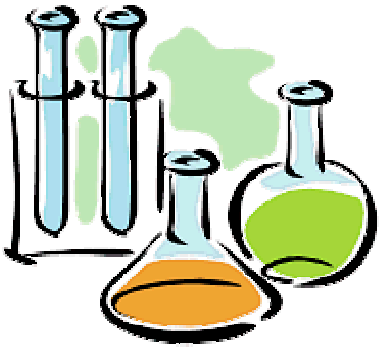

Advanced Placement Chemistry

2010 – 2011 Student Data Booklet

**These items will be provided separately for use on exams and quizzes.*

1–	
acetate	CH_3COO
amide	NH_2
azide	N_3
benzoate	C_6H_5COO
bromate	BrO_3
chlorate	ClO_3
chlorite	ClO_2
cyanate	OCN
cyanide	CN
dihydrogen phosphate	H_2PO_4
formate	HCOO
hydrogen carbonate (bicarbonate)	HCO_3
hydrogen sulfate (bisulfate)	HSO_4
hydrogen sulfide (bisulfide)	HS
hydrogen sulfite (bisulfite)	HSO_3
hydroxide	OH
hypochlorite	ClO
iodate	IO_3
nitrate	NO_3
nitrite	NO_2
perchlorate	ClO_4
permanganate	MnO_4
thiocyanate	SCN
triiodide	I_3
vanadate	VO_3

1+	
ammonium	NH_4
mercury(I)	Hg_2

2+	
mercury(II)	Hg

2–	
carbonate	CO_3
chromate	CrO_4
dichromate	Cr_2O_7
imide	NH
manganate	MnO_4
metasilicate	SiO_3
monohydrogen phosphate	HPO_4
oxalate	C_2O_4
peroxide	O_2
peroxydisulfate	S_2O_8
phthalate	$C_8H_4O_4$
selenate	SeO_4
sulfate	SO_4
sulfite	SO_3
tartrate	$C_4H_4O_6$
tellurate	TeO_4
tetraborate	B_4O_7
thiosulfate	S_2O_3
tungstate	WO_4
zincate	ZnO_2

3–	
aluminate	AlO_3
arsenate	AsO_4
borate	BO_3
citrate	$C_6H_5O_7$
phosphate	PO_4

4–	
orthosilicate	SiO_4
pyrophosphate	P_2O_7

5–	
tripolyphosphate	P_3O_{10}

ATOMIC STRUCTURE

$$E = h\nu \qquad c = \lambda\nu$$

$$\lambda = \frac{h}{m\upsilon} \qquad p = m\upsilon$$

$$E_n = \frac{-2.178\times10^{-18}}{n^2} \text{ joule}$$

E = energy υ = velocity

ν = frequency n = principal quantum number

λ = wavelength m = mass

p = momentum

EQUILIBRIUM

$$K_a = \frac{[\mathrm{H^+}][\mathrm{A^-}]}{[\mathrm{HA}]}$$

$$K_b = \frac{[\mathrm{OH^-}][\mathrm{HB^+}]}{[\mathrm{B}]}$$

$$K_w = [\mathrm{OH^-}][\mathrm{H^+}] = 1.0\times10^{-14} \quad @\ 25°\mathrm{C}$$
$$= K_a \times K_b$$

$$\mathrm{pH} = -\log[\mathrm{H^+}],\ \mathrm{pOH} = -\log[\mathrm{OH^-}]$$

$$14 = \mathrm{pH} + \mathrm{pOH}$$

$$\mathrm{pH} = \mathrm{p}K_a + \log\frac{[\mathrm{A^-}]}{[\mathrm{HA}]}$$

$$\mathrm{pOH} = \mathrm{p}K_b + \log\frac{[\mathrm{HB^+}]}{[\mathrm{B}]}$$

$$\mathrm{p}K_a = -\log K_a,\ \mathrm{p}K_b = -\log K_b$$

$$K_p = K_c(RT)^{\Delta n},$$

where Δn = mol product gas - mol reactant gas

Equilbrium Constants

K_a (weak acid)

K_b (weak base)

K_w (water)

K_p (gas pressure)

K_c (molar concentration)

THERMODYNAMICS/KINETICS

$$\Delta S° = \Sigma S° \text{ products} - \Sigma S° \text{ reactants}$$

$$\Delta H° = \Sigma H_f° \text{ products} - \Sigma H_f° \text{ reactants}$$

$$\Delta G° = \Sigma G_f° \text{ products} - \Sigma G_f° \text{ reactants}$$

$$\Delta G° = \Delta H° - T\Delta S°$$
$$= -RT\ln K = -2.303\,RT\log K$$
$$= -nFE°$$

$$\Delta G = \Delta G° + RT\ln Q = \Delta G° + 2.303\,RT\log Q$$

$$q = mc\Delta T$$

$$C_p = \frac{\Delta H}{\Delta T}$$

$$\ln[\mathrm{A}]_t - \ln[\mathrm{A}]_0 = -kt$$

$$\frac{1}{[\mathrm{A}]_t} - \frac{1}{[\mathrm{A}]_0} = kt$$

$$\ln k = \frac{-E_a}{R}\left(\frac{1}{T}\right) + \ln A$$

$S°$ = standard entropy

$H°$ = standard enthalpy

$G°$ = standard free energy

$E°$ = standard reduction potential

T = temperature

n = mol

m = mass

q = heat

c = specific heat capacity

C_p = molar heat capacity at constant pressure

E_a = activation energy

k = rate constant

A = collision frequency factor

Speed of light, $c = 3.0\times10^8\ \mathrm{m\ s^{-1}}$

Planck's constant, $h = 6.63\times10^{-34}\ \mathrm{J\ s^{-1}}$

Boltzmann's constant, $k = 1.38\times10^{-23}\ \mathrm{J\ K^{-1}}$

Avogadro's number $= 6.022\times10^{23}\ \mathrm{mol^{-1}}$

Electron charge, $e = -1.602\times10^{-19}$ coulomb

1 electron volt per atom $= 96.5\ \mathrm{kJ\ mol^{-1}}$

Faraday' s constant, F = 96,500 coulombs per mol e -

Gas constant, R = 8.31 J mol^{-1} K^{-1}

= 0.0821 L atm mol^{-1} K^{-1}

= 8.31 volt coulomb mol^{-1} K^{-1}

GASES, LIQUIDS AND SOLUTIONS

$$PV = nRT$$

$$\left(P + \frac{n^2 a}{V^2}\right)(V - nb) = nRT$$

$$P_A = P_{total} \times X_A, \text{ where } X_A = \frac{\text{mol A}}{\text{total mol}}$$

$$P_{total} = P_A + P_B + P_C + \cdots$$

$$n = \frac{m}{M}$$

$$\text{K} = ^\circ\text{C} + 273$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$D = \frac{m}{V}$$

$$u_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M}}$$

$$KE \text{ per molecule} = \frac{1}{2} m\upsilon^2$$

$$KE \text{ per mol} = \frac{3}{2} RT$$

$$\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$$

molarity, M = mol solute per liter solution

molality = mol solute per kg solvent

$$\Delta T_f = iK_f \times \text{molality}$$

$$\Delta T_b = iK_b \times \text{molality}$$

$$\pi = iMRT$$

$$A = abc$$

P = pressure

V = volume

T = temperature

n = number of mol

D = density

m = mass

υ = velocity

u_{rms} = root - mean - square speed

KE = kinetic energy

r = rate of effusion

M = molar mass

π = osmotic pressure

i = van' t Hoff factor

K_f = molal freezing - point depression constant

K_b = molal boiling - point elevation constant

A = absorbance

a = molar absorptivity

b = path length

c = concentration

Q = reaction quotient

I = current (amperes)

q = charge (coulombs)

t = time (seconds)

E° = standard reduction potential

K = equilibrium constant

OXIDATION–REDUCTION; ELECTROCHEMISTRY

$$Q = \frac{[\text{C}]^c[\text{D}]^d}{[\text{A}]^a[\text{B}]^b}, \text{ where } a\text{A} + b\text{B} \rightarrow c\text{C} + d\text{D}$$

$$I = \frac{q}{t}$$

$$E_{cell} = E^\circ_{cell} - \frac{RT}{nF}\ln Q = E^\circ_{cell} - \frac{0.0592}{n}\log Q \text{ @ } 25^\circ\text{C}$$

$$\log K = \frac{nE^\circ}{0.0592}$$

Gas constant, $R = 8.31 \text{ J mol}^{-1}\text{K}^{-1}$

$= 0.0821 \text{ L atm mol}^{-1}\text{K}^{-1}$

$= 8.31 \text{ volt coulomb mol}^{-1}\text{K}^{-1}$

Boltzmann's constant, $k = 1.38 \times 10^{-23} \text{ J K}^{-1}$

K_f for $H_2O = 1.86 \text{ K kg mol}^{-1}$

K_b for $H_2O = 0.512 \text{ K kg mol}^{-1}$

1 atm = 760 mm Hg

= 760 torr

STP = 0.000°C and 1.000 atm

Faraday's constant, F = 96,500 coulombs per mol e -

Half–reaction			E_{red}, V
$Ag^{+}_{(aq)} + e–$	⇋	$Ag_{(s)}$	+0.799
$AgBr_{(s)} + e–$	⇋	$Ag_{(s)} + Br^{-}_{(aq)}$	+0.095
$AgCl_{(s)} + e–$	⇋	$Ag_{(s)} + Cl^{-}_{(aq)}$	+0.222
$Al^{3+}_{(aq)} + 3e–$	⇋	$Al_{(s)}$	–1.66
$H_3AsO_{4(aq)} + 2H^{+}_{(aq)} + 2e–$	⇋	$H_3AsO_{3(aq)} + H_2O_{(l)}$	+0.559
$Ba^{2+}_{(aq)} + 2e–$	⇋	$Ba_{(s)}$	–2.90
$Br_{2(l)} + 2e–$	⇋	$2Br^{-}_{(aq)}$	+1.065
$BrO_3^{-}{}_{(aq)} + 6H^{+}_{(aq)} + 5e–$	⇋	$½Br_{2(l)} + 3H_2O_{(l)}$	+1.52
$2CO_{2(g)} + 2H^{+}_{(aq)} + 2e–$	⇋	$H_2C_2O_{4(aq)}$	–0.49
$Ca^{2+}_{(aq)} + 2e–$	⇋	$Ca_{(s)}$	–2.87
$Cd^{2+}_{(aq)} + 2e–$	⇋	$Cd_{(s)}$	–0.403
$Ce^{4+}_{(aq)} + e–$	⇋	$Ce^{3+}_{(s)}$	+1.61
$Cl_{2(g)} + 2e–$	⇋	$2Cl^{-}_{(aq)}$	+1.359
$HClO_{(aq)} + H^{+}_{(aq)} + e–$	⇋	$½Cl_{2(g)} + H_2O_{(l)}$	+1.63
$ClO^{-}_{(aq)} + H_2O_{(l)} + 2e–$	⇋	$Cl^{-}_{(aq)} + 2OH^{-}_{(aq)}$	+0.89
$ClO_3^{-}{}_{(aq)} + 6H^{+}_{(aq)} + 5e–$	⇋	$½Cl_{2(g)} + 3H_2O_{(l)}$	+1.47
$Co^{2+}_{(aq)} + 2e–$	⇋	$Co_{(s)}$	–0.277
$Co^{3+}_{(aq)} + e–$	⇋	$Co^{2+}_{(aq)}$	+1.842
$Cr^{3+}_{(aq)} + 3e–$	⇋	$Cr_{(s)}$	–0.74
$Cr^{3+}_{(aq)} + e–$	⇋	$Cr^{2+}_{(aq)}$	–0.41
$Cr_2O_7^{2-}{}_{(aq)} + 14H^{+}_{(aq)} + 6e–$	⇋	$2Cr^{3+}_{(aq)} + 7H_2O_{(l)}$	+1.33

Half–reaction			E_{red}, V
$CrO_4^{2-}{}_{(aq)} + 4H_2O_{(l)} + 3e-$	⇋	$Cr(OH)_{3(s)} + 5OH-_{(aq)}$	–0.13
$Cu^{2+}{}_{(aq)} + 2e-$	⇋	$Cu_{(s)}$	+0.337
$Cu^{2+}{}_{(aq)} + e-$	⇋	$Cu^{+}{}_{(aq)}$	+0.153
$Cu^{+}{}_{(aq)} + e-$	⇋	$Cu_{(s)}$	+0.521
$F_{2(g)} + 2e-$	⇋	$2F^{-}{}_{(aq)}$	+2.87
$Fe^{2+}{}_{(aq)} + 2e-$	⇋	$Fe_{(s)}$	–0.440
$Fe^{3+}{}_{(aq)} + e-$	⇋	$Fe^{2+}{}_{(aq)}$	+0.771
$2H^{+}{}_{(aq)} + 2e-$	⇋	$H_{2(g)}$	0.000
$2H_2O_{(l)} + 2e-$	⇋	$H_{2(g)} + 2OH^{-}{}_{(aq)}$	–0.83
$H_2O_{2(aq)} + 2H^{+}{}_{(aq)} + 2e-$	⇋	$2H_2O_{(l)}$	+1.776
$Hg_2^{2+}{}_{(aq)} + 2e-$	⇋	$2Hg_{(l)}$	+0.789
$2Hg^{2+}{}_{(aq)} + 2e-$	⇋	$Hg_2^{2+}{}_{(aq)}$	+0.920
$Hg^{2+}{}_{(aq)} + 2e-$	⇋	$Hg_{(l)}$	+0.854
$I_{2(s)} + 2e-$	⇋	$2I^{-}{}_{(aq)}$	+0.536
$IO_3^{-}{}_{(aq)} + 6H^{+}{}_{(aq)} + 5e-$	⇋	$½I_{2(s)} + 3H_2O_{(l)}$	+1.195
$K^{+}{}_{(aq)} + e-$	⇋	$K_{(s)}$	–2.925
$Li^{+}{}_{(aq)} + e-$	⇋	$Li_{(s)}$	–3.05
$Mg^{2+}{}_{(aq)} + 2e-$	⇋	$Mg_{(s)}$	–2.37
$Mn^{2+}{}_{(aq)} + 2e-$	⇋	$Mn_{(s)}$	–1.18
$MnO_{2(s)} + 4H^{+}{}_{(aq)} + 2e-$	⇋	$Mn^{2+}{}_{(aq)} + 2H_2O_{(l)}$	+1.23
$MnO_4^{-}{}_{(aq)} + 8H^{+}{}_{(aq)} + 5e-$	⇋	$Mn^{2+}{}_{(aq)} + 4H_2O_{(l)}$	+1.51
$MnO_4^{-}{}_{(aq)} + 2H_2O_{(l)} + 3e-$	⇋	$MnO_{2(s)} + 4OH^{-}{}_{(aq)}$	+0.59

Half–reaction			E_{red}, V
$HNO_{2(aq)} + H^{+}_{(aq)} + e–$	⇋	$NO_{(g)} + H_2O_{(l)}$	+1.00
$N_{2(g)} + 4H_2O_{(l)} + 4e–$	⇋	$4OH^{–}_{(aq)} + N_2H_{4(aq)}$	–1.16
$N_{2(g)} + 5H^{+}_{(aq)} + 4e–$	⇋	$N_2H_5^{+}{}_{(aq)}$	–0.23
$NO_3^{-}{}_{(aq)} + 4H^{+}_{(aq)} + 3e–$	⇋	$NO_{(g)} + 2H_2O_{(l)}$	+0.96
$Na^{+}_{(aq)} + e–$	⇋	$Na_{(s)}$	–2.71
$Ni^{2+}_{(aq)} + 2e–$	⇋	$Ni_{(s)}$	–0.28
$O_{2(g)} + 4H^{+}_{(aq)} + 4e–$	⇋	$2H_2O_{(l)}$	+1.23
$O_{2(g)} + 2H_2O_{(l)} + 4e–$	⇋	$4OH^{-}_{(aq)}$	+0.40
$O_{2(g)} + 2H^{+}_{(aq)} + 2e–$	⇋	$H_2O_{2(aq)}$	+0.68
$O_{3(g)} + 2H^{+}_{(aq)} + 2e–$	⇋	$O_{2(g)} + H_2O_{(l)}$	+2.07
$Pb^{2+}_{(aq)} + 2e–$	⇋	$Pb_{(s)}$	–0.126
$PbO_{2(s)} + HSO_4^{-}{}_{(aq)} + 3H^{+}_{(aq)} + 2e–$	⇋	$PbSO_{4(s)} + 2H_2O_{(l)}$	+1.685
$PbSO_{4(s)} + H^{+}_{(aq)} + 2e–$	⇋	$Pb_{(s)} + HSO_4^{-}{}_{(aq)}$	–0.356
$PtCl_4^{2-}{}_{(aq)} + 2e–$	⇋	$Pt_{(s)} + 4Cl^{-}_{(aq)}$	+0.73
$S_{(s)} + 2H^{+}_{(aq)} + 2e–$	⇋	$H_2S_{(g)}$	+0.141
$H_2SO_{3(aq)} + 4H^{+}_{(aq)} + 4e–$	⇋	$S_{(s)} + 3H_2O_{(l)}$	+0.45
$HSO_4^{-}{}_{(aq)} + 3H^{+}_{(aq)} + 2e–$	⇋	$H_2SO_{3(aq)} + H_2O_{(l)}$	+0.17
$Sn^{2+}_{(aq)} + 2e–$	⇋	$Sn_{(s)}$	–0.136
$Sn^{4+}_{(aq)} + 2e–$	⇋	$Sn^{2+}_{(aq)}$	+0.154
$VO_2^{+}{}_{(aq)} + 2H^{+}_{(aq)} + e–$	⇋	$VO^{2+}_{(aq)} + H_2O_{(l)}$	+1.00
$Zn^{2+}_{(aq)} + 2e–$	⇋	$Zn_{(s)}$	–0.763

The following compounds are generally soluble in water:	Important Exceptions
Common compounds of the Group 1 metal ions	None
Common compounds of ammonium ion	None
Common nitrates, acetates, chlorates and perchlorates	None
Common fluorides	MgF_2, CaF_2, AgF, Hg_2F_2, PbF_2
Common chlorides	AgCl, Hg_2Cl_2, $PbCl_2$
Common bromides	AgBr, Hg_2Br_2, $PbBr_2$
Common iodides	AgI, Hg_2I_2, PbI_2
Common sulfates	$SrSO_4$, $BaSO_4$, Hg_2SO_4, $PbSO_4$

The following compounds are generally insoluble in water:	Important Exceptions
Metal hydroxides	Strong bases
Common carbonates, phosphates and sulfites	Those containing a Group 1 metal ion or ammonium ion
Common sulfides	Those containing a Group 1 metal ion, Ca^{2+}, Sr^{2+}, Ba^{2+} or ammonium ion

E_{red}	Element	
–3.05	Li	
–2.925	K	
–2.87	Ca	To Na displaces H from cold water
–2.71	Na	
–2.37	Mg	
–1.66	Al	
–1.18	Mn	
–0.763	Zn	
–0.74	Cr	To Fe displaces H from steam
–0.440	Fe	
–0.403	Cd	
–0.277	Co	
–0.28	Ni	
–0.136	Sn	To Pb displaces H from nonoxidizing acid
–0.126	Pb	
0.000	H	
+0.204	Sb	
+0.337	Cu	
+0.789	Hg	
+0.799	Ag	
+1.188	Pt	
+1.52	Au	

Synthesis Reactions

- Metals combine with nonmetals to form salts
- Metals react with oxygen to form metallic oxides
- Soluble metallic oxides react with water to form metallic hydroxides
- Nonmetals react with oxygen to form nonmetallic oxides
- Metallic oxides react with nonmetallic oxides to form salts
- Nonmetallic oxides react with water to form ternary acids

Decomposition Reactions

- Binary salts decompose into elemental metals and elemental nonmetals
- Metallic carbonates decompose into carbon dioxide and metal oxides
- Metallic chlorates decompose into metal chlorides and oxygen gas
- Ternary acids decompose into nonmetallic oxides and water
- Metal hydroxides decompose into metal oxides and water
- Carbonic acid, sulfurous acid and ammonium hydroxide decompose upon formation

Single–Replacement Reactions

- More–active free metals replace less–active metals in solution
- More–active free metals replace hydrogen in non–oxidizing acid solutions
- More–active free metals replace hydrogen in water (check phase) to produce hydrogen gas and a metallic hydroxide
- Halogens higher on the periodic table replace lower halogens
- Copper and concentrated nitric acid react to form copper(II) nitrate, nitrogen(IV) oxide and water
- Copper and dilute nitric acid react to form copper(II) nitrate, nitrogen(II) oxide and water
- Copper and concentrated sulfuric acid react to form copper(II) sulfate, sulfur(IV) oxide and water
- Hydrogen gas replaces metals from hot metallic oxides

Double–Replacement (Metathesis) Reactions

- Two soluble salts may form a precipitate
- Metal sulfides react with acids to from hydrogen sulfide gas and a salt
- Metallic carbonates react with acids to form carbonic acid and a salt
- Metallic sulfites react with acids to form sulfurous acid and a salt
- Ammonium salts react with strong bases to form ammonium hydroxide and a salt
- Acids and bases react to form a salt and water
- The salt of a strong acid and weak base will undergo hydrolysis
- The salt of a weak acid and strong base will undergo hydrolysis
- The salt of strong acid and strong base will not undergo hydrolysis

Simple Organic Reactions

- Hydrocarbons burn in very limited oxygen, limited oxygen or excess oxygen to produce carbon and water, carbon monoxide and water, or carbon dioxide and water, respectively
- Alkanes react with halogens to form haloalkanes and binary inorganic acids
- Alkenes and alkynes react with halogens to form halogen–substituted compounds
- Alkenes and alkynes are hydrogenated in the presence of a catalyst when they react with hydrogen
- Carboxylic acids and alcohols form esters and water

Acid Formula	*Acid Name*	K_a
$HC_2H_3O_2$	acetic	$1.8 \cdot 10^{-5}$
$HC_6H_7O_6$	ascorbic	$8.0 \cdot 10^{-5}$
$HC_7H_5O_2$	benzoic	$6.3 \cdot 10^{-5}$
$HC_4H_7O_2$	butanoic	$1.5 \cdot 10^{-5}$
H_2CO_3	carbonic	$4.3 \cdot 10^{-7}$
$HClO_2$	chlorous	$1.1 \cdot 10^{-2}$
$H_3C_6H_5O_7$	citric	$7.4 \cdot 10^{-4}$
$HCNO$	cyanic	$3.5 \cdot 10^{-4}$
$HCHO_2$	formic	$1.8 \cdot 10^{-4}$
HCN	hydrocyanic	$4.9 \cdot 10^{-10}$
HF	hydrofluoric	$6.8 \cdot 10^{-4}$
H_2S	hydrosulfuric	$9.5 \cdot 10^{-8}$
$HBrO$	hypobromous	$2.5 \cdot 10^{-9}$
$HClO$	hypochlorous	$3.0 \cdot 10^{-8}$
HIO	hypoiodious	$2.3 \cdot 10^{-11}$
HIO_3	iodic	$1.7 \cdot 10^{-1}$
$HC_3H_5O_3$	lactic	$1.4 \cdot 10^{-4}$
$HC_3H_2O_4$	malonic	$1.5 \cdot 10^{-3}$
HNO_2	nitrous	$4.5 \cdot 10^{-4}$
$H_2C_2O_4$	oxalic	$5.9 \cdot 10^{-2}$
HC_6H_5O	phenol	$1.3 \cdot 10^{-10}$
H_3PO_4	phosphoric	$7.5 \cdot 10^{-3}$
$HC_3H_5O_2$	propanoic	$1.3 \cdot 10^{-5}$
H_2SO_3	sulfurous	$1.7 \cdot 10^{-2}$
$H_2C_4H_4O_6$	tartaric	$1.0 \cdot 10^{-3}$

Base Formula	*Base Name*	K_b
NH_3O_2	ammonia	$1.8 \cdot 10^{-5}$
$(CH_3)_2NH$	diethylamine	$5.4 \cdot 10^{-4}$
$C_2H_5NH_2$	ethylamine	$6.4 \cdot 10^{-4}$
$HONH_2$	hydroxylamine	$1.1 \cdot 10^{-8}$
CH_3NH_2	methylamine	$4.4 \cdot 10^{-4}$
C_5H_5N	pyridine	$1.7 \cdot 10^{-9}$
$(CH_3)_3N$	triethylamine	$6.4 \cdot 10^{-5}$

Formula	K_{sp}
$BaCO_3$	$5.0 \cdot 10^{-9}$
$BaCrO_4$	$2.1 \cdot 10^{-10}$
BaF_2	$1.7 \cdot 10^{-6}$
BaC_2O_4	$1.6 \cdot 10^{-6}$
$BaSO_4$	$1.1 \cdot 10^{-10}$
$CdCO_3$	$1.8 \cdot 10^{-14}$
$Cd(OH)_2$	$2.5 \cdot 10^{-14}$
CdS*	$8 \cdot 10^{-28}$
$CaCO_3$	$4.5 \cdot 10^{-9}$
$CaCrO_4$	$7.1 \cdot 10^{-4}$
CaF_2	$3.9 \cdot 10^{-11}$
$Ca(OH)_2$	$6.5 \cdot 10^{-6}$
$Ca_3(PO_4)_2$	$2.0 \cdot 10^{-29}$
$CaSO_4$	$2.4 \cdot 10^{-5}$
$Cr(OH)_3$	$1.6 \cdot 10^{-30}$
$CoCO_3$	$1.0 \cdot 10^{-10}$
$Co(OH)_2$	$1.3 \cdot 10^{-15}$
CoS*	$5 \cdot 10^{-22}$
CuBr	$5.3 \cdot 10^{-9}$
$CuCO_3$	$2.3 \cdot 10^{-10}$
$Cu(OH)_2$	$4.8 \cdot 10^{-20}$
CuS*	$6 \cdot 10^{-37}$
$FeCO_3$	$2.1 \cdot 10^{-11}$
$Fe(OH)_2$	$7.9 \cdot 10^{-16}$
LaF_3	$2 \cdot 10^{-19}$
$La(IO_3)_3$	$6.1 \cdot 10^{-12}$
$PbCO_3$	$7.4 \cdot 10^{-14}$
$PbCl_2$	$1.7 \cdot 10^{-5}$
$PbCrO_4$	$2.8 \cdot 10^{-13}$

Formula	K_{sp}
PbF_2	$3.6 \cdot 10^{-8}$
$PbSO_4$	$6.3 \cdot 10^{-7}$
PbS*	$3 \cdot 10^{-28}$
$Mg(OH)_2$	$1.6 \cdot 10^{-12}$
$MgCO_3$	$3.5 \cdot 10^{-8}$
MgC_2O_4	$8.6 \cdot 10^{-5}$
$MnCO_3$	$5.0 \cdot 10^{-10}$
$Mn(OH)_2$	$1.6 \cdot 10^{-13}$
MnS*	$2 \cdot 10^{-53}$
Hg_2Cl_2	$1.2 \cdot 10^{-18}$
Hg_2I_2	$1.1 \cdot 10^{-28}$
HgS*	$2 \cdot 10^{-53}$
$NiCO_3$	$1.3 \cdot 10^{-7}$
$Ni(OH)_2$	$6.0 \cdot 10^{-16}$
NiS*	$3 \cdot 10^{-20}$
$AgBrO_3$	$5.5 \cdot 10^{-5}$
AgBr	$5.0 \cdot 10^{-13}$
Ag_2CO_3	$8.1 \cdot 10^{-12}$
AgCl	$1.8 \cdot 10^{-10}$
Ag_2CrO_4	$1.2 \cdot 10^{-12}$
AgI	$8.3 \cdot 10^{-17}$
Ag_2SO_4	$1.5 \cdot 10^{-5}$
Ag_2S*	$6 \cdot 10^{-51}$
$SrCO_3$	$9.3 \cdot 10^{-10}$
SnS*	$1 \cdot 10^{-26}$
$ZnCO_3$	$1.0 \cdot 10^{-10}$
$Zn(OH)_2$	$3.0 \cdot 10^{-16}$
ZnC_2O_4	$2.7 \cdot 10^{-8}$
ZnS*	$2 \cdot 10^{-25}$

*Dissociation products for metal(II) sulfides in aqueous solutions are of the form: $M^{2+}_{(aq)} + HS^-_{(aq)} + OH^-_{(aq)}$

Single Bonds

Bond	Bond Enthalpy, kJ/mol	Bond	Bond Enthalpy, kJ/mol
C – H	413	O – H	463
C – C	348	O – O	146
C – N	293	O – F	190
C – O	358	O – Cl	203
C – F	485	O – I	234
C – Cl	328	S – H	339
C – Br	276	S – F	327
C – I	240	S – Cl	253
C – S	259	S – Br	218
N – H	391	S – S	266
N – N	163	Si – Cl	464
N – O	201	Si – O	368
N – F	272	Si – C	301
N – Cl	200	Si – Si	226
N – Br	243	Si – H	323
H – H	436	F – F	155
H – F	567	Br – F	237
H – Cl	431	Br – Cl	218
H – Br	366	Br – Br	193
H – I	299	I – Cl	208
Cl – F	253	I – Br	175
Cl – Cl	242	I – I	151

Multiple Bonds

Bond	Bond Enthalpy, kJ/mol	Bond	Bond Enthalpy, kJ/mol
C = C	614	N = N	418
C ≡ C	839	N ≡ N	941
C = N	615	N = O	607
C ≡ N	891	O = O	495
C = O	799	S = O	523
C ≡ O	1072	S = S	418

Substance	ΔH_f°, kJ · mol^{-1}	ΔG_f°, kJ · mol^{-1}	ΔS°, J · mol^{-1} K^{-1}
$Al_{(s)}$	0	0	28.32
$AlCl_{3(s)}$	–705.6	–630.0	109.3
$Al_2O_{3(s)}$	–1669.8	–1576.5	51.00
$Ba_{(s)}$	0	0	63.2
$BaCO_{3(s)}$	–1216.3	–1137.6	112.1
$BaO_{(s)}$	–553.5	–525.1	70.42
$Be_{(s)}$	0	0	9.44
$BeO_{(s)}$	–608.4	–579.1	13.77
$Be(OH)_{2(s)}$	–905.8	–817.9	50.21
$Br_{(g)}$	111.8	82.38	174.9
$Br^-_{(aq)}$	–120.9	–102.8	80.71
$Br_{2(g)}$	30.71	3.14	245.3
$Br_{2(l)}$	0	0	152.3
$HBr_{(g)}$	–36.23	–53.22	198.49
$Ca_{(g)}$	179.3	145.5	154.8
$Ca_{(s)}$	0	0	41.4
$CaCO_{3(s)}$	–1207.1	–1128.76	92.88
$CaCl_{2(s)}$	–795.8	–748.1	104.6
$CaF_{2(s)}$	–1219.6	–1167.3	68.87
$CaO_{(s)}$	–635.5	–604.17	39.75
$Ca(OH)_{2(s)}$	–986.2	–898.5	83.4
$CaSO_{4(s)}$	–1434.0	–1321.8	106.7
$C_{(g)}$	718.4	672.9	158.0
$C_{(s,\ diamond)}$	1.88	2.84	2.43
$C_{(s,\ graphite)}$	0	0	5.69
$CCl_{4(g)}$	–106.7	–64.0	309.4
$CCl_{4(l)}$	–139.3	–68.6	214.4
$CF_{4(g)}$	–679.9	–635.1	262.3
$CH_{4(g)}$	–74.8	–50.8	186.3
$C_2H_{2(g)}$	226.77	209.2	200.8
$C_2H_{4(g)}$	52.30	68.11	219.4
$C_2H_{6(g)}$	–84.68	–32.89	229.5
$C_3H_{8(g)}$	–103.85	–23.47	269.9
$C_4H_{10(g)}$	–124.73	–15.71	310.0
$C_4H_{10(l)}$	–147.6	–15.0	231.0

Substance	ΔH_f°, kJ · mol^{-1}	ΔG_f°, kJ · mol^{-1}	ΔS°, J · mol^{-1} K^{-1}
$C_6H_{6(g)}$	82.9	129.7	269.2
$C_6H_{6(l)}$	49.0	124.5	172.8
$CH_3OH_{(g)}$	–201.2	–161.9	237.6
$CH_3OH_{(l)}$	–238.6	–166.23	126.8
$C_2H_5OH_{(g)}$	–235.1	–168.5	282.7
$C_2H_5OH_{(l)}$	–277.7	–174.76	160.7
$C_6H_{12}O_{6(s)}$	–1273.02	–910.4	212.1
$CO_{(g)}$	–110.5	–137.2	197.9
$CO_{2(g)}$	–393.5	–394.4	213.6
$HC_2H_3O_{2(l)}$	–487.0	–392.4	159.8
$Cs_{(g)}$	76.50	49.53	175.6
$Cs_{(l)}$	2.09	0.03	92.07
$Cs_{(s)}$	0	0	85.15
$CsCl_{(s)}$	–442.8	–414.4	101.2
$Cl_{(g)}$	121.7	105.7	165.2
$Cl^-_{(aq)}$	–167.2	–131.2	56.5
$Cl_{2(g)}$	0	0	222.96
$HCl_{(aq)}$	–167.2	–131.2	56.5
$HCl_{(g)}$	–92.30	–95.27	186.69
$Cr_{(g)}$	397.5	352.6	174.2
$Cr_{(s)}$	0	0	23.6
$Cr_2O_{3(s)}$	–1139.7	–1058.1	81.2
$Co_{(g)}$	439	393	179
$Co_{(s)}$	0	0	28.4
$Cu_{(g)}$	338.4	298.6	166.3
$Cu_{(s)}$	0	0	33.30
$CuCl_{2(s)}$	–205.9	–161.7	108.1
$CuO_{(s)}$	–156.1	–128.3	42.59
$Cu_2O_{(s)}$	–170.7	–147.9	92.36
$F_{(g)}$	80.0	61.9	158.7
$F^-_{(aq)}$	–332.6	–278.8	–13.8
$F_{2(g)}$	0	0	202.7
$HF_{(g)}$	–268.61	–270.70	173.51
$H_{(g)}$	217.94	203.26	114.60
$H^+_{(aq)}$	0	0	0
$H^+_{(g)}$	1536.2	1517.0	108.9

Substance	ΔH_f°, kJ · mol^{-1}	ΔG_f°, kJ · mol^{-1}	ΔS°, J · mol^{-1} K^{-1}
$H_{2(g)}$	0	0	130.58
$I_{(g)}$	106.60	70.16	180.66
$I^-_{(aq)}$	–55.19	–51.57	111.3
$I_{2(g)}$	62.25	19.37	260.57
$I_{2(s)}$	0	0	116.73
$HI_{(g)}$	25.94	1.30	206.3
$Fe_{(g)}$	415.5	369.8	180.5
$Fe_{(s)}$	0	0	27.15
$Fe^{2+}_{(aq)}$	–87.86	–84.93	113.4
$Fe^{3+}_{(aq)}$	–47.69	–10.54	293.3
$FeCl_{2(s)}$	–341.8	–302.3	117.9
$FeCl_{3(s)}$	–400	–334	142.3
$FeO_{(s)}$	–271.9	–255.2	60.75
$Fe_2O_{3(s)}$	–822.16	–740.98	89.96
$Fe_3O_{4(s)}$	–1117.1	–1014.2	146.4
$FeS_{2(s)}$	–171.5	–160.1	52.92
$Pb_{(s)}$	0	0	68.85
$PbBr_{2(s)}$	–277.4	–260.7	161
$PbCO_{3(s)}$	–699.1	–625.5	131.0
$Pb(NO_3)_{2(aq)}$	–421.3	–246.9	303.3
$Pb(NO_3)_{2(s)}$	–451.9	––	––
$PbO_{(s)}$	–217.3	–187.9	68.70
$Li_{(g)}$	159.3	126.6	138.8
$Li_{(s)}$	0	0	29.09
$Li^+_{(aq)}$	–278.5	–273.4	12.2
$Li^+_{(g)}$	685.7	648.5	133.0
$LiCl_{(s)}$	–408.3	–384.0	59.30
$Mg_{(g)}$	147.1	112.5	148.6
$Mg_{(s)}$	0	0	32.51
$MgCl_{2(s)}$	–641.6	–592.1	89.6
$MgO_{(s)}$	–601.8	–569.6	26.8
$Mg(OH)_{2(s)}$	–924.7	–833.7	63.24
$Mn_{(g)}$	280.7	238.5	173.6
$Mn_{(s)}$	0	0	32.0
$MnO_{(s)}$	–385.2	–362.9	59.7
$MnO_{2(s)}$	–519.6	–464.8	53.14

Substance	ΔH_f°, kJ · mol^{-1}	ΔG_f°, kJ · mol^{-1}	ΔS°, J · mol^{-1} K^{-1}
$MnO_4^-{}_{(aq)}$	–541.4	–447.2	191.2
$Hg_{(g)}$	60.83	31.76	174.89
$Hg_{(l)}$	0	0	77.40
$HgCl_{2(s)}$	–230.1	–184.0	144.5
$Hg_2Cl_{2(s)}$	–264.9	–210.5	192.5
$Ni_{(g)}$	429.7	384.5	182.1
$Ni_{(s)}$	0	0	29.9
$NiCl_{2(s)}$	–305.3	–259.0	97.65
$NiO_{(s)}$	–239.7	–211.7	37.99
$N_{(g)}$	472.7	455.5	153.3
$N_{2(g)}$	0	0	191.50
$NH_{3(aq)}$	–80.29	–26.50	111.3
$NH_{3(g)}$	–46.19	–16.66	192.5
$NH_4^+{}_{(aq)}$	–132.5	–79.31	113.4
$N_2H_{4(g)}$	95.40	159.4	238.5
$NH_4CN_{(s)}$	0.0	––	––
$NH_4Cl_{(s)}$	–314.4	–203.0	94.6
$NH_4NO_{3(s)}$	–365.6	–184.0	151
$NO_{(g)}$	90.37	86.71	210.62
$NO_{2(g)}$	33.84	51.84	240.45
$N_2O_{(g)}$	81.6	103.59	220.0
$N_2O_{4(g)}$	9.66	98.28	304.3
$NOCl_{(g)}$	52.6	66.3	264
$HNO_{3(aq)}$	–206.6	–110.5	146
$HNO_{3(g)}$	–134.3	–73.94	266.4
$O_{(g)}$	247.5	230.1	161.0
$O_{2(g)}$	0	0	205.0
$O_{3(g)}$	142.3	163.4	237.6
$OH^-{}_{(aq)}$	–230.0	–157.3	–10.7
$H_2O_{(g)}$	–241.82	–228.57	188.83
$H_2O_{(l)}$	–285.83	–237.13	69.91
$H_2O_{2(g)}$	–136.10	–105.48	232.9
$H_2O_{2(l)}$	–187.8	–120.4	109.6
$P_{(g)}$	316.4	280.0	163.2
$P_{2(g)}$	144.3	103.7	218.1
$P_{4(g)}$	58.9	24.4	280

Periodic Table of the Elements

1																17	18
1 **H** hydrogen 1.0079	**2**						26 **Fe** iron 55.847	**atomic number** **symbol** **name** **average atomic mass**				**13**	**14**	**15**	**16**	1 **H** hydrogen 1.0079	2 **He** helium 4.003
3 **Li** lithium 6.941	4 **Be** beryllium 9.012											5 **B** boron 10.811	6 **C** carbon 12.011	7 **N** nitrogen 14.0067	8 **O** oxygen 15.9994	9 **F** fluorine 18.998	10 **Ne** neon 20.180
11 **Na** sodium 22.990	12 **Mg** magnesium 24.305	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	13 **Al** aluminum 26.982	14 **Si** silicon 28.086	15 **P** phosphorus 30.974	16 **S** sulfur 32.066	17 **Cl** chlorine 35.453	18 **Ar** argon 39.948
19 **K** potassium 39.098	20 **Ca** calcium 40.078	21 **Sc** scandium 44.956	22 **Ti** titanium 47.88	23 **V** vanadium 50.942	24 **Cr** chromium 51.996	25 **Mn** manganese 54.938	26 **Fe** iron 55.847	27 **Co** cobalt 58.933	28 **Ni** nickel 58.693	29 **Cu** copper 63.546	30 **Zn** zinc 65.39	31 **Ga** gallium 69.723	32 **Ge** germanium 72.61	33 **As** arsenic 74.922	34 **Se** selenium 78.96	35 **Br** bromine 79.904	36 **Kr** krypton 83.80
37 **Rb** rubidium 85.468	38 **Sr** strontium 87.62	39 **Y** yttrium 88.906	40 **Zr** zirconium 91.224	41 **Nb** niobium 92.906	42 **Mo** molybdenum 95.94	43 **Tc** technetium 97.907	44 **Ru** ruthenium 101.07	45 **Rh** rhodium 102.906	46 **Pd** palladium 106.42	47 **Ag** silver 107.868	48 **Cd** cadmium 112.411	49 **In** indium 114.82	50 **Sn** tin 117.710	51 **Sb** antimony 121.757	52 **Te** tellurium 127.60	53 **I** iodine 126.904	54 **Xe** xenon 131.290
55 **Cs** cesium 132.905	56 **Ba** barium 137.327	71 **Lu** lutetium 174.967	72 **Hf** hafnium 178.49	73 **Ta** tantalum 180.948	74 **W** tungsten 183.84	75 **Re** rhenium 186.207	76 **Os** osmium 190.2	77 **Ir** iridium 192.22	78 **Pt** platinum 195.08	79 **Au** gold 196.967	80 **Hg** mercury 200.59	81 **Tl** thallium 204.383	82 **Pb** lead 207.2	83 **Bi** bismuth 208.980	84 **Po** polonium 208.982	85 **At** astatine 209.987	86 **Rn** radon 222.018
87 **Fr** francium 223.020	88 **Ra** radium 226.025	103 **Lr** lawrencium 260.105	104 **Rf** rutherfordium (261)	105 **Db** dubnium (262)	106 **Sg** seaborgium (263)	107 **Bh** bohrium (262)	108 **Hs** hassium (265)	109 **Mt** meitnerium (266)	110 **Uun** unnamed (269)	111 **Uuu** unnamed (272)	112 **Uub** unnamed						

57 **La** lanthanum 138.906	58 **Ce** cerium 140.115	59 **Pr** praseodymium 140.908	60 **Nd** neodymium 144.24	61 **Pm** promethium 144.903	62 **Sm** samarium 150.36	63 **Eu** europium 151.965	64 **Gd** gadolinium 157.25	65 **Tb** terbium 158.925	66 **Dy** dysprosium 162.50	67 **Ho** holmium 164.930	68 **Er** erbium 167.26	69 **Tm** thulium 168.934	70 **Yb** ytterbium 173.04
89 **Ac** actinium 227.028	90 **Th** thorium 232.038	91 **Pa** protactinium 231.036	92 **U** uranium 238.029	93 **Np** neptunium 237.048	94 **Pu** plutonium 244.064	95 **Am** americium 243.061	96 **Cm** curium 247.070	97 **Bk** berkelium 247.070	98 **Cf** californium 251.080	99 **Es** einsteinium 252.083	100 **Fm** fermium 257.095	101 **Md** mendelevium 258.099	102 **No** nobelium 259.101