0597	−362.9
$MnO_2(s)$	−520.0	+0.0530	−465.2
$MnO_4^-(aq)$	−541.4	+0.1912	−447.2
$N_2(g)$	0.0	+0.1915	0.0
$NH_3(g)$	−46.1	+0.1923	−16.5
$NH_4^+(aq)$	−132.5	+0.1134	−79.3
$NH_4Cl(s)$	−314.4	+0.0946	−203.0
$NH_4NO_3(s)$	−365.6	+0.1511	−184.0
$N_2H_4(l)$	+50.6	+0.1212	+149.2
$NO(g)$	+90.2	+0.2107	+86.6
$NO_2(g)$	+33.2	+0.2400	+51.3
$NO_2^-(aq)$	−104.6	+0.1230	−32.2
$NO_3^-(aq)$	−205.0	+0.1464	−108.7
$N_2O_4(g)$	+9.2	+0.3042	+97.9
$Na(s)$	0.0	+0.0512	0.0
$Na^+(aq)$	−240.1	+0.0590	−261.9
$NaCl(s)$	−411.2	+0.0721	−384.2
$NaF(s)$	−573.6	+0.0515	−543.5
$NaOH(s)$	−425.6	+0.0645	−379.5
$Ni(s)$	0.0	+0.0299	0.0
$Ni^{2+}(aq)$	−54.0	−0.1289	−45.6
$NiO(s)$	−239.7	+0.0380	−211.7
$O_2(g)$	0.0	+0.2050	0.0
$OH^-(aq)$	−230.0	−0.0108	−157.2
$P_4(s)$	0.0	+0.1644	0.0
$PCl_3(g)$	−287.0	+0.3117	−267.8
$PCl_5(g)$	−374.9	+0.3645	−305.0
$PO_4^{3-}(aq)$	−1277.4	−0.222	−1018.7
$Pb(s)$	0.0	+0.0648	0.0
$Pb^{2+}(aq)$	−1.7	+0.0105	−24.4
$PbBr_2(s)$	−278.7	+0.1615	−261.9
$PbCl_2(s)$	−359.4	+0.1360	−314.1
$PbO(s)$	−219.0	+0.0665	−188.9
$PbO_2(s)$	−277.4	+0.0686	−217.4
$S(s)$	0.0	+0.0318	0.0
$S^{2-}(aq)$	+33.1	−0.0146	+85.8
$SO_2(g)$	−296.8	+0.2481	−300.2
$SO_3(g)$	−395.7	+0.2567	−371.1
$SO_4^{2-}(aq)$	−909.3	+0.0201	−744.5
$Si(s)$	0.0	+0.0188	0.0
$SiO_2(s)$	−910.9	+0.0418	−856.7
$Sn(s)$	0.0	+0.0516	0.0
$Sn^{2+}(aq)$	−8.8	−0.0174	−27.2
$SnO_2(s)$	−580.7	+0.0523	−519.6
$Zn(s)$	0.0	+0.0416	0.0
$Zn^{2+}(aq)$	−153.9	−0.1121	−147.1
$ZnI_2(s)$	−208.0	+0.1611	−209.0
$ZnO(s)$	−348.3	+0.0436	−318.3
$ZnS(s)$	−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}	$Al(H_2O)_6^{3+}$	1.2×10^{-5}
$HAsO_4^{2-}$	2.5×10^{-12}	$H_2PO_4^-$	6.2×10^{-8}	$Ag(H_2O)_2^+$	1.2×10^{-12}
$HBrO$	2.6×10^{-9}	HPO_4^{2-}	4.5×10^{-13}	$Ca(H_2O)_6^{2+}$	2.2×10^{-13}
$HCHO_2$	1.9×10^{-4}	H_2S	1.0×10^{-7}	$Cd(H_2O)_4^{2+}$	4.0×10^{-10}
$HC_2H_3O_2$	1.8×10^{-5}	H_2SO_3	1.7×10^{-2}	$Fe(H_2O)_6^{3+}$	6.7×10^{-3}
HCN	5.8×10^{-10}	HSO_3^-	6.0×10^{-8}	$Fe(H_2O)_6^{2+}$	1.7×10^{-7}
H_2CO_3	4.4×10^{-7}	HSO_4^-	1.0×10^{-2}	$Mg(H_2O)_6^{2+}$	3.7×10^{-12}
HCO_3^-	4.7×10^{-11}	H_2Se	1.5×10^{-4}	$Mn(H_2O)_6^{2+}$	2.8×10^{-11}
$HClO_2$	1.0×10^{-2}	H_2SeO_3	2.7×10^{-3}	$Ni(H_2O)_6^{2+}$	2.2×10^{-10}
$HClO$	2.8×10^{-8}	$HSeO_3^-$	5.0×10^{-8}	$Pb(H_2O)_6^{2+}$	6.7×10^{-7}
HF	6.9×10^{-4}	$CH_3NH_3^+$	2.4×10^{-11}	$Sc(H_2O)_6^{3+}$	1.1×10^{-4}
HIO	2.4×10^{-11}	NH_4^+	5.6×10^{-10}	$Zn(H_2O)_4^{2+}$	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}
$C_2H_3O_2^-$	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}	c-$Pt(NH_3)_2Cl_2$	3×10^{29}
$Al(OH)_4^-$	1×10^{33}	$HgBr_4^{2-}$	1×10^{21}	t-$Pt(NH_3)_2Cl_2$	3×10^{28}
$Cd(CN)_4^{2-}$	2×10^{18}	$HgCl_4^{2-}$	1×10^{15}	c-$Pt(NH_3)_2(H_2O)_2^{2+}$	4×10^{23}
CdI_4^{2-}	4.0×10^{5}	$Hg(CN)_4^{2-}$	2×10^{41}	c-$Pt(NH_3)_2I_2$	2×10^{33}
$Cd(NH_3)_4^{2+}$	2.8×10^{7}	HgI_4^{2-}	1×10^{30}	t-$Pt(NH_3)_2I_2$	5×10^{32}
$Cd(OH)_4^{2-}$	1.2×10^{9}	$Hg(NH_3)_4^{2+}$	2×10^{19}	c-$Pt(NH_3)_2(OH)_2$	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}
$Co(NH_3)_5Cl^{2+}$	2×10^{28}	PbI_4^{2-}	1.7×10^{4}	$Zn(NH_3)_4^{2+}$	3.6×10^{8}
$Co(NH_3)_5NO_2^{2+}$	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}
$AgC_2H_3O_2$	1.9×10^{-3}	$Co_3(PO_4)_2$	1×10^{-35}	$Ni_3(PO_4)_2$	1×10^{-32}
Ag_2CO_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_2CrO_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_3PO_4	1×10^{-16}	CuS	1×10^{-36}	$PbCrO_4$	2×10^{-14}
Ag_2S	1×10^{-49}	Cu_2S	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_2Br_2	6×10^{-23}	$SrCO_3$	5.6×10^{-10}
Bi_2S_3	1×10^{-99}	Hg_2Cl_2	1×10^{-18}	$SrCrO_4$	3.6×10^{-5}
$CaCO_3$	4.9×10^{-9}	Hg_2I_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_2CO_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_2S	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	

Exponents and Logarithms Appendix 3

The mathematics you will use in general chemistry is relatively simple. You will, however, be expected to

- make calculations involving exponential numbers, such as 6.022×10^{23} or 1.6×10^{-10}.
- work with logarithms or inverse logarithms, particularly in problems involving pH:

$$pH = -\log_{10} (\text{conc. } H^+)$$

This appendix reviews each of these topics.

Exponential Notation

Chemists deal frequently with very large or very small numbers. In one gram of the element carbon there are

$$50{,}140{,}000{,}000{,}000{,}000{,}000{,}000 \text{ atoms of carbon}$$

At the opposite extreme, the mass of a single atom is

$$0.00000000000000000000001994 \text{ g}$$

Numbers such as these are very awkward to work with. For example, neither of the numbers just written could be entered directly on a calculator. Operations involving very large or very small numbers can be simplified by using *exponential* (*scientific*) notation. To express a number in exponential notation, write it in the form

$$C \times 10^n$$

where C is a number between 1 and 10 (for example, 1, 2.62, 5.8) and n is a positive or negative integer such as 1, −1, −3. To find n, count the number of places that the decimal point must be moved to give the coefficient, C. If the decimal point must be moved to the *left*, n is a *positive* integer; if it must be moved to the *right*, n is a *negative* integer. Thus

$$26.23 = 2.623 \times 10^1 \qquad \text{(decimal point moved 1 place to left)}$$
$$5609 = 5.609 \times 10^3 \qquad \text{(decimal point moved 3 places to left)}$$
$$0.0918 = 9.18 \times 10^{-2} \qquad \text{(decimal point moved 2 places to right)}$$

Multiplication and Division

A major advantage of exponential notation is that it simplifies the processes of multiplication and division. To *multiply, add exponents:*

$$10^1 \times 10^2 = 10^{1+2} = 10^3 \qquad 10^6 \times 10^{-4} = 10^{6+(-4)} = 10^2$$

To *divide, subtract* exponents:

$$10^3/10^2 = 10^{3-2} = 10^1 \qquad 10^{-3}/10^6 = 10^{-3-6} = 10^{-9}$$

It often happens that multiplication or division yields an answer that is not in standard exponential notation. For example,

$$(5.0 \times 10^4) \times (6.0 \times 10^3) = (5.0 \times 6.0) \times 10^4 \times 10^3 = 30 \times 10^7$$

The product is not in standard exponential notation because the coefficient, 30, does not lie between 1 and 10. To correct this situation, rewrite the coefficient as 3.0×10^1 and then add exponents:

$$30 \times 10^7 = (3.0 \times 10^1) \times 10^7 = 3.0 \times 10^8$$

In another case,

$$0.526 \times 10^3 = (5.26 \times 10^{-1}) \times 10^3 = 5.26 \times 10^2$$

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:

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

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) $\dfrac{6.0 \times 10^{2}}{4.2 \times 10^{-4}} = ?$
(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 (0.333333333) 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.

$(3.12)^{5} = ?$	answer: 2.96×10^{2}
$(3.12 \times 10^{-2})^{5} = ?$	answer: 2.96×10^{-8}
$(3.12)^{1/5} = ?$	answer: 1.26
$(3.12 \times 10^{-2})^{1/5} = ?$	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:

$$\log_{10} 100 = 2.00 \qquad (10^{2} = 100)$$
$$\log_{10} 1 = 0.000 \qquad (10^{0} = 1)$$
$$\log_{10} 0.001 = -3.000 \qquad (10^{-3} = 0.001)$$

2. *Natural logarithms,* where the base is the quantity $\boldsymbol{e} = 2.718\ldots$ 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 $\ln n = x$.

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

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,

$$\log_{10} 100 = 2 \qquad \ln 100 = 4.605$$
$$\log_{10} 10 = 1 \qquad \ln 10 = 2.303$$
$$\log_{10} 0.1 = -1 \qquad \ln 0.1 = -2.303$$
$$\log_{10} 0.01 = -2 \qquad \ln 0.01 = -4.605$$

(**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,

$$10^2 = 100 \qquad \text{inverse } \log_{10} 2 = 100$$
$$10^{-3} = 0.001 \qquad \text{inverse } \log_{10}(-3) = 0.001$$

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.

$$e^{4.606} = 100 \qquad \text{inverse } \ln 4.606 = 100$$
$$e^{-6.908} = 0.001 \qquad \text{inverse } \ln -6.908 = 0.001$$

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

$$\log_{10} 2.00 = 0.301\ldots$$
$$\log_{10} 0.526 = -0.279\ldots$$

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

$$\ln 2.00 = 0.693\ldots$$
$$\ln 0.526 = -0.642\ldots$$

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

$$\log_{10} 2.00 \times 10^3 = 3.301\ldots \qquad \ln 2.00 \times 10^3 = 7.601\ldots$$
$$\log_{10} 5.3 \times 10^{-12} = -11.28\ldots \qquad \ln 5.3 \times 10^{-12} = -25.96\ldots$$

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

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

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

$$\text{inverse } \log_{10} 1.632 = 42.8\ldots \qquad \text{inverse } \ln 1.632 = 5.11\ldots$$
$$\text{inverse } \log_{10} - 8.82 = 1.5 \times 10^{-9} \qquad \text{inverse } \ln -8.82 = 1.5 \times 10^{-4}$$

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:

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

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

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

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

$$\log_{10} 209 = 2.320 \qquad \text{(3 sig. fig.)}$$
$$\log_{10} 209.0 = 2.3201 \qquad \text{(4 sig. fig.)}$$

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

$$\ln 209 = 5.342 \qquad \text{(3 sig. fig.)}$$
$$\ln 209.0 = 5.3423 \qquad \text{(4 sig. fig.)}$$

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

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

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

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

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

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

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

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

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

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

Molecular Orbitals Appendix 4

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

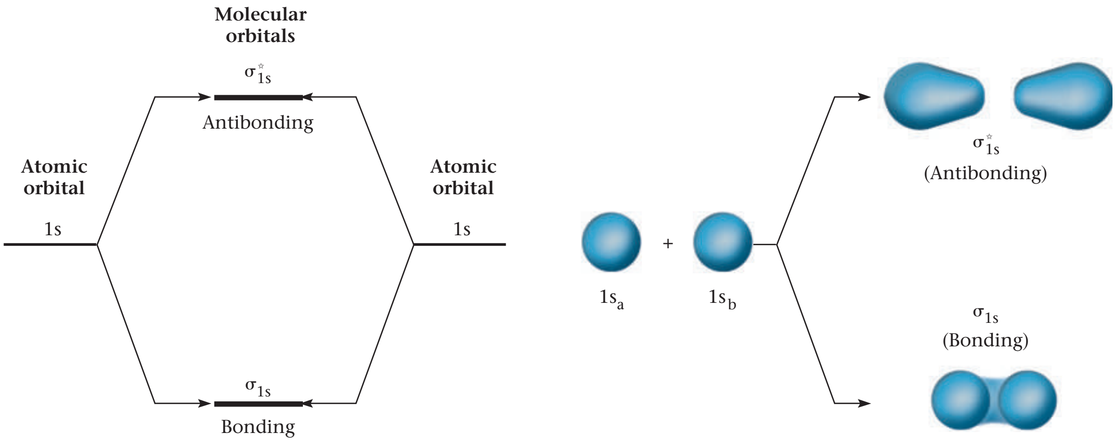


Figure 1 Molecular orbital formation. Two molecular orbitals are formed by combining two 1s atomic orbitals.

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

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

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.

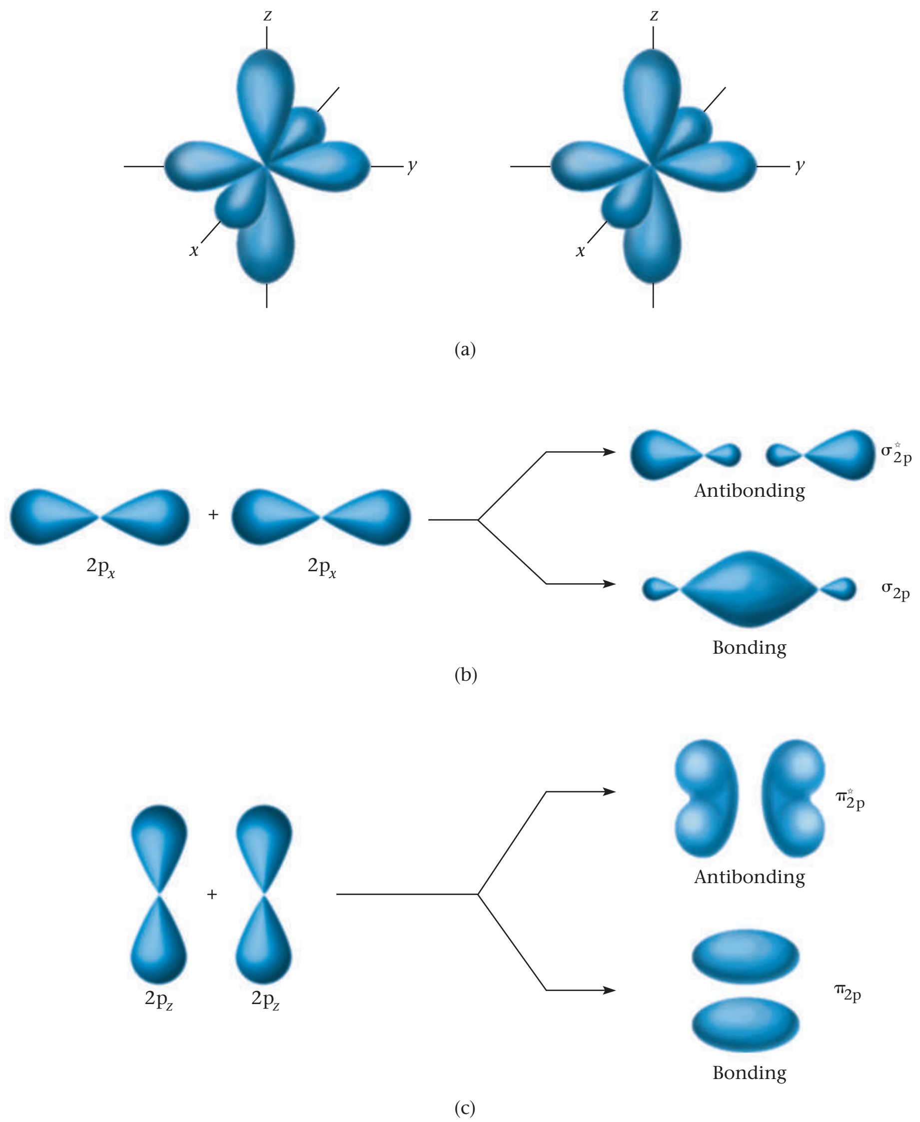


Figure 2 When p orbitals from two different atoms (a) overlap, there are two quite different possibilities. If they overlap head-to-head (b), two sigma molecular orbitals are produced. If, on the other hand, they overlap side-to-side (c), two pi molecular orbitals result.

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:

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

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

	σ_{2s}	σ^*_{2s}	π_{2p}	π_{2p}	σ_{2p}	π^*_{2p}	π^*_{2p}	σ^*_{2p}
O_2^{2-}	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)	( )

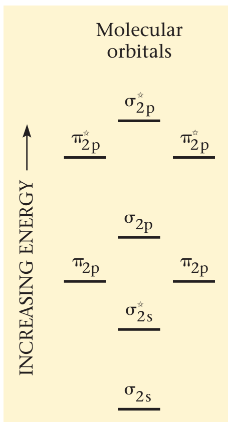


Figure 3 Relative energies, so far as filling order is concerned, for the molecular orbitals formed by combining 2s and 2p atomic orbitals.

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	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)

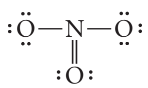
	Predicted Properties		Observed Properties	
	Number of Unpaired e^-	Bond Order	Number of Unpaired e^-	Bond Energy (kJ/mol)
Li_2	0	1	0	105
Be_2	0	0	0	Unstable
B_2	2	1	2	289
C_2	0	2	0	628
N_2	0	3	0	941
O_2	2	2	2	494
F_2	0	1	0	153
Ne_2	0	0	0	Nonexistent

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: $(:\ddot{\underset{..}{O}}-\ddot{\underset{..}{O}}:)^{2-}$.

Polyatomic Molecules; Delocalized π Electrons

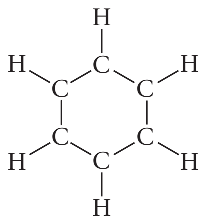
The bonding in molecules containing more than two atoms can also be described in terms of molecular orbitals. We will not attempt to do this; the energy level structure is considerably more complex than the one we considered. However, one point is worth mentioning. In polyatomic species, *a pi molecular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

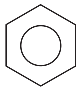


Valence bond theory (Chapter 7) explains the fact that the three N—O bonds are identical by invoking the idea of resonance, with three contributing structures. MO theory, on the other hand, considers that the skeleton of the nitrate ion is established by the three sigma bonds while the electron pair 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



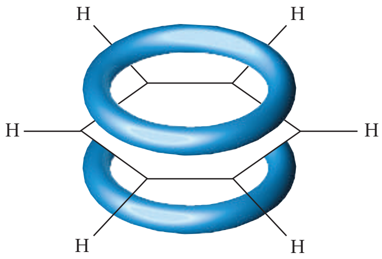


Figure 4 In benzene, three electron pairs are not localized on particular carbon atoms. Instead, they are spread out over two lobes of the shape shown, one above the plane of the benzene ring and the other below it.

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. Li = $1s^22s^1$). 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 $1s^22s^2$. 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.

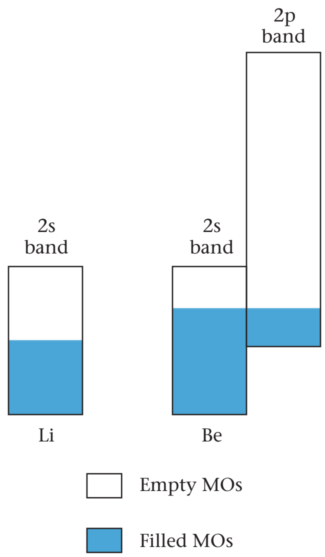


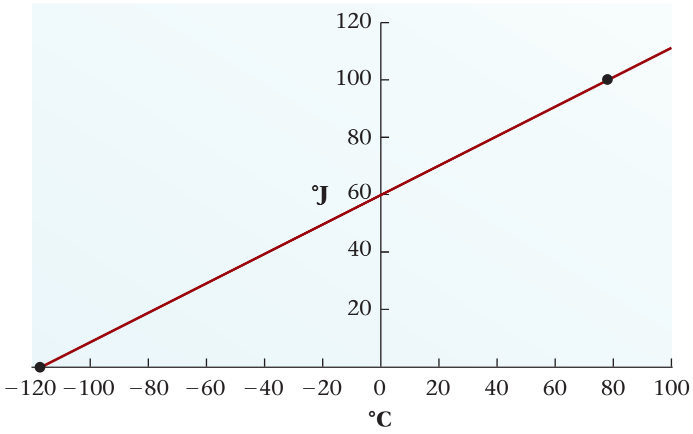
Figure 5 In both lithium and beryllium metal, there are vacant MOs only slightly higher in energy than filled MOs. This is the basic requirement for metallic conductivity.

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; 4.50×10^2 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) 5.00×10^2 °C (d) 198 oz
22. (a) 4.0206×10^3 mL
    (b) 1.006 g
    (c) 1.001×10^2 °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) 2.1×10^2 mi
40. 1.85×10^{-3} g/mL
42. 3.97×10^{14} L
44. 393.8 mg
46. 1.07 g/mL
48. 1.6 g/mL
50. 508 m
52. 3.88×10^4 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. 6.5×10^{-4} 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) ≈23°C (c) no; (see answer to (a))
73. (a)

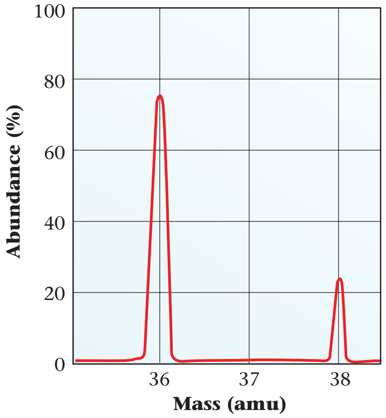


    (b) 0.51
    (c) 60
    (d) °J = 0.512(°C) + 60
74. 320°F = 160°C
75. 1.2 km^2
76. 21.9 cm
77. 8.1×10^{-3} g Pb
78. 6.87 g/cm^3

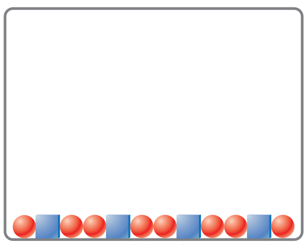
Chapter 2

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) $^{54}_{26}Fe$; $^{56}_{26}Fe$
    (b) They differ in the number of neutrons. Fe-54 has 28, whereas Fe-56 has 30.
12. (a) 95 (b) 241 (c) $^{241}_{95}Am$
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; $^{65}_{29}Cu$
28. lightest isotope 78.6%; heaviest isotope 11.4%
30. (a) two: HCl-35 and HCl-37 (b) 36 and 38

(c)



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, $C_2H_4O_2$ (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) $Ba(C_2H_3O_2)_2$
64. (a) lead(II) acetate
(b) aluminum hydroxide
(c) strontium hydrogen carbonate
(d) copper(II) phosphate
(e) rubidium oxide
66. (a) $HNO_3(aq)$ (b) K_2SO_4 (c) $Fe(ClO_4)_3$ (d) $Al(IO_3)_3$ (e) $H_2SO_3(aq)$
68. $HBrO_2(aq)$; cobalt(III) periodate; $PtCl_4$; nitrous acid; N_2O_3
70. (a) Ge (b) W (c) Sr (d) Bi
72. (a) C_2H_7N (b) $C_2H_5NH_2$
74. (a) always true (b) usually true (c) never true
76. 9.64×10^{3} cm^3
78. a
80. only #4.
82.



84. $^{234}_{90}Th$
86. $^{126}_{52}Te^{2-}$
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. 2.3443×10^{-23} 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) 5.93×10^{17} g
(b) 7.65×10^{-22} 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) $[K^+] = 0.757\ M$; $[O^{2-}] = 0.379\ M$
(b) $[Na^+] = [HCO_3^-] = 0.425\ M$
(c) $[Sc^{3+}] = 0.0684\ M$; $[IO_2^-] = 0.205\ M$
(d) $[Mg^{2+}] = 0.407\ M$; $[PO_4^{3-}] = 0.272\ M$
20. (a) Dissolve 2.50×10^{2} g of $Ni(NO_3)_2$ in 2.00 L of solution
(b) Dissolve 184 g of $CuCl_2$ in 2.00 L of solution
(c) Dissolve 241 g of $C_6H_8O_6$ in 2.00 L of solution
22. (a) 303.9 mL (b) 1.074×10^{2} 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) $C_8H_{20}Pb$ (b) $C_6H_8O_7$ (c) $N_2H_6Cl_2Pt$
40. $C_8H_8O_3$
42. $C_7H_5O_3SN$
44. Simplest formula: CH_4N Molecular formula: $C_2H_8N_2$
46. (a) 47.24% (b) 8.366 g
48. (a) $C_6H_{12}O_6(s) + 6O_2(g) \longrightarrow 6CO_2(g) + 6H_2O$
(b) $XeF_4(g) + 2H_2O(l) \longrightarrow Xe(g) + O_2(g) + 4HF(g)$
(c) $4NaCl(s) + 2H_2O(g) + 2SO_2(g) + O_2(g) \longrightarrow 2Na_2SO_4(s) + 4HCl(g)$
50. (a) $2Sc(s) + 3S(s) \longrightarrow Sc_2S_3(s)$
(b) $2Sc(s) + 3Cl_2(g) \longrightarrow 2ScCl_3(s)$

(c) $2Sc(s) + N_2(g) \longrightarrow 2ScN(s)$
(d) $4Sc(s) + 3O_2(g) \longrightarrow 2Sc_2O_3(s)$

52. (a) $2H_2S(g) + SO_2(g) \longrightarrow 3S(s) + 2H_2O(g)$
(b) $2CH_4(g) + 2NH_3(g) + 3O_2(g) \longrightarrow 2HCN(g) + 6H_2O(g)$
(c) $Fe_2O_3(s) + 3H_2(g) \longrightarrow 2\ Fe(s) + 3H_2O(g)$
(d) $UO_2(s) + 4HF(g) \longrightarrow UF_4(s) + 2H_2O(g)$
(e) $C_2H_5OH(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(l)$

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) $SiO_2(s) + 2C(s) \longrightarrow Si(s) + 2CO(g)$
(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) 68.60g/mol

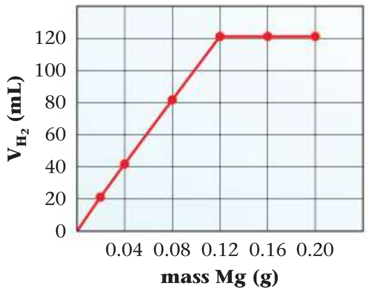
66. (a) $Cl_2(g) + 3F_2(g) \longrightarrow 2ClF_3(g)$
(b) F_2 (c) 2.45 mol (d) 0.52 mol

68. 9.4×10^2 g

70. (a) $4NH_3(g) + 5O_2(g) \longrightarrow 4NO(g) + 6H_2O(g)$
(b) 7.502 g NO (c) 3.34 g (d) 82.9%

72. 2.76×10^3 g; 526 mL

74. (a)

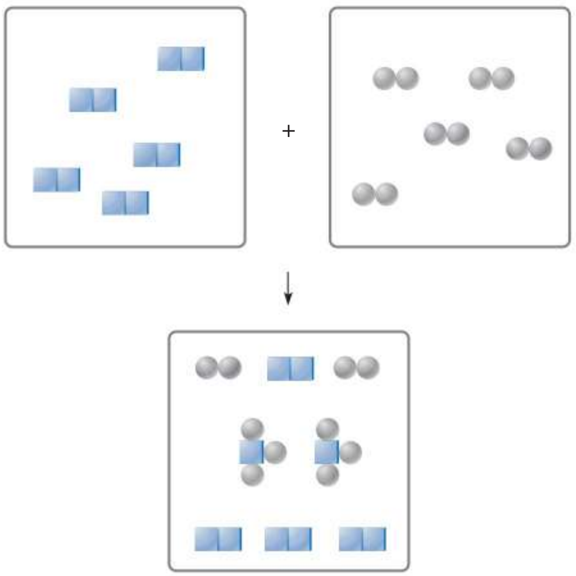


(b) Mg (c) Mg
(d) acid (e) 4
(f) 122 mL; 11 mL

76. 54.3 mL

78. $2AB_3 + 3C \longrightarrow 3CB_2 + 2A$

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) $4PH_3(g) + 8O_2(g) \longrightarrow P_4O_{10}(s) + 6H_2O(g)$; 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) $Mg(OH)_2$; insoluble
(c) $Cr_2(CO_3)_3$; insoluble (d) K_3PO_4; soluble

4. (a) NaOH (b) Na_2CO_3 (c) Na_3PO_4

6. (a) $Fe^{3+}(aq) + 3OH^-(aq) \longrightarrow Fe(OH)_3(s)$
(b) $Ba^{2+}(aq) + SO_4{}^{2-}(aq) \longrightarrow BaSO_4(s)$; $Mg^{2+}(aq) + 2OH^-(aq) \longrightarrow Mg(OH)_2(s)$

8. (a) $Ag^+(aq) + Cl^-(aq) \longrightarrow AgCl(s)$
(b) $Co^{2+}(aq) + 2OH^-(aq) \longrightarrow Co(OH)_2(s)$
(c) no reaction
(d) $Cu^{2+}(aq) + CO_3{}^{2-}(aq) \longrightarrow CuCO_3(s)$
(e) $Ba^{2+}(aq) + SO_4{}^{2-}(aq) \longrightarrow BaSO_4(s)$

10. (a) $3Ba^{2+}(aq) + 2PO_4{}^{3-}(aq) \longrightarrow Ba_3(PO_4)_2(s)$
(b) $Zn^{2+}(aq) + 2OH^-(aq) \longrightarrow Zn(OH)_2(s)$
(c) no reaction
(d) $Co^{3+}(aq) + PO_4{}^{3-}(aq) \longrightarrow CoPO_4(s)$

12. (a) 0.04976 *M* (b) 1.43 *M* (c) 0.04195 *M*

14. (a) $2Al^{3+}(aq) + 3CO_3{}^{2-}(aq) \longrightarrow Al_2(CO_3)_3(s)$
(b) 0.108 *M* (c) 0.379 g

16. (a) $Al^{3+}(aq) + 3OH^-(aq) \longrightarrow Al(OH)_3(s)$
(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) $HC_2H_3O_2$
(d) H^+ (e) H_2SO_3

22. (a) C_7H_9N (b) OH^-
(c) C_8H_6NH (d) NH_3

24. (a) $HC_2H_3O_2(aq) + OH^-(aq) \longrightarrow H_2O + C_2H_3O_2{}^-(aq)$
(b) $(C_2H_5)_2NH(aq) + H^+(aq) \longrightarrow (C_2H_5)_2NH_2{}^+(aq)$
(c) $HF(aq) + OH^-(aq) \longrightarrow H_2O + F^-(aq)$

26. (a) $H^+(aq) + C_5H_5N(aq) \longrightarrow C_5H_5NH^+(aq)$
(b) $H^+(aq) + OH^-(aq) \longrightarrow H_2O$
(c) correct
(d) $NH_3(aq) + H^+(aq) \longrightarrow NH_4{}^+(aq)$
(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) $[OH^-] = 0$; $[Ba^{2+}] = 0.125\ M$; $[Al^{3+}] = 0.0415\ M$; $[NO_3^-] = 0.375\ M$

Chapter 5

2. $V = 2.5 \times 10^3$ L; $n_{He} = 2.14 \times 10^4$ mol; $T = 298$ K
4. (a) 3.20×10^2 mm Hg 0.422 atm 6.20 psi
(b) 1.50×10^3 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. 1.02×10^3 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) $2NF_3(g) + 3H_2O(g) \longrightarrow NO(g) + NO_2(g) + 6HF(g)$
(b) 1.74 L
34. (a) 3.72 L
(b) 2.64 L
36. 3.2×10^3 g
38. 2.83 L
40. (a) $2C_9H_{18}O_6(s) + 21O_2(g) \longrightarrow 18H_2O(g) + 18CO_2(g)$
(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) $2NH_4NO_3(s) \longrightarrow 2N_2(g) + O_2(g) + 4H_2O(g)$
(b) 2.38 atm
(c) $P_{N_2} = 0.681$ atm; $P_{O_2} = 0.341$ atm; $P_{H_2O} = 1.37$ 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: Xe < CH_2F_2 < F_2 < CH_4
(b) time: CH_4 < F_2 < CH_2F_2 < 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) ≈ 340 atm
68. (a) $2C_8H_{18}(l) + 25O_2(g) \longrightarrow 16CO_2(g) + 18H_2O(l)$
(b) 1.5×10^4 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%; $C_2H_5NO_2$
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.

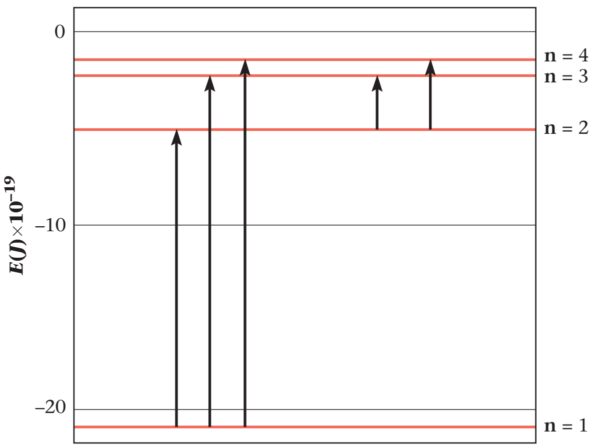
80. (**a**) same (**b**) N_2 (A) (**c**) same
(**d**) NH_3 (B) (**e**) P stays the same (**f**) 1/2
82. (**a**) $tank_A = tank_B$
(**b**) $tank_A = 2(tank_B)$
(**c**) $tank_A = tank_B$
84. (**a**) A (**b**) B (**c**) B
86. (**a**) C (**b**) 2.5 atm (**c**) 4.0 atm
(**d**) 4.0 atm (same)

(**e**) 4.0 atm

88. Ideal gas pressures: at 40°C = 25.0 mm Hg; at 70°C = 27.3 mm Hg; at 100°C = 29.7 mm Hg
Vapor pressures: at 40°C = 55.3 mm Hg; at 70°C = 233.7 mm Hg; at 100°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**) $\mathbf{m}_\ell = -2, -1, 0, +1, +2$
(**b**) $\mathbf{m}_\ell = 0$
(**c**) $\ell = 0$; $\mathbf{m}_\ell = 0$ $\ell = 1$, $\mathbf{m}_\ell = -1, 0, +1$
$\ell = 2$; $\mathbf{m}_\ell = -2, -1, 0, +1, +2$
$\ell = 3$, $\mathbf{m}_\ell = -3, -2, -1, 0, +1, +2, +3$
$\ell = 4$, $\mathbf{m}_\ell = -4, -3, -2, -1, 0, +1, +2, +3, +4$
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**) $\mathbf{m}_\ell$ cannot exceed 1
(**e**) $\mathbf{m}_\ell = 0$
30. (**a**) $1s^22s^22p^63s^23p^4$
(b) $1s^22s^22p^63s^23p^64s^23d^1$
(c) $1s^22s^22p^63s^23p^2$
(d) $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^2$
(e) $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^24d^{10}5p^3$
32. (**a**) $[_{10}Ne]3s^2$ (**b**) $[_{54}Xe]6s^24f^{14}5d^6$
(**c**) $[_{18}Ar]4s^23d^{10}4p^2$ (**d**) $[_{18}Ar]4s^23d^3$
(**e**) $[_{54}Xe]6s^24f^{14}5d^{10}6p^5$
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**) (↑↓) (↑↓) (↑↓)(↑↓)(↑↓) (↑)
(**b**) (↑↓) (↑↓) (↑↓)(↑)(↑)
(**c**) (↑↓) (↑↓) (↑↓)(↑↓)(↑↓) (↑↓) (↑↓)(↑↓)(↑↓) (↑↓) (↑↓)(↑↓)(↑)(↑)(↑)
(**d**) (↑↓) (↑↓) (↑↓)(↑↓)(↑↓) (↑↓) (↑↓)(↑↓)(↑)
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: $1s^22s^22p^5$ F^-: $1s^22s^22p^6$
(**b**) Sc: $1s^22s^22p^63s^23p^64s^23d^1$ Sc^{3+}: $1s^22s^22p^63s^23p^6$
(**c**) Mn^{2+}: $1s^22s^22p^63s^23p^63d^5$
Mn^{5+}: $1s^22s^22p^63s^23p^63d^2$
(**d**) O^-: $1s^22s^22p^5$ O^{2-}: $1s^22s^22p^6$
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

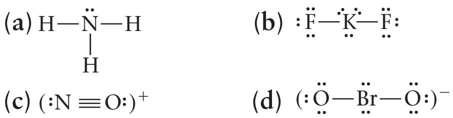
74. (a) True
(b) True
(c) False; absorbed
76. +2954 kJ
77. $\Delta E = 2.180 \times 10^{-18}\left(\frac{1}{4} - \frac{1}{\mathbf{n}^2}\right)$

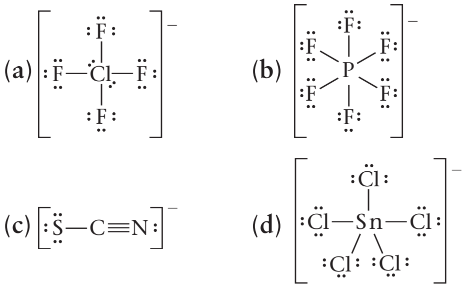
$$\lambda = \frac{hc}{\Delta E} = \frac{(6.626 \times 10^{-34})(2.998 \times 10^{8})(1 \times 10^{9})}{2.180 \times 10^{-18}\left(\frac{1}{4} - \frac{1}{\mathbf{n}^2}\right)}$$

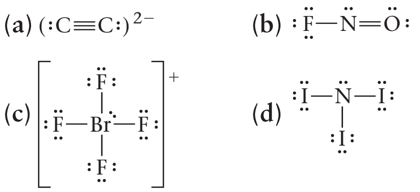
$$= \frac{91.12}{\left(\frac{1}{4} - \frac{1}{\mathbf{n}^2}\right)} = \frac{364.5\,\mathbf{n}^2}{\mathbf{n}^2 - 4}$$

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) $1s^32s^32p^2$ $\quad 1s^32s^32p^93s^2$
80. (a) 3.42×10^{-19} J
(b) 581 nm

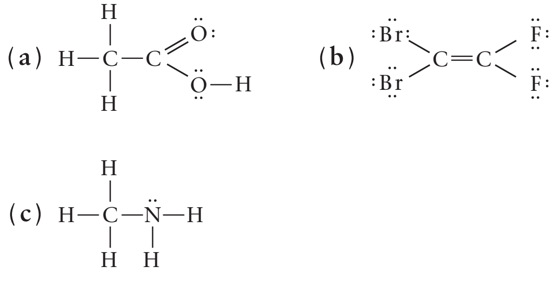
Chapter 7

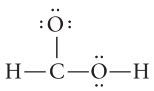
2. 

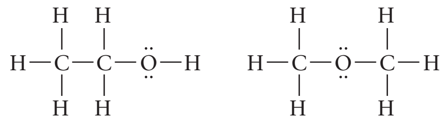
4. 

6. 

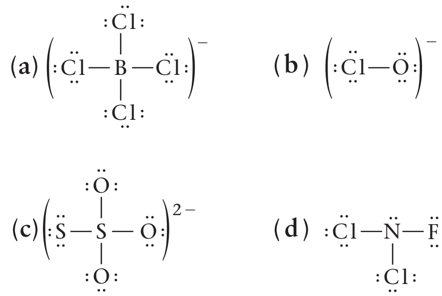
8. $(H{-}O{\equiv}C{:})^+$

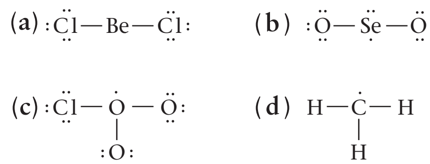
10. 

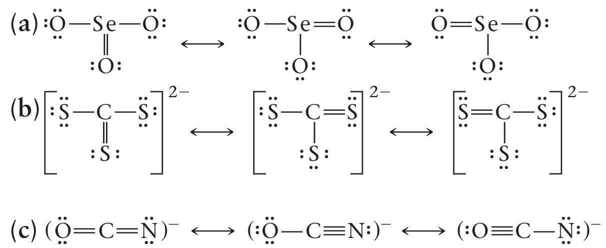
12. 

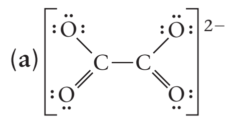
14. 

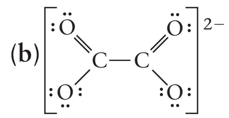
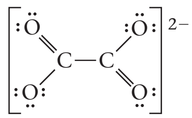
16. (a) Br_2 (b) CH_4 (c) CO (d) SiF_4

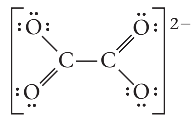
18. 

20. 

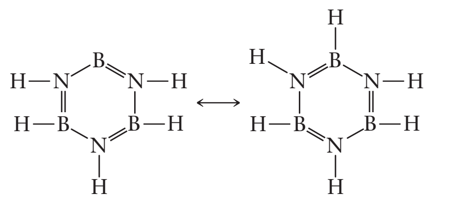
22. 

24. 

 and  and

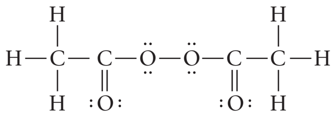


(c) No. Different skeleton.

26. 

28. (a) 0 (b) 0 (c) 0
30. Structure I
32. (a) bent (b) bent
(c) trigonal pyramid (d) linear
34. (a) linear (b) bent
(c) tetrahedron (d) bent
36. (a) square pyramid (b) square planar
(c) octahedral (d) trigonal bipyramid

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

40. (a)


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

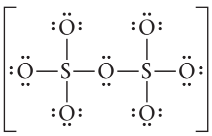
58. C_1 and C_2 = sp^2, C_3 and N = sp

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

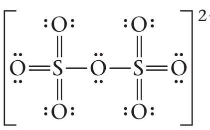
62. (a) sp^3 (b) sp^3 (c) sp^3

64. 6 σ, 3 π

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

68. (a)


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

(c)


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

70.

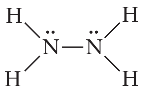
AX_2E_2	2	2	bent	sp^3	polar
AX_3	3	0	trigonal planar	sp^2	nonpolar
AX_4E_2	4	2	square planar	sp^3d^2	nonpolar
AX_5	5	0	trigonal bipyramid	sp^3d	nonpolar

72. (a) C (b) N

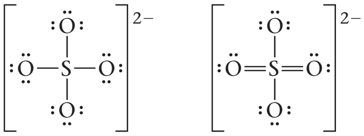
74. PH_3 and H_2S—unshared pairs on central atom

76. $SnCl_2$ and SO_2; unshared pairs occupy more space

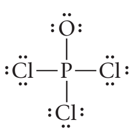
78. x = 3; T-shaped; polar; sp^3d; 90°, 180°; 3 σ bonds

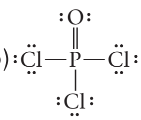
79.  bent; 109.5°; polar

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

81. (a)


(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

82. (a)  Formal charges: P = +1; Cl = 0; O = −1

(b)  Formal charges: P = 0; Cl = 0; O = 0

Chapter 8

2. 2.06°C

4. 0.140 J/g · °C

6. 3.7×10^2 J

8. (a) no (b) −669 J (c) 24.2°C

10. 1.3×10^2 mL

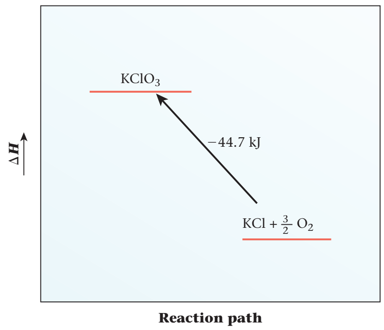
12. (a) 18.6 mL (b) 34.0°C

14. (a) 81.3 kJ (b) 86.2 kJ (c) −167.5 kJ
(d) -3.48×10^3 kJ/mol

16. (a) −218 kJ (b) 77.6 kJ
(c) 1.40×10^2 kJ (d) 5.67 kJ/°C

18. 27.0°C

20. 2.00 mL

22. (a) $KClO_3(s) \longrightarrow KCl(s) + \frac{3}{2}O_2(g)$ $\Delta H° = -44.7$ kJ
(b) yes
(c)


(d) −1.09 kJ (e) 41.1 g

24. (a) 13.4 kJ (b) 0.965 kJ

26. (a) $2C_3H_5(NO_3)_3(l) \longrightarrow 3N_2(g) + 6CO_2(g) + 5H_2O(g) + \frac{1}{2}O_2(g)$; $\Delta H = -2.84 \times 10^3$ kJ
(b) −911 kJ

28. (a) $C_{57}H_{104}O_6(s) + 83O_2(g) \longrightarrow 57CO_2(g) + 52H_2O(l)$ $\Delta H° = -3.022 \times 10^4$ kJ
(b) 1.78×10^3 kJ
(c) 0.804 lb

30. benzene

32. −48.9 kJ

34. (a) $2Mg(s) + SiO_2(s) + 2C(s) + 2Cl_2(g) \longrightarrow 2CO(g) + 2MgCl_2(s) + Si(s)$
(b) −592.7 kJ
(c) yes

36. −35.6 kJ

38. (a) $K(s) + \frac{1}{2}Cl_2(g) + \frac{3}{2}O_2(g) \longrightarrow KClO_3(s)$ $\Delta H = -397.7$ kJ
(b) $C(s) + 2Cl_2(g) \longrightarrow CCl_4(l)$ $\Delta H = -135.4$ kJ
(c) $\frac{1}{2}H_2(g) + \frac{1}{2}I_2(g) \longrightarrow HI(g)$ $\Delta H = 26.5$ kJ
(d) $2Ag(s) + \frac{1}{2}O_2(g) \longrightarrow Ag_2O(s)$ $\Delta H = -31.0$ kJ

40. (a) −1134.7 kJ (b) −101.9 kJ

42. (a) $N_2H_4(l) + O_2(g) \longrightarrow N_2(g) + 2H_2O(g)$ $\Delta H = -534.2$ kJ
(b) 14.0 kJ of heat are evolved

44. (a) −153.9 kJ (b) −1036.0 kJ (c) −714.8 kJ

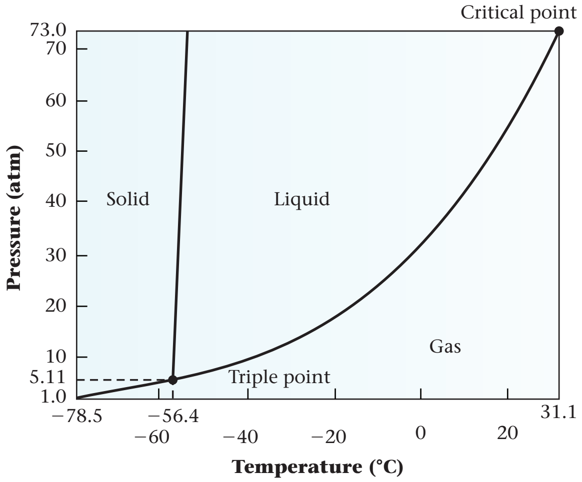
46. (a) −50.3 kJ (b) −84.5 kJ

48. (a) $CaCO_3(s) + 2NH_3(g) \longrightarrow CaCN_2(s) + 3H_2O(l)$ $\Delta H° = 90.1$ kJ
(b) −351.6 kJ/mol

50. −680 kJ/mol
52. −3.36 kJ
54. 1.20×10^2 L-atm
56. (a) −18 J (b) +64 J
58. (a) yes (b) −102 J
60. (a) 29.6 kJ (b) 2.76 kJ (c) 26.8 kJ
62. (a) $CH_3OH(l) + \frac{3}{2}O_2(g) \longrightarrow CO_2(g) + 2H_2O(g)$ $\Delta H = -638.4$ kJ
(b) $\Delta E = -642.1$ kJ
64. 1.00 BTU/lb-°F
66. 29 min
68. -8.451×10^4 kJ
70. $\Delta E = -885$ kJ; $\Delta H = -890$ kJ
72. 0.793
74. 1.65×10^{-6} °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) 1.69×10^5 J (b) 505 g
86. 22%
87. (a) −851.5 kJ (b) 6.6×10^3 °C (c) yes
88. 76.0%
89. 7.5 g
90. 3.50×10^2 kJ

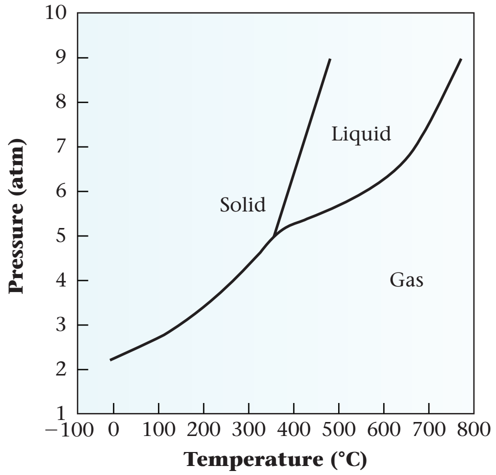
Chapter 9

2. (a) 50°C: 297 mm Hg; 60°C: 307 mm Hg
(b) 297 mm Hg > 269 mm Hg
307 mm Hg < 389 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) ≈30 atm (c) yes

24. (a)

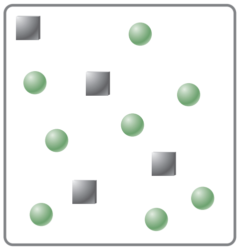


(b) 600°C (c) sublimes
26. He < Ne < Ar < Xe
28. dipole forces: b, d; dispersion forces: all
30. b and c
32. (a) Na_2CO_3 is ionic.
(b) N_2H_4 has hydrogen bonding.
(c) Benzoic acid has larger dispersion forces.
(d) CO has dipole forces.
34. a and b
36. (a) LiCl—ionic bonds
(b) CH_3OH—hydrogen bonds
(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. $V = 0.05631$ nm^3; $r = 0.1355$ 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) 1.43×10^{-8} cm (b) 1.22×10^{-23} 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) ≈34°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. $\frac{r_{cation}}{r_{anion}} = 0.414$
81. $P_{C_3H_8}$ 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 $Ba(OH)_2$ to enough water to make 750.0 mL of solution.
(b) Add enough water to 55.1 mL of 0.493 M $Ba(OH)_2$ 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) 1.0×10^1%
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°C/m
46. 183.1 g/mol
48. 403 g/mol
50. $C_6H_4N_2O_4$
52. 1.50×10^5 g/mol
54. boiling point: $Al(ClO_3)_3 > (NH_4)_2Cr_2O_7 > MgSO_4 > CH_3OH$
freezing point: $CH_3OH > MgSO_4 > (NH_4)_2Cr_2O_7 > Al(ClO_3)_3$
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°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 g/cm³—intoxicated
87. (a) 2.08 M
(b) 1.872 mol
(c) 47.4 L
88. 0.055
89. $V_{gas} = \frac{n_{gas} \times RT}{P_{gas}}$; $n_{gas} = k \times P_{gas}$; $V_{gas} = kRT$

V_{gas} depends only on temperature.

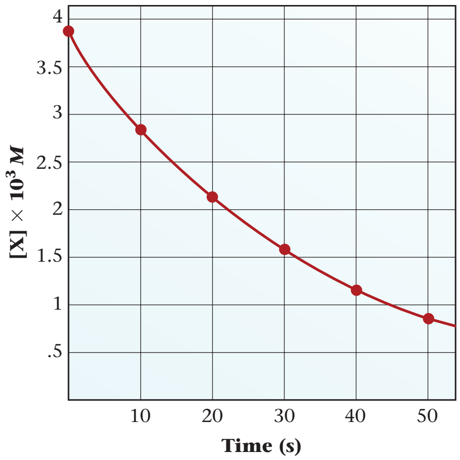
Chapter 11

2. (a) rate $= \frac{-\Delta[N_2O]}{2\Delta t}$ (b) rate $= \frac{\Delta[O_2]}{\Delta t}$
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·s (b) 0.029 mol/L·s
(c) 0.048 mol/L·s
8. (a) $N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$
(b) rate $= \frac{\Delta[NH_3]}{2\Delta t}$ (c) 0.0186 mol/L·min

10. (a)



(b) 3.7×10^{-5} mol/L·s (c) 4.8×10^{-5} mol/L·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) mol/L·min (b) L^2/mol^2·min
(c) L/mol·min (d) L/mol·min

16. (a) 0 (b) rate $= k[Y]^0$ (c) $k = 0.045\ M/h$

18. (a) 0.0756 mol/L·h (b) 0.300 M
(c) 0.143 M (d) 0.00801 L/mol·h

20. (a) rate $= 2.5 \times 10^{-4}$ mol/L·min
(b) 2.5×10^{-4} mol/L·min
(c) any concentration

22. (a) 4.05 L^2/mol^2·min (b) 0.230 M
(c) 0.0915 M

24. (a) 1 (b) rate $= k[Y]$ (c) 1.44 min^{-1}

26. (a) second-order with respect to NO_2; zero-order with respect to CO; second-order overall
(b) rate $= k[NO_2]^2$
(c) $k = 0.297$ L/mol·s
(d) 0.0526 mol/L·s

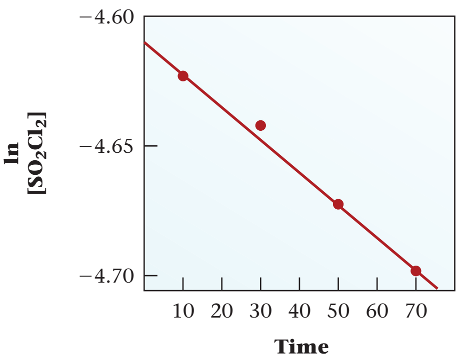
28. (a) first-order with respect to O_2; second-order with respect to NO
(b) rate $= k[NO]^2[O_2]$
(c) 99.3 L^2/mol^2·min
(d) 4.59×10^{-4} M/min

30. (a) first-order in CH_3COCH_3, first-order in H^+, zero-order in I_2
(b) rate $= k[CH_3COCH_3][H^+]$
(c) 2.6×10^{-5} L/mol·s
(d) 6.8×10^{-5} mol/L·s

32. (a) rate $= k[CH_3CO_2CH_3][OH^-]$ (b) 0.26 L/mol·s
(c) 0.51 mol/L·s

34. second-order

36. (a)



(b) 0.0015 min^{-1} (c) 462 min
(d) 567 min (e) 2.30×10^{-5} M/min

38. (a) 4.05×10^{-3} 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) 1.53×10^{-3} mol/L·h
(c) 2.4×10^1 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

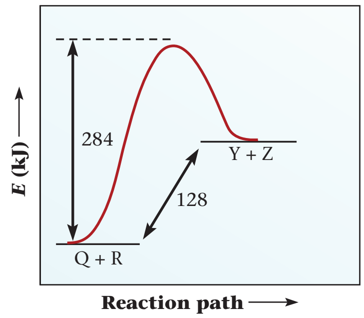
54. (a) 0.0153 L/mol·s (b) 327 s (c) 47.6 s
(d) 2.51×10^{-4} mol/L·s

56. 2.9 L/mol·min

58. 57%

60. $E_a = 2.2 \times 10^2$ kJ/mol

62.



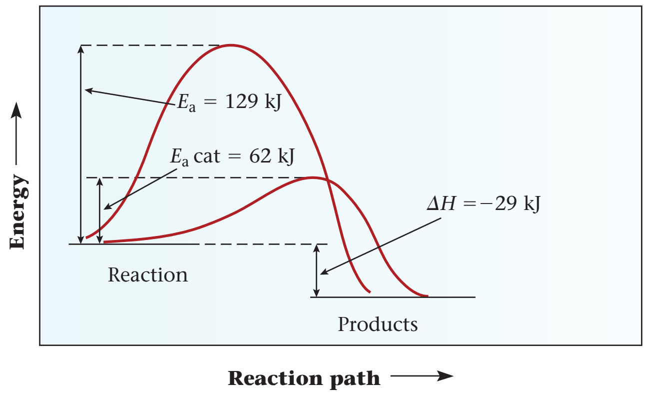
64. Decrease by 31%

66. (a) At 25°C: 148 chirps/min; at 35°C: 220 chirps/min
(b) 3.0×10^1 kJ (c) 49%

68. (a) 0.062 s^{-1} (b) 35°C

70. 86 kJ/mol

72.



74. 357 kJ

76. (a) rate $= k\,[Cl]^2$
(b) rate $= k\,[N_2O_2][O_2]$
(c) rate $= k\,[I^-]\,[HClO]$

78. yes

80. (1) rate $= k \times [NO_3] \times [NO]$;
$k_2 \times [NO_3] = k_1 \times [NO] \times [O_2]$

$$\text{rate} = \frac{kk_1}{k_2} \times [NO]^2 \times [O_2]$$

(2) rate $= k \times [N_2O_2] \times [O_2]$ $\quad k_2 \times [N_2O_2] = k_1 \times [NO]^2$

$$\text{rate} = \frac{kk_1}{k_2} \times [NO]^2 \times [O_2]$$

82. 0.097 mol/L·s
84. ≈15 times faster
86. 7×10^{17} years; very unlikely
88. $\ln\left(\frac{k_2}{k_1}\right) = \frac{1}{RT}(E_{a_{uncat}} - E_{a_{cat}})$
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/min; rate = 0.1 mol/L·min; E_a = 32 kJ
Expt. 3: rate = 0.1 mol/L·min; E_a cannot be determined
Expt. 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. 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) $K = P_{CO_2}$

(b) $K = \frac{(P_{CO_2})^2(P_{H_2})^5}{P_{C_2H_6}}$

(c) $K = \frac{(P_{NH_3})^4(P_{O_2})^5}{(P_{NO})^4(P_{H_2O})^6}$

(d) $K = \frac{1}{P_{NH_3}}$

8. (a) $K = \frac{(P_{Cl_2})[I^-]^2}{[Cl^-]^2}$

(b) $K = \frac{[CH_3NH_3^+]}{[CH_3NH_2][H^+]}$

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

10. (a) $C_3H_6O(l) \rightleftharpoons C_3H_6O(g)$ $\quad K = P_{C_3H_6O}$
(b) $7H_2(g) + 2NO_2(g) \rightleftharpoons 2NH_3(g) + 4H_2O(g)$

$$K = \frac{(P_{NH_3})^2(P_{H_2O})^4}{(P_{H_2})^7(P_{NO_2})^2}$$

(c) $H_2S(g) + Pb^{2+}(aq) \rightleftharpoons PbS(s) + 2H^+(aq)$

$$K = \frac{[H^+]^2}{(P_{H_2S})[Pb^{2+}]}$$

12. (a) $2H_2O(g) + 2SO_2(g) \rightleftharpoons 2H_2S(g) + 3O_2(g)$
(b) $IF(g) \rightleftharpoons \frac{1}{2}F_2(g) + \frac{1}{2}I_2(g)$
(c) $Cl_2(g) + 2Br^-(aq) \rightleftharpoons 2Cl^-(aq) + Br_2(l)$
(d) $2NO_3{}^-(aq) + 8H^+(aq) + 3Cu(s) \rightleftharpoons 2NO(g) + 3Cu^{2+}(aq) + 4H_2O(g)$

14. (a) $K' = \frac{P_{NOCl}}{(P_{NO})(P_{Cl_2})^{1/2}}$

(b) $K'' = \frac{(P_{NO})(P_{Cl_2})}{(P_{NOCl})^2}$

(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) $NOBr(g) \rightleftharpoons NO(g) + \frac{1}{2}Br_2(g)$ (b) K = 0.090
26. 3.39
28. (a) No; Q ≠ K (b) ⟶
30. (a) ⟵ (b) ⟵ (c) ⟶
32. ⟶
34. 2.3 atm
36. P_{I_2} = 0.32 atm; P_{Cl_2} = 0.96 atm
38. P_{NO} = 0.42 atm; P_{NO_2} = 0.32 atm
40. $P_Q = P_R$ = 0.188 atm; P_Z = 0.308 atm
42. (a) $P_{NO} = P_{SO_3}$ = 2.25 atm; P_{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. $P_{H_2} = P_{I_2}$ = 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) ⟶ (b) ⟶ (c) ⟶

54. (a) 0.23 (b) P_{X_2} = 4.3 atm; P_{X_2R} = 0.98 atm
(c) P_{X_2} = 2.41 atm; P_{X_2R} = 0.56 atm
56. (a) 5.9
(b) P_{SO_2} = 1.93 atm; P_{Cl_2} = 0.73 atm; $P_{SO_2Cl_2}$ = 0.22 atm
58. 0.132
60. −57 kJ
62. (a) $P_{S(CH_2CH_2Cl)_2}$ = 0.168 atm; P_{SCl_2} = 1.07 atm; $P_{C_2H_4}$ = 2.51 atm
(b) 0.0249
64. 5.40 g
66. (a) 0.283 (b) 0.21
68. (a) $3A(g) \rightleftharpoons 2B(g)$
(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. $$K = \frac{(P_C)^c(P_D)^d}{(P_A)^a(P_B)^b} = \frac{([C]RT)^c([D]RT)^d}{([A]RT)^a([B]RT)^b} = \frac{[C]^c[D]^d}{[A]^a[B]^b}(RT)^{(c+d)-(a+b)}$$
$\Delta n_g = (c + d) - (a + b)$; $K = K_c(RT)^{\Delta n_g}$
79. P_{N_2} = 0.33 atm; P_{H_2} = 0.99 atm; P_{NH_3} = 0.34 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: $HC_2H_3O_2$, H_2S
Brønsted-Lowry base: HS^-, $C_2H_3O_2^-$
acid-base pairs: $HC_2H_3O_2$, $C_2H_3O_2^-$; 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) $Fe(H_2O)_4(OH)_2$ (c) ClO_3^-
(d) NH_3 (e) $C_2H_3O_2^-$
8. (a) acid: $HCO_3^-(aq) \rightleftharpoons H^+(aq) + CO_3^{2-}(aq)$
(b) base: $HCO_3^-(aq) + H_2O \rightleftharpoons OH^-(aq) + H_2CO_3(aq)$
10. (a) $Zn(H_2O)_3OH^+(aq) + H_2O \rightleftharpoons Zn(H_2O)_2(OH)_2(aq) + H_3O^+(aq)$
(b) $HSO_4^-(aq) + H_2O \rightleftharpoons SO_4^{2-}(aq) + H_3O^+(aq)$
(c) $HNO_2(aq) + H_2O \rightleftharpoons NO_2^-(aq) + H_3O^+(aq)$
(d) $Fe(H_2O)_6^{2+}(aq) + H_2O \rightleftharpoons Fe(H_2O)_5OH^+(aq) + H_3O^+(aq)$
(e) $HC_2H_3O_2(aq) + H_2O \rightleftharpoons C_2H_3O_2^-(aq) + H_3O^+(aq)$
(f) $H_2PO_4^-(aq) + H_2O \rightleftharpoons HPO_4^{2-}(aq) + H_3O^+(aq)$
12. (a) $(CH_3)_3N(aq) + H_2O \rightleftharpoons (CH_3)_3NH^+(aq) + OH^-(aq)$
(b) $HC_2O_4^-(aq) + H_2O \rightleftharpoons H_2C_2O_4(aq) + OH^-(aq)$
(c) $CN^-(aq) + H_2O \rightleftharpoons HCN(aq) + OH^-(aq)$
(d) $S^{2-}(aq) + H_2O \rightleftharpoons HS^-(aq) + OH^-(aq)$
(e) $BrO_3^-(aq) + H_2O \rightleftharpoons HBrO_3(aq) + OH^-(aq)$
(f) $H_2C_6O_5H_7^-(aq) + H_2O \rightleftharpoons H_3C_6O_5H_7(aq) + OH^-(aq)$
14. (a) 2.57 acidic
(b) −0.18 acidic
(c) 12.84 basic
(d) 8.19 basic
16. (a) $[H^+] = 5.8$; $[OH^-] = 1.7 \times 10^{-15}$
(b) $[H^+] = 7.8 \times 10^{-10}$; $[OH^-] = 1.3 \times 10^{-5}$
(c) $[H^+] = 1.5 \times 10^{-4}$; $[OH^-] = 6.7 \times 10^{-11}$
(d) $[H^+] = 8.3 \times 10^{-13}$; $[OH^-] = 0.012$
18.

(a)	1.4×10^{-6} M	7.2×10^{-9} M	5.86	8.14	No
(b)	5.2×10^{-14} M	0.19 M	13.28	0.72	Yes
(c)	2.3×10^{-12} M	4.3×10^{-3} M	11.63	2.37	Yes
(d)	2.75 M	3.64×10^{-15} M	−0.44	14.44	No

20. Solution R is more basic; solution Q has a smaller pH.
22. (a) A: 4.8×10^{-13} M B: 1.4×10^{-12} M
C: 6.9×10^{-7} M
(b) B: 11.85 C: 6.16
(c) A is basic, B is basic, C is acidic
24. (a) cola: 7.9×10^{-4} M; green tea: 1.6×10^{-6} M
(b) ratio: 5.0×10^2; cola is 500 times more acidic than green tea
26. (a) $[H^+]$ = 1.90 M; pH = −0.28; same pH in 10.0-mL sample
(b) $[H^+]$ = 0.021 M; pH = 1.67 in 1.28 L of solution; $[H^+]$ = 0.21 M; pH = 0.67 in 0.128 L of solution
28. (a) $[OH^-]$ = 0.0293 M; $[H^+] = 3.4 \times 10^{-13}$ M; pH = 12.47
(b) $[OH^-]$ = 0.199 M; $[H^+] = 5.02 \times 10^{-14}$ M; pH = 13.30
30. 0.792
32. 11.94
34. (a) $HSO_3^-(aq) \rightleftharpoons H^+(aq) + SO_3^{2-}(aq)$
$$K_a = \frac{[H^+][SO_3^{2-}]}{[HSO_3^-]}$$
(b) $HPO_4^{2-}(aq) \rightleftharpoons H^+(aq) + PO_4^{3-}(aq)$
$$K_a = \frac{[H^+]PO_4^{3-}]}{[HPO_4^{2-}]}$$
(c) $HNO_2(aq) \rightleftharpoons NO_2^-(aq) + H^+(aq)$
$$K_a = \frac{[H^+][NO_2^-]}{[HNO_2]}$$
36. (a) 3.74 (b) 7.17 (c) 10.31
38. (a) C < D < B < A (b) A
40. HCl > HF > HClO > HCN
42. HCl < HF < HClO < 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) 3.07×10^{-3} M (b) 3.3×10^{-12} M
(c) 2.51 (d) 1.3%
56. 2.29; 1.3%

58.

$H_3C_6H_5O_7(aq) \rightleftharpoons H^+(aq) + H_2C_6H_5O_7^-(aq)$ $K_{a1} = 7.5 \times 10^{-4}$
$H_2C_6H_5O_7^-(aq) \rightleftharpoons H^+(aq) + HC_6H_5O_7^{2-}(aq)$ $K_{a2} = 1.7 \times 10^{-5}$
$HC_6H_5O_7^{2-}(aq) \rightleftharpoons H^+(aq) + C_6H_5O_7^{3-}(aq)$ $K_{a3} = 4.0 \times 10^{-7}$

$H_3C_6H_5O_7(aq) \rightleftharpoons 3H^+(aq) + C_6H_5O_7^{3-}(aq)$ $K = 5.1 \times 10^{-15}$

60. pH = 2.00; $[HX^-] = 1.0 \times 10^{-2}$ *M*; $[X^{2-}] = 9.7 \times 10^{-8}$ *M*
62. pH = 1.05; $[HSeO_3^-]$ =0.088 *M*, $[SeO_3^{2-}] = 5.0 \times 10^{-8}$ *M*
64. (a) $NH_3(aq) + H_2O \rightleftharpoons NH_4^+(aq) + OH^-(aq)$

$$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]}$$

(b) $HS^-(aq) + H_2O \rightleftharpoons H_2S(aq) + OH^-(aq)$

$$K_b = \frac{[H_2S][OH^-]}{[HS^-]}$$

(c) $(CH_3)_3N(aq) + H_2O \rightleftharpoons (CH_3)_3NH^+(aq) + OH^-(aq)$

$$K_b = \frac{[(CH_3)_3NH^+][OH^-]}{[(CH_3)_3N]}$$

66. $NO_2^- < CHO_2^- < SO_3^{2-}$
68. $Ba(OH)_2 > KOH > NaCN > HCO_3^-$
70. (a) 6.7×10^{-11} (b) 6.7×10^{-10}
72. $[OH^-] = 1.3 \times 10^{-4}$ *M*; pH = 10.11
74. (a) $C_6H_5N(aq) + H_2O \rightleftharpoons C_6H_5NH^+(aq) + OH^-(aq)$
(b) 1.5×10^{-9} (c) 8.94
76. 2.1×10^2 g
78. (a) $(NH_4)_2SO_3$, NH_4CN (b) Na_2CO_3, K_2CO_3
(c) NaBr, KBr (d) $FeCrO_4$, $(NH_4)_2CrO_4$
80. (a) acidic (b) neutral (c) acidic (d) basic
(e) basic
82. (a) $Fe(H_2O)_6^{3+}(aq) + H_2O \rightleftharpoons [Fe(H_2O)_5OH]^{2+}(aq) + H_3O^+(aq)$
(b) BaI_2 is neutral
(c) $NH_4^+(aq) + H_2O \rightleftharpoons NH_3(aq) + H_3O^+(aq)$
$K_a = 5.6 \times 10^{-10}$
$NO_2^-(aq) + H_2O \rightleftharpoons OH^-(aq) + HNO_2(aq)$
$K_b = 1.7 \times 10^{-11}$
(d) $HPO_4^{2-}(aq) + H_2O \rightleftharpoons PO_4^{3-}(aq) + H_3O^+(aq)$
$K_a = 4.5 \times 10^{-13}$
$HPO_4^{2-}(aq) + H_2O \rightleftharpoons H_2PO_4^-(aq) + OH^-(aq)$
$K_b = 1.6 \times 10^{-7}$
(e) $PO_4^{3-}(aq) + H_2O \rightleftharpoons HPO_4^{2-}(aq) + OH^-(aq)$
84. $ZnBr_2 < KClO_4 < LiF < NaOH < Sr(OH)_2$
86. $NH_4^+(aq) + NO_2^-(aq) \rightleftharpoons NH_3(aq) + HNO_2(aq)$
$K = 9.3 \times 10^{-7}$

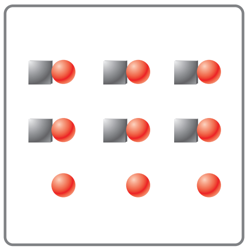
Equilibrium is in the direction of the reactants; reaction unlikely.

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
100. (1) weak acid; (2) strong acid
102. Dissolve 0.10 mol in water, measure pH. If pH > 7, solid is basic; pH < 13.0, it is a weak base. If pH < 7, solid is acidic; if pH > 1.0, it is a weak acid.
103. 1.52
104. (a) −5.58 kJ (b) −6.83 kJ
105. 13.06
106. 1.7×10^2 mL
107. −1.64°C
108. 12.62
109. HA
110. 5.2×10^{-7}

Chapter 14

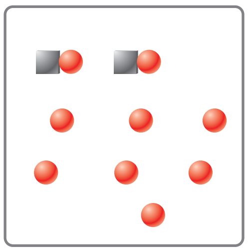
2. (a) $H^+(aq) + C_2H_3O_2^-(aq) \longrightarrow HC_2H_3O_2(aq)$
(b) $H^+(aq) + OH^-(aq) \longrightarrow H_2O$
(c) $HOCl(aq) + CN^-(aq) \longrightarrow HCN(aq) + OCl^-(aq)$
(d) $HNO_2(aq) + OH^-(aq) \longrightarrow NO_2^-(aq) + H_2O$
4. (a) $[Fe(H_2O)_6^{3+}](aq) + OH^-(aq) \longrightarrow [Fe(OH)(H_2O)_5^{2+}](aq) + H_2O$
(b) $HCO_3^-(aq) + OH^-(aq) \longrightarrow CO_3^{2-}(aq) + H_2O$
(c) $NH_4^+(aq) + OH^-(aq) \longrightarrow NH_3(aq) + H_2O$
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) $[OH^-] = 9.67 \times 10^{-9}$; pH = 5.99
(b) $[OH^-] = 9.60 \times 10^{-8}$; pH = 6.98
(c) $[OH^-] = 1.95 \times 10^{-7}$; pH = 7.29
(d) $[OH^-] = 3.1 \times 10^{-7}$; pH = 7.50
(e) $[OH^-] = 4.75 \times 10^{-7}$; 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
24. (a) $HC_2H_3O_2/C_2H_3O_2^-$ (b) HCN/CN^-
(c) HCO_3^-/CO_3^{2-}
26. (a) 0.18:1 (b) 0.10
(c) 9.2×10^2 mL (d) 4.8×10^2 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) $[K^+] = [Cl^-] = 0.109\ M$
44. (a) $HSO_3^-(aq) + OH^-(aq) \longrightarrow SO_3^{2-}(aq) + H_2O$
(b) 0.109 M
(c) $[Na^+] = [K^+] = [SO_3^{2-}] = 0.0749\ M$; $[OH^-] = [HSO_3^-] = 1.1 \times 10^{-4}\ M$
(d) 10.04
46. (a) $BrO_3^-(aq) + H^+(aq) \rightleftharpoons HBrO(aq)$
(b) 64.6 mL
(c) 4.68
(d) $[H^+] = [BrO^-] = 2.07 \times 10^{-5}\ M$; $[K^+] = [NO_3^-] = [HBrO] = 0.171\ M$
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)



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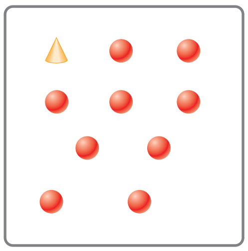


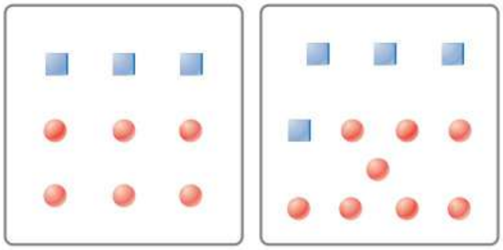
base

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. 1.1×10^2 g/mol
73. $\dfrac{[NH_4^+]}{[NH_3]} = 5.7 \times 10^2$
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

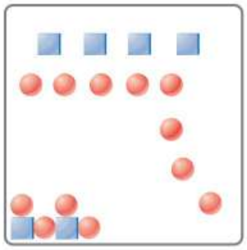
Chapter 15

2. (a) $3 \times 10^{-3}\ M$ (b) $5 \times 10^{-5}\ M$
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) $[Li^+] = 0.016\ M$ (b) $[NO_2^-] = 0.024\ M$
(c) $[Sn^{2+}] = 2.9 \times 10^{-19}\ M$
12. (a) 4.0×10^{-5} (b) 0.18 M (c) 2×10^{-11}
14. (a) $[Ba^{2+}] = [C_2O_4^{2-}] = 1.3 \times 10^{-3}\ M$
(b) $[OH^-] = 2.9 \times 10^{-8}\ M$
(c) $[Pb^{2+}] = 2 \times 10^{-15}\ M$
16. (a) $3 \times 10^{-4}\ M$ (b) $1 \times 10^{-10}\ M$ (c) $6 \times 10^{-6}\ M$
18. (a) 8.5×10^{-5} (b) 1.7×10^{-13} (c) 8.2×10^{-33}
20. (a) 6×10^{-3} g/L (b) 5×10^{-8} g/L (c) 1×10^{-3} g/L
22. 5.49×10^{-16}
24. (a) yes (b) no
26. 9.1×10^{-15}
28. (a) $[Cd^{2+}] = 1.4 \times 10^{-5}\ M$
(b) 8.64
(c) 1.0×10^1 %
30. yes; $1.0 \times 10^{-2}\ M$
32. (a) yes
(b) $[Ag^+] = 1.6 \times 10^{-2}\ M$; $[CO_3^{2-}] = 3 \times 10^{-8}\ M$; $[Na^+] = 6.22 \times 10^{-4}\ M$; $[NO_3^-] = 1.7 \times 10^{-2}\ M$
34. (a) $Pb(OH)_2$ (b) 9.26
36. (a) $PbCrO_4$ (b) $3 \times 10^{-12}\ M$
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)** $Al^{3+}(aq) + 4OH^-(aq) \rightleftharpoons Al(OH)_4^-(aq)$
(b) $Al^{3+}(aq) + PO_4^{3-}(aq) \rightleftharpoons AlPO_4(s)$
(c) $Al(OH)_3(s) + 3H^+(aq) \rightleftharpoons Al^{3+}(aq) + 3H_2O$
46. $Co(OH)_2(s) + 2H^+(aq) \rightleftharpoons Co^{2+}(aq) + 2H_2O$; $K = 2 \times 10^{12}$
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)** $\longleftarrow$ **(b)** $\longleftarrow$ **(c)** $\longleftarrow$
62. **(a)** 3.8×10^{-4} M **(b)** no **(c)** 0.022 M
64. ≈ 2 mg
66.



(1) (2)



(3)

68. a
70. yes
72. **(a)** (3) **(b)** (5) **(c)** (2) **(d)** (1)
73. In HCN: 2×10^{-3} M; In H_2O: 2×10^{-6} M
74. 1.9×10^{-4} mol/L
75. 1.4×10^{-4} M
76. **(a)** 1×10^{-5} M **(b)** $Al(OH)_3$, $Fe(OH)_3$
(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)** $O_2(g)$ with 758 mm Hg pressure
(b) glucose(s)
(c) 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. $\Delta G° = -6.0 \times 10^1$ 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 $P = 1$ atm
54. 332 K = 59°C
56. **(a)** no; $\Delta G = 20.3$ kJ
(b) yes; $\Delta G = -12.3$ kJ
58. **(a)** 368.0 kJ **(b)** 323 kJ
60. **(a)** 55.7 kJ **(b)** 1.1×10^{-5} 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)** $\Delta G° = 201.3$ kJ (nonspontaneous)
(b) $\Delta G° = -98.9$ kJ
76. $C_6H_{12}O_6(s) + 6\,O_2(g) + 80ADP + 80HPO_4^{2-}(aq) + 160\,H^+(aq) \longrightarrow 80ATP + 86H_2O + 6CO_2(g)$
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 $S°_{gas} > S°_{solid}$ or $S°_{liq}$
(b) $\Delta S°$ 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 $\Delta G°$ **(b)** yes **(c)** no
(d) ≈350 K = 77°C **(e)** 7.6×10^{-3}
92. **(a)** LT **(b)** LT **(c)** MI
93. 0.2827 kJ/mol
94. $P_{H_2} = P_{I_2} = 0.07$ atm $P_{HI} = 0.46$ 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) $\Delta G° = 146 - 0.1104\,T$; becomes spontaneous above 1050°C
(2) $\Delta G° = 168.6 - 0.0758\,T$; 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) $CH_3OH(aq) + H_2O \longrightarrow CO_2(g) + 6e^- + 6H^+(aq)$
(b) $NO_3^-(aq) + 8e^- + 10H^+ \longrightarrow NH_4^+(aq) + 3H_2O$
(c) $Fe^{3+}(aq) + 3e^- \longrightarrow Fe(s)$
(d) $V^{2+}(aq) + 6OH^-(aq) \longrightarrow VO_3^- + 3e^- + 3H_2O$
4. (a) $2H^+(aq) + H_2O_2(aq) + 2Ni^{2+}(aq) \longrightarrow 2Ni^{3+}(aq) + 2H_2O$
(b) $14H^+(aq) + Cr_2O_7^{2-}(aq) + 3Sn^{2+}(aq) \longrightarrow 2Cr^{3+}(aq) + 3Sn^{4+}(aq) + 7H_2O$
6. (a) $P_4(s) + 12Cl^-(aq) + 12H^+(aq) \longrightarrow 4PH_3(g) + 6Cl_2(g)$
(b) $2MnO_4^-(aq) + 6H^+(aq) + 5NO_2^-(aq) \longrightarrow 2Mn^{2+}(aq) + 3H_2O + 5NO_3^-(aq)$
(c) $3HBrO_3(aq) + 2Bi(s) \longrightarrow 3HBrO_2(aq) + Bi_2O_3(s)$
(d) $2CrO_4^{2-}(aq) + 3SO_3^{2-}(aq) + 10H^+(aq) \longrightarrow 2Cr^{3+}(aq) + 3SO_4^{2-}(aq) + 5H_2O$
8. (a) $3Ca(s) + 8H_2O + 2VO_4^{3-}(aq) \longrightarrow 3Ca^{2+}(aq) + 2V^{2+}(aq) + 16OH^-(aq)$
(b) $C_2H_4(g) + 10H_2O + 6BiO_3^-(aq) \longrightarrow 2CO_2(g) + 6Bi^{3+}(aq) + 24OH^-(aq)$
(c) $2H_2O + 2PbO_2(s) \longrightarrow 2Pb^{2+}(aq) + O_2(g) + 4OH^-(aq)$
(d) $16Cl^-(aq) + 9H_2O + 3IO_3^-(aq) \longrightarrow 8Cl_2(g) + I_3^-(aq) + 18OH^-(aq)$
10. (a) $2NO(g) + 5H_2(g) \longrightarrow 2NH_3(g) + 2H_2O(g)$
(b) $H_2O_2(aq) + 2ClO^-(aq) + 2H^+(aq) \longrightarrow O_2(g) + Cl_2(g) + 2H_2O$
(c) $Zn(s) + 2VO^{2+}(aq) + 4H^+(aq) \longrightarrow Zn^{2+}(aq) + 2V^{3+}(aq) + 2H_2O$
12. (a) $3Cd(s) + 2Sb^{3+}(aq) \longrightarrow 3Cd^{2+}(aq) + 2Sb(s)$
(b) $2Cu^+(aq) + Mg^{2+}(aq) \longrightarrow 2Cu^{2+}(aq) + Mg(s)$
(c) $2Cr^{3+}(aq) + ClO_3^-(aq) + 4H_2O \longrightarrow Cr_2O_7^{2-}(aq) + Cl^-(aq) + 8H^+(aq)$
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) $MnO_4^-(aq) + 8H^+(aq) + 5e^- \longrightarrow Mn^{2+}(aq) + 4H_2O$
18. anode: $2I^-(aq) \longrightarrow I_2(s) + 2e^-$
cathode: $Br_2(l) + 2e^- \longrightarrow 2Br^-(aq)$
overall: $Br_2(l) + 2I^-(aq) \longrightarrow 2Br^-(aq) + I_2(s)$
cell notation: Pt | I^- | I_2 || Br_2, Br^- | Pt
20. (a) Br^- (b) Ni (c) Hg_2^{2+}
22. $K^+ < Mn^{2+} < S < Cl_2 < Co^{3+}$
24. oxidizing agents: $Fe^{2+} < Ni^{2+} < H^+ < Cu^+$
reducing agents: $Fe^{2+} < Cu^+ < Zn$
both oxidizing and reducing agents: Cu^+, Fe^{2+}
26. (a) Co^{2+} (b) Mn (c) Co^{3+} (d) Mn^{2+} (e) yes (f) no (g) Co^{3+}, 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) $2Co^{3+}(aq) + 2I^-(aq) \longrightarrow 2Co^{2+}(aq) + I_2(s)$ $E° = 1.419$ V
(2) $6Co^{3+}(aq) + 2Cr^{3+}(aq) + 7H_2O \longrightarrow 6Co^{2+}(aq) + 14H^+(aq) + Cr_2O_7^{2-}(aq)$ $E° = 0.623$ V
(3) $Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6I^-(aq) \longrightarrow 3I_2(s) + 2Cr^{3+}(aq) + 7H_2O$ $E° = 0.796$ 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) $MnO_2(s) + 4H^+(aq) + 2Hg(l) \longrightarrow Mn^{2+}(aq) + 2H_2O + Hg_2^{2+}(aq)$ $E° = +0.433$ V
(c) no reaction
46. Na and Pb
48. (a) no reaction
(b) no reaction
(c) $2Cr^{2+}(aq) + S(s) + 2H^+(aq) \longrightarrow 2Cr^{3+}(aq) + H_2S(aq)$
50. (a) $\Delta G° = 15.9$ kJ; $E° = -0.041$ V
(b) $\Delta G° = -45.2$ kJ; $K = 8.3 \times 10^7$
(c) $E° = 0.015$ V; $K = 10$
52. (a) -104 kJ (b) -208 kJ (c) -312 kJ
54. $E° = 0.054$ V; $\Delta G° = -52$ 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) $E = 0.152 - \dfrac{0.0257}{2} \ln \dfrac{[Mn^{2+}]}{[Br^-]^2[H^+]^4}$
(c) -0.221 V
66. (a) 0.305 V
(b) $E = 0.305 - \dfrac{0.0257}{6} \ln \dfrac{(P_{NO})^2[OH^-]^8}{[S^{2-}]^3[NO_3^-]^2}$
(c) 0.299 V
68. (a) 0.319 V (b) -0.369 V
70. 1.2
72. $[H^+] = 8 \times 10^{-7}\,M$
74. (a) yes; $E° = 0.899$ V (b) yes; $E = 0.534$ V (c) no; $E = -0.058$ V (d) 7.51
76. (a) 0.127 V (b) $1.6 \times 10^{-3}\,M$ (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) $2Tl(s) + Tl^{3+}(aq) \longrightarrow 3Tl^{+}(aq)$
(2) $2Tl(s) + Tl^{3+}(aq) \longrightarrow 3Tl^{+}(aq)$
(3) $2Tl(s) + Tl^{3+}(aq) \longrightarrow 3Tl^{+}(aq)$
(b) (1) 1.62 V (2) 0.54 V (3) 1.08 V
(c) (1) −313 kJ (2) −313 kJ (3) −313 kJ
(d) $\Delta G°$ is a state property; $E°$ is not.
102. Y > X > Z
103. ≈31.8% Sn and 68.2% Cu
104. 2.007 V
105. (a) 0.621 V (b) increases; decreases
(c) 1×10^{-21}
(d) $[Zn^{2+}] = 2.0\ M$; $[Sn^{2+}] = 2 \times 10^{-21}\ M$
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

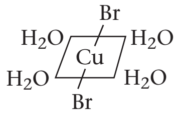
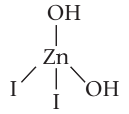
Chapter 18

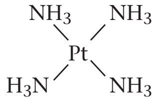
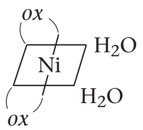
2. (a) $^{28}_{14}Si$ (b) $^{6}_{3}Li$ (c) $^{23}_{11}Na$
4. (a) Ni (b) Se (c) Cd
6. $^{51}_{24}Cr \longrightarrow ^{0}_{1}e + ^{51}_{23}V$
8. (a) Th-231 (b) Pa-231
10. (a) $^{52}_{26}Fe \longrightarrow ^{52}_{25}Mn + ^{0}_{1}e$
(b) $^{228}_{88}Ra \longrightarrow ^{228}_{89}Ac + ^{0}_{-1}e$
(c) $^{236}_{95}Am \longrightarrow ^{232}_{93}Np + ^{4}_{2}He$
12. (a) $^{230}_{90}Th \longrightarrow ^{4}_{2}He + ^{226}_{88}Ra$
(b) $^{210}_{82}Pb \longrightarrow ^{0}_{-1}e + ^{210}_{83}Bi$
(c) $^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{140}_{56}Ba + 3^{1}_{0}n + ^{93}_{36}Kr$
(d) $^{37}_{18}Ar + ^{0}_{-1}e \longrightarrow ^{37}_{17}Cl$
14. (a) $^{272}_{111}Rg$
(b) $^{260}_{105}Db$
16. The product ($^{282}_{114}Z$) is the same.
18. (a) $^{54}_{26}Fe + ^{4}_{2}He \longrightarrow 2\,^{1}_{1}H + ^{56}_{26}Fe$
(b) $^{96}_{42}Mo + ^{2}_{1}H \longrightarrow ^{1}_{0}n + ^{97}_{43}Tc$
(c) $^{40}_{18}Ar + ^{4}_{2}He \longrightarrow ^{43}_{19}K + ^{1}_{1}H$
(d) $^{31}_{16}S + ^{1}_{0}n \longrightarrow ^{1}_{1}H + ^{31}_{15}P$
20. (a) $^{78}_{35}Br$ (b) $^{59}_{26}Fe$ (c) $^{4}_{2}He$ (d) $^{24}_{11}Na$
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) $^{90}_{38}Sr \longrightarrow 2\,^{0}_{-1}e + ^{90}_{40}Zr$
(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. $2C_2O_4^{2-}/Cr^{3+}$
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 rems
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

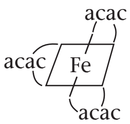
2. (a) *en* = 0; SCN = −1, OH = −1
(b) +3
(c) $Mg[Cd(en)(SCN)_2(OH)_2]$
4. (a) $Pt(NH_3)_2(C_2O_4)$ (b) $Pt(NH_3)_2(SCN)Br$
(c) $Pt(en)(NO_2)_2$
6. (a) 6 (b) 4 (c) 6 (d) 2
8. (a) 3 (b) 2 (c) 2 (d) 3
10. (a) $[Fe(H_2O)_6]_2(CO_3)_3$
(b) $Ba[Pt(OH)_3Br_3]_2$
(c) $Ba[V(en)Cl_4]$
(d) $[Au(CN)_2]_2CO_3$
12. (a) $Pt(NH_3)_6^{4+}$ (b) $Ag(CN)_2^{-}$
(c) $Zn(C_2O_4)_2^{2-}$ (d) $Cd(CN)_4^{2-}$
14. 28.4%
16. one
18. (a) $[Cr(NH_3)_2(H_2O)_4]Cl_2$ (b) $[Cd(Cl)_4(SO_4)^{3-}]$
(c) $Na_2[Ni(OH)_4]$ (d) $[Fe(Br)_2(en)_2^{+}]$
20. (a) sodium tetrahydroxoaluminate(III)
(b) diaquadioxalatocobaltate(III)
(c) triamminetrichloroiridium(III)
(d) diamminedibromoethylenediaminechromium(III) sulfate
22. (a) hexaaquairon(III)
(b) amminetribromoplatinate(II)

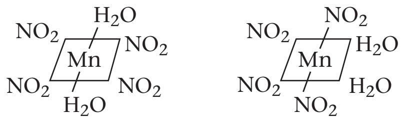
(c) tetrachloroethylenediaminevanadate(II)
(d) dicyanogold(III)

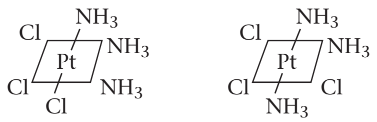
24. (a)  (b) 

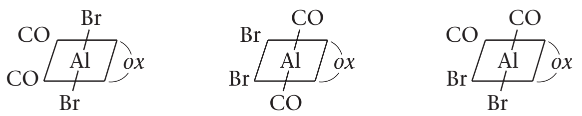
(c)  (d) 

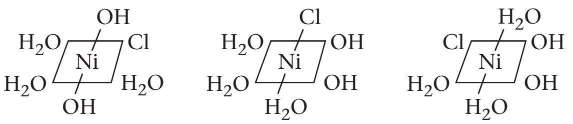
(e) H_3N — Au — CN

26. 

28.
(a) 

(b) 

(c) 

30. 

32. (a) $[_{36}Kr]4d^{10}$
(b) $[_{18}Ar]3d^6$
(c) $[_{54}Xe]4f^{14}5d^8$
(d) $[_{18}Ar]3d^5$
(e) $[_{18}Ar]3d^7$

34. (a) $[_{36}Kr]$ (↑↓)(↑↓)(↑↓)(↑↓)(↑↓) no unpaired electrons
(b) $[_{18}Ar]$ (↑↓)(↑)(↑)(↑)(↑) 4 unpaired electrons
(c) $[_{54}Xe]4f^{14}$ (↑↓)(↑↓)(↑↓)(↑)(↑) 2 unpaired electrons
(d) $[_{18}Ar]$ (↑)(↑)(↑)(↑)(↑) 5 unpaired electrons
(e) $[_{18}Ar]$ (↑↓)(↑↓)(↑)(↑)(↑) 3 unpaired electrons

36. (a) for both high and low spin:
(↑↓)(↑↓)
(↑↓)(↑↓)(↑↓)

(b) for low spin:
(↑)( )
(↑↓)(↑↓)(↑↓)

for high spin:
(↑)(↑)
(↑↓)(↑↓)(↑)

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

( )( ) (↑)( )
(↑↓)(↑)(↑) (↑)(↑)(↑)
low spin high spin

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. 4.60×10^2 nm

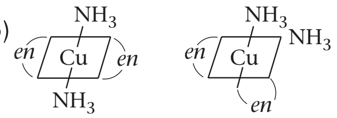
46. ≈ 500 nm; green

48. (a) $CoN_6H_{18}Cl_3$
(b) $Co(NH_3)_6Cl_3(s) \rightleftharpoons Co(NH_3)_6^{3+}(aq) + 3Cl^-(aq)$

50. (a) 6, not 5 (b) shorter, not longer
(c) true (d) eight, not seven

51. 0.92 g

52. $[Pt(NH_3)_4]$ $[PtCl_4]$ or $[Pt(NH_3)_3Cl]$ $[Pt(NH_3)Cl_3]$

53. (a) $CuC_4H_{22}N_6SO_4$
(b) 

54. red-violet

Chapter 20

2. $2Al_2O_3(l) \longrightarrow 4Al(l) + 3O_2(g)$; 2.91 g

4. $Cu_2S(s) + O_2(g) \longrightarrow 2Cu(s) + SO_2(g)$

6. −211.9 kJ

8. (a) $Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(l) + 3CO_2(g)$
(b) $C(s) + O_2(g) \longrightarrow CO_2(g)$

10. 2.5×10^3 kWh

12. 1.7×10^6 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) $Na_2O_2(s) + 2H_2O \longrightarrow 2Na^+(aq) + 2OH^-(aq) + H_2O_2(aq)$
sodium and hydroxide ions, hydrogen peroxide
(b) $2Ca(s) + O_2(g) \longrightarrow 2CaO(s)$; calcium oxide
(c) $Rb(s) + O_2(g) \longrightarrow RbO_2(s)$; rubidium superoxide
(d) $SrH_2(s) + 2H_2O \longrightarrow Sr^{2+}(aq) + 2OH^-(aq) + 2H_2(g)$
strontium and hydroxide ions, hydrogen gas

18. 0.126 g

20. (a) $Co(s) + 2H^+(aq) \longrightarrow Co^{2+}(aq) + H_2(g)$
(b) $3Cu(s) + 2NO_3^-(aq) + 8H^+(aq) \longrightarrow 3Cu^{2+}(aq) + 2NO(g) + 4H_2O$
(c) $Cr_2O_7^{2-}(aq) + 6e^- + 14H^+(aq) \longrightarrow 2Cr^{3+}(aq) + 7H_2O$

22. $3Cd(s) + 12Cl^-(aq) + 2NO_3^-(aq) + 8H^+(aq) \longrightarrow 3CdCl_4^{2-}(aq) + 2NO(g) + 4H_2O$

24. (a) $Fe(s) + 3NO_3^-(aq) + 6H^+(aq) \longrightarrow Fe^{3+}(aq) + 3NO_2(g) + 3H_2O$
(b) $4Cr(OH)_3(s) + 3O_2(g) + 8OH^-(aq) \longrightarrow 4CrO_4^{2-}(aq) + 10H_2O$

26. (a) Cd ($E° = 1.366$ V) (b) Cr ($E° = 1.708$ V)
(c) Co ($E° = 1.246$ V) (d) Ag ($E° = 0.165$ V)
(e) no reaction

28. (a) 0.724 V (b) 0.942 V

30. (a) 9×10^9 (b) 2×10^{-4} *M*

32. 208 g

34. 6.7

36. 53.8% Zn, 46.2% Cu

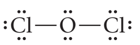
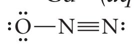
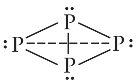
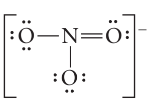
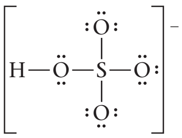
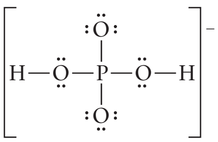
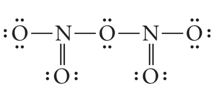
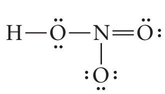
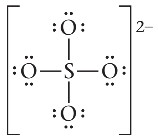
38. $2Ag_2S(s) + 8CN^-(aq) + 3O_2(g) + 2H_2O \longrightarrow 4Ag(CN)_2^-(aq) + 2SO_2(g) + 4OH^-(aq)$
$2Ag(CN)_2^-(aq) + Zn(s) \longrightarrow Zn(CN)_4^{2-}(aq) + 2Ag(s)$

40. (a) Cr^{2+} (b) Au^+ (c) Co^{2+} (d) Mn^{2+}

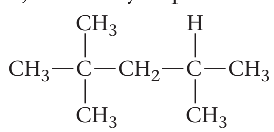
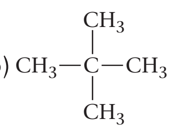
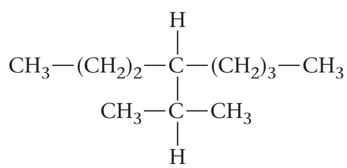
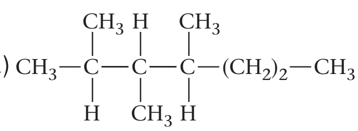
41. 2% BaO_2

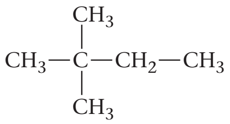
42. (a) $Fe(OH)_3(s) + 3H_2C_2O_4(aq) \longrightarrow Fe(C_2O_4)_3^{3-}(aq) + 3H_2O + 3H^+(aq)$
(b) 0.28 L
43. 2.80%
44. 2.83×10^3 K
45. $Cr_2O_7^{2-}(aq) + 2OH^-(aq) \longrightarrow 2CrO_4^{2-}(aq) + H_2O$
$2Ag^+(aq) + CrO_4^{2-}(aq) \longrightarrow Ag_2CrO_4(s)$
$Ag_2CrO_4(s) + 4NH_3(aq) \longrightarrow 2Ag(NH_3)_2^+(aq) + CrO_4^{2-}(aq)$
$2Ag(NH_3)_2^+(aq) + 4H^+(aq) + CrO_4^{2-}(aq) \longrightarrow Ag_2CrO_4(s) + 4NH_4^+(aq)$

Chapter 21

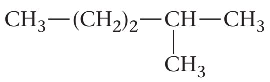
2. (a) bromic acid (b) potassium hypoiodite
(c) sodium chlorite (d) sodium perbromate
4. (a) $KBrO_2$ (b) $CaBr_2$
(c) $NaIO_4$ (d) $Mg(ClO)_2$
6. (a) NO_3^- (b) SO_4^{2-} (c) ClO_4^-
8. (a) H_2SO_3 (b) HClO (c) H_3PO_3
10. (a) NaN_3 (b) H_2SO_3
(c) N_2H_4 (d) NaH_2PO_4
12. (a) H_2S (b) N_2H_4 (c) PH_3
14. (a) NH_3, N_2H_4 (b) HNO_3
(c) HNO_2 (d) HNO_3
16. (a) $2I^-(aq) + SO_4^{2-}(aq) + 4H^+(aq) \longrightarrow I_2(s) + SO_2(g) + 2H_2O$
(b) $2I^-(aq) + Cl_2(g) \longrightarrow I_2(s) + 2Cl^-(aq)$
18. (a) $3HClO(aq) \longrightarrow Cl_2(g) + HClO_2(g) + H_2O$
(b) $2ClO_3^-(aq) \longrightarrow ClO_4^-(aq) + ClO_2^-(aq)$
20. (a) $Cl_2(g) + 2Br^-(aq) \longrightarrow 2Cl^-(aq) + Br_2(l)$
(b) NR (c) NR (d) NR
22. (a) $Pb(N_3)_2(s) \longrightarrow 3N_2(g) + Pb(s)$
(b) $2O_3(g) \longrightarrow 3O_2(g)$
(c) $2H_2S(g) + O_2(g) \longrightarrow 2S(s) + 2H_2O$
24. (a) $Cd^{2+}(aq) + H_2S(aq) \longrightarrow CdS(s) + 2H^+(aq)$
(b) $H_2S(aq) + OH^-(aq) \longrightarrow H_2O + HS^-(aq)$
(c) $2H_2S(aq) + O_2(g) \longrightarrow 2H_2O + 2S(s)$
26. (a) $2H^+(aq) + CaCO_3(s) \longrightarrow CO_2(g) + H_2O + Ca^{2+}(aq)$
(b) $H^+(aq) + OH^-(aq) \longrightarrow H_2O$
(c) $Cu(s) + 4H^+(aq) + SO_4^{2-}(aq) \longrightarrow Cu^{2+}(aq) + 2H_2O + SO_2(g)$
28. (a)  (b) 
(c)  (d) 
30. a and b
32. (a)  (b) 
(c) 
34. (a)  (b) 
(c) 
36. 14.3 L
38. 0.204 *M*
40. 7.7×10^4 L; 1.5×10^5 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. 2.26×10^5 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 $NaN_3(s) \longrightarrow Na(s) + \frac{3}{2}N_2(g)$
Assume 25°C, 1 atm pressure; mass of NaN_3 is 35 g.

Chapter 22

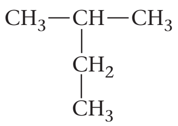
2. (a) alkene (b) alkyne (c) alkane
4. (a) C_9H_{16} (b) $C_{22}H_{44}$ (c) $C_{10}H_{22}$
6. (a) 2-methyloctane (b) 2,2-dimethylpropane
(c) 2,2,4-trimethylpentane
(d) 2,5-dimethylheptane
8.
(a) 
(b) 
(c) 
(d) 

10. (a) 

2,2-dimethylbutane

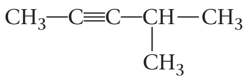
(b) 

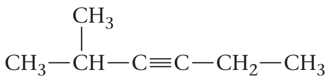
2-methylpentane

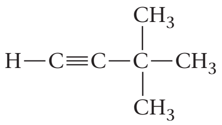
(c) 

2-methylbutane

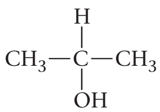
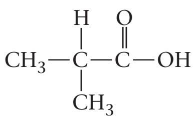
12. (a) $CH_3-C\equiv C-CH_2-CH_3$

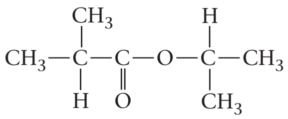
(b) 

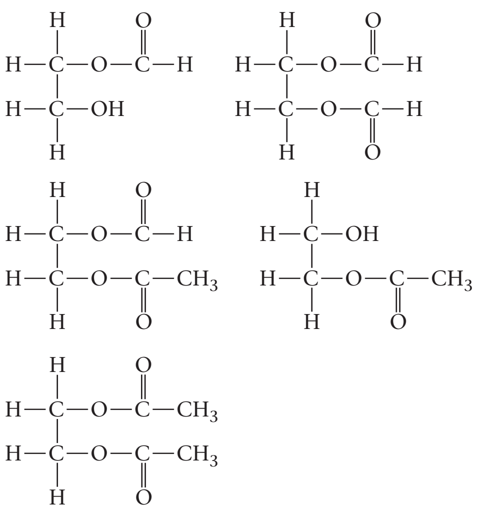
(c) 

(d) 

14. (a) *o*-chlorotoluene (b) *m*-bromotoluene
(c) 1,2,5-tribromotoluene
16. (a) alcohol (b) ester (c) ester, acid
18. (a) ether (b) ester (c) amine
(d) carboxylic acid (e) ketone

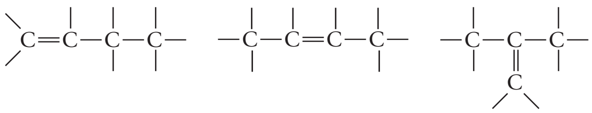
20. (a)  (b) 

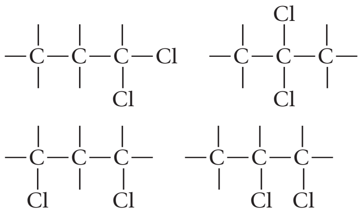
(c) 

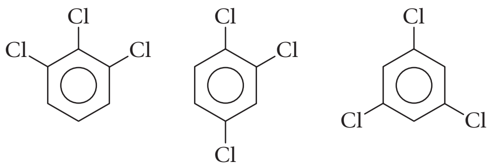
22. 

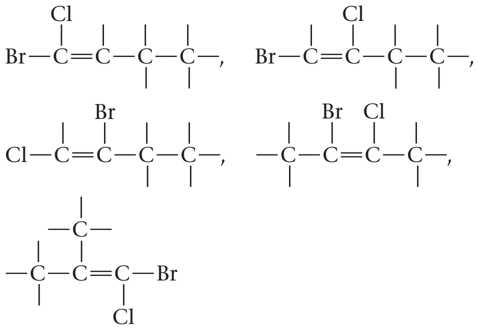
24. (a) butane < diethylether < 1-butanol
(b) hexane < dipropylether < 1-hexanol
26. pH of $C_6H_5NH_3^+$ = 2.93; pH of CH_3COOH = 2.86; pHs are comparable.

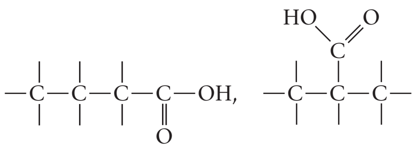
28. 0.73

30. 

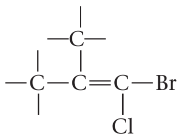
32. 

34. 

36. 

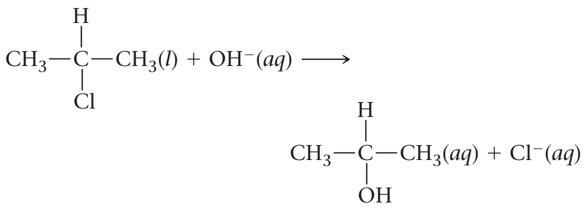
38. 

40. All of the compounds in Problem 36 show *cis-trans* isomerism except

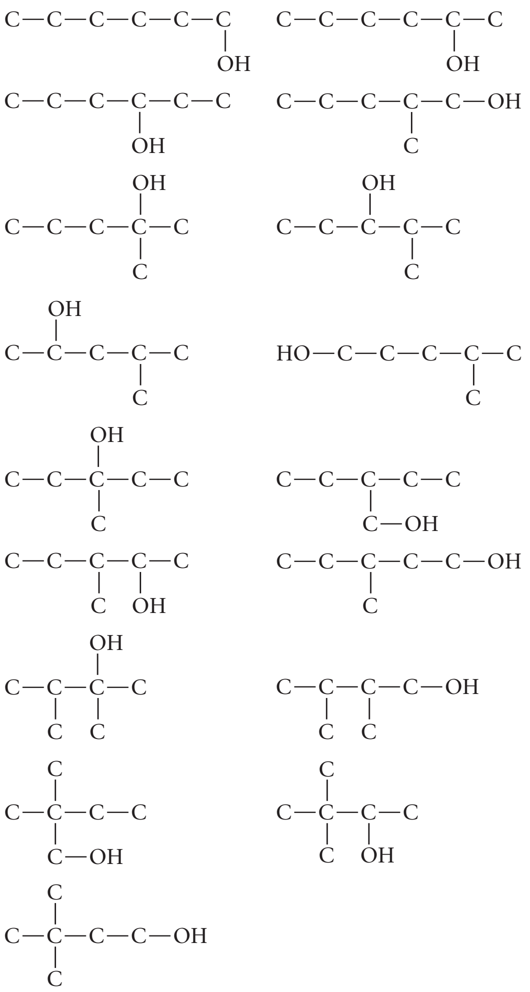


where there are two —CH_3 groups attached to the same carbon.

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
56. (a) $(CH_3)_2NH(aq) + H^+(aq) \longrightarrow (CH_3)_2NH_2^+(aq)$
(b) $CH_3COOH(aq) + OH^-(aq) \longrightarrow CH_3COO^-(aq) + H_2O$

(c) 

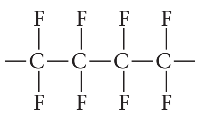
57. $C_{27}H_{46}O$

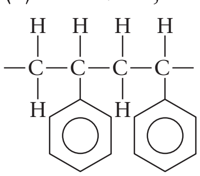
58. 

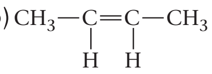
59. Approximately 6 g (Assume $H_2O(l)$ is a product; neglect heat capacity of pan.)

60. $ClCH_2COOH(aq) + (CH_3)_3N(aq) \longrightarrow ClCH_2COO^-(aq) + (CH_3)_3NH^+(aq)$
$K = 8.8 \times 10^6$; $3.4 \times 10^{-5}\ M$

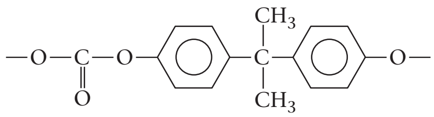
Chapter 23

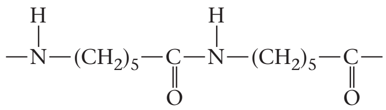
2. (a) 
(b) 2.5×10^6 g/mol
(c) 24.02% C, 75.98% F

4. 

6. (a) $H_2C{=}CHF$
(b) 

8. Polystyrene

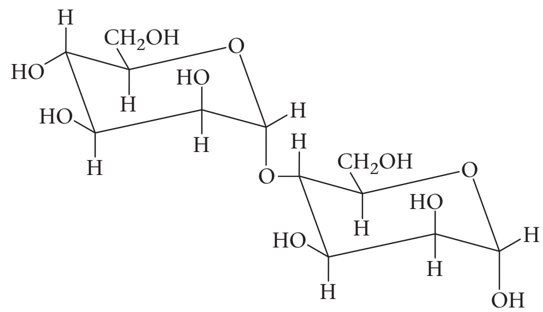
10. 

12. 

14. (a) $H_2N{-}CH_2{-}CH_2{-}NH_2$ and $HOOC{-}CH_2{-}COOH$
(b) 

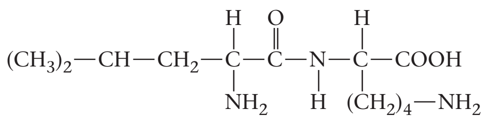
16. $C_{12}H_{22}O_{11}(aq) + H_2O \longrightarrow 2C_6H_{12}O_6(aq)$

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

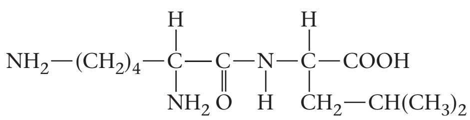
20. 

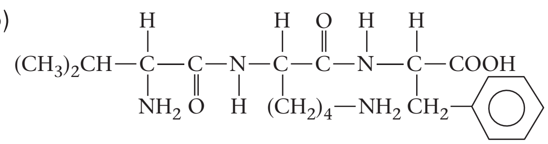
22. 9; 10

24. Leu-Lys:

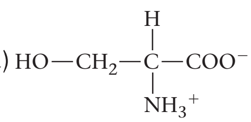
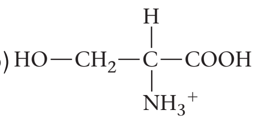


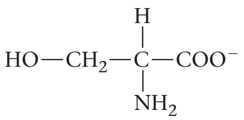
Lys-Leu:

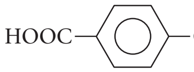
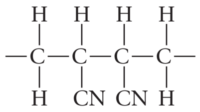


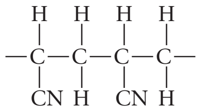
26. (a) 6
(b) 

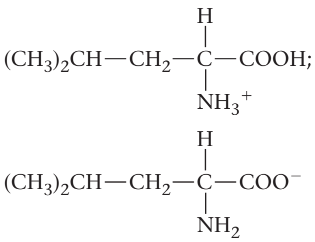
Val-Lys-Phe

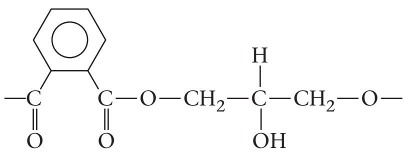
28.
(a) 
(b) 

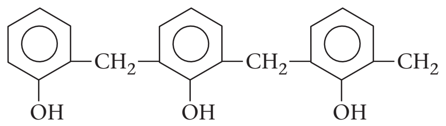
(c) 

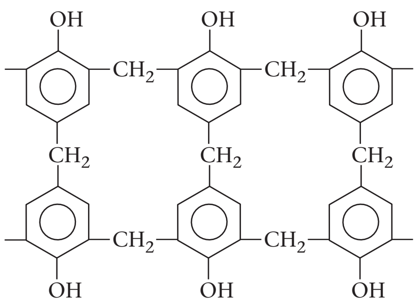
30. (a) 2.29 (b) 9.74 (c) 6.0
32. Ala-Phe-Leu-Met-Val-Ala
34. Double bond for addition; two functional groups for condensation
36. (a) Linear has straight chain with no branches.
(b) See page 585
(c) See page 585
38. (a)  and $HO—(CH_2)_2—OH$
(b) ClHC$=$CHCl (c) $H_2N—(CH_2)_5—COOH$
40.
head to head: 

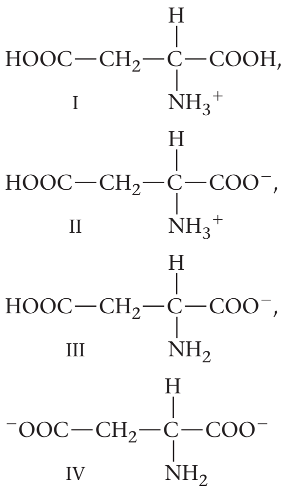
head to tail: 

42.


44. 1.59×10^4 g/mol
46. −214 kJ
48. (a) 

(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
51. linear: 

crossed-linked: 

52.


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.

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