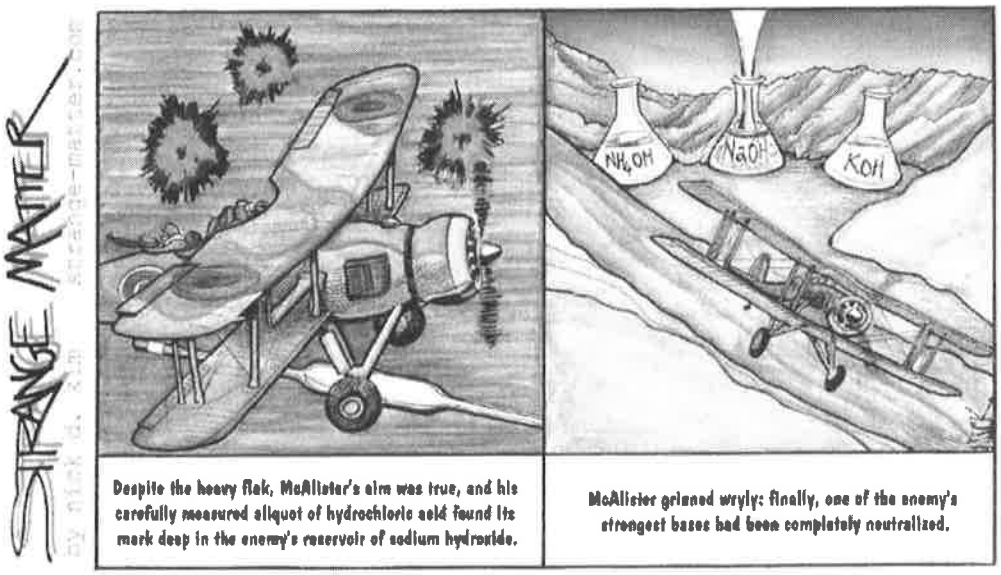
Chemistry 1142
Spring 2013
Exam 4a

Name: KEY

Take a deep breath, and relax! First, answer the questions you know how to do and then work on the more difficult problems. Don't forget to show all your work, so I can give you as much credit as possible.

Good Luck!

Andy



Show all work to receive credit. Be sure to include units, and express answers to the correct number of significant figures / decimal places.

Q1. [12 pts.] Predict whether the following reactions have a positive, negative, or ≈0 value of ΔS.

a) $C_3H_8(g) + 7O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)$ $\Delta S < 0$ (reduction in #mol gas)

b) $C_2H_5OH(g) \rightarrow C_2H_5OH(l)$ $\Delta S < 0$ (")

c) $Fe_2O_3(s) + C(s) \rightarrow 2Fe(s) + \frac{3}{2} CO_2(g)$ $\Delta S > 0$ (increase in #mol gas)

d) $N_2O_4(g) + CO_2(g) \rightarrow N_2O_5(g) + CO(g)$ $\Delta S \approx 0$ (same # gas molecules on each side)

Q2. [12 pts.] Calculate $\Delta G°$ at 15 °C and 105 °C for the reaction:

$2CH_3CH_2OH(l) + 2O_2(g) \rightarrow 2CH_3CO_2H(l) + 2H_2O(l)$

given the following data:

Compound	$\Delta H°_f$ / kJ·mol^{-1}	$S°$ / J·mol^{-1}·K^{-1}
$CH_3CH_2OH(l)$	–276.98	161.04
$O_2(g)$	0	205.0
$CH_3CO_2H(l)$	–484.2	159.83
$H_2O(l)$	–285.8	69.9

$\Delta G° = \Delta H° - T\Delta S°$

$\Delta H° = \sum n \cdot \Delta H_f°(\text{Prod}) \ominus \sum m \cdot \Delta H_f°(\text{Reac})$

$\Delta S° = \sum n \cdot S°(\text{Prods}) \ominus \sum m \cdot S°(\text{Reac})$

$\Delta H° = [2 \times \Delta H_f°(CH_3CO_2H(l)) + 2 \times \Delta H_f°(H_2O(l))] - [2 \times \Delta H_f°(CH_3CH_2OH(l)) + 2 \times \Delta H_f°(O_2(g))]$

$= [2 \times -484.2\ kJ/mol + 2 \times -285.8\ kJ/mol] \ominus [2 \times -276.98\ kJ/mol + 2 \times 0] = -986.04\ kJ/mol$

$\Delta S° = [2 \times 159.83\ J/mol\cdot K + 2 \times 69.9\ J/mol\cdot K] \ominus [2 \times 161.04\ J/mol\cdot K + 2 \times 205.0\ J/mol\cdot K] = -272.62\ J/mol\cdot K$

$15°C = 288K \Rightarrow \Delta G° = \Delta H° - T\Delta S° = -986.04\ kJ/mol \ominus 288K \times -0.27262\ kJ/mol\cdot K = -907.5\ kJ/mol$

$105°C = 378K \Rightarrow \Delta G° = -986.04\ kJ/mol \ominus 378K \times -0.27262\ kJ/mol\cdot K = -883.0\ kJ/mol$

Q3. [8 pts.] Calculate ΔG° for the process:
$Ag^+(aq) + NH_3(aq) \rightleftharpoons Ag(NH_3)_2^+(aq)$, if $K = 1.5 \times 10^7$ at 25 °C.

$\Delta G^\circ = -RT\ln K = -8.3145\ J/mol\cdot K \times 298K \times \ln(1.5\times10^7)$

$= -40.9\ kJ/mol$

Q4. [12 pts.] Using the standard electrode potentials given on the back page of this exam, calculate E°_{cell} for the following cells:

a) $Zn(s)\,|\,Zn^{2+}(aq)\ ||\ Cu^{2+}(aq)\,|\,Cu(s)$

$E^\circ_{cell} = E^\circ_{RHS} - E^\circ_{LHS}$

$= E^\circ_{Cu^{2+}/Cu} - E^\circ_{Zn^{2+}/Zn}$

$= +0.34V \ominus -0.76V = \boxed{+1.10V}$

b) $Cr(s)\,|\,Cr^{3+}(aq)\ ||\ Cd^{2+}(aq)\,|\,Cd(s)$

$E^\circ_{cell} = E^\circ_{Cd^{2+}/Cd} - E^\circ_{Cr^{3+}/Cr}$

$= -0.40V \ominus -0.74V = \boxed{+0.34V}$

c) $Al(s)\,|\,Al^{3+}(aq)\ ||\ Cu^{2+}(aq)\,|\,Cu(s)$

$E^\circ_{cell} = E^\circ_{Cu^{2+}/Cu} - E^\circ_{Al^{3+}/Al}$

$= +0.34V - -1.66V$

$= \boxed{+2.00V}$

"Now, in the second law of thermodynamics..."

Q5. [20 pts.] Balance the following redox reactions using the half-reaction method.

a) $Zn(s) + ClO^-(aq) \rightarrow Zn(OH)_2(s) + Cl^-(aq)$ (BASIC Conditions)

$2H_2O + Zn \xrightarrow{ox} Zn(OH)_2 + 2H^+ + 2e^-$

$2e^- + 2H^+ + ClO^- \xrightarrow{red} Cl^- + H_2O$

$H_2O + Zn + ClO^- \xrightarrow{2e^-} Zn(OH)_2 + Cl^-$

b) $MnO_2(s) + Cl^-(aq) \rightarrow Mn^{2+}(aq) + Cl_2(g)$ (ACIDIC Conditions)

$2Cl^- \xrightarrow{ox} Cl_2 + 2e^-$

$2e^- + 4H^+ + MnO_2 \xrightarrow{red} Mn^{2+} + 2H_2O$

$4H^+ + MnO_2 + 2Cl^- \longrightarrow Cl_2 + Mn^{2+} + 2H_2O$

Q6. [16 pts.] Calculate E_{cell} for the following cell:

$$\text{Al(s)} \,|\, \text{Al}^{3+}\text{(aq, 0.010 M)} \;||\; \text{Zn}^{2+}\text{(aq, 2.50 M)} \,|\, \text{Zn(s)}$$

$E^\circ_{cell} = E^\circ_{Zn^{2+}/Zn} - E^\circ_{Al^{3+}/Al}$
$= -0.76\text{V} \ominus -1.66\text{V} = +0.90\text{V}$

Be sure to write out the overall balanced equation for the cell reaction as part of your answer. The cell operates at a temperature of 298 K.

$(Al \rightarrow Al^{3+} + 3e^-) \times 2$

$(2e^- + Zn^{2+} \rightarrow Zn) \times 3$

$$2Al(s) + 3Zn^{2+}(aq) \xrightarrow{6e^-} 2Al^{3+}(aq) + 3Zn(s)$$

$Q = \dfrac{[Al^{3+}]^2}{[Zn^{2+}]^3_i}$ Nernst: $E_{cell} = E^\circ_{cell} - \dfrac{RT}{nF} \ln Q$

$$\Rightarrow E_{cell} = +0.90\text{V} - \frac{8.3145\,\text{J/mol·K} \times 298\text{K}}{6 \times 96{,}500\,\text{C/mol}} \times \ln\left(\frac{0.010^2}{2.50^3}\right)$$

$$= \boxed{+0.95\text{V}}$$

Q7. [10 pts.] A particular chemical reaction is non-spontaneous at low temperatures, but becomes spontaneous at high temperatures. What can you say about the signs (+ve or –ve) of ΔS and ΔH? Be sure to explain your answer.

ΔG = +ve (low T)
ΔG = –ve (high T)
$\rightarrow \Delta G = \Delta H - T\Delta S$

low T ... $\Delta G \approx \Delta H$

$\Rightarrow \boxed{\Delta H = +\text{ve}}$

high T ... $\Delta G \approx -T\Delta S$

$\Rightarrow -T\Delta S = -\text{ve}$

$\Rightarrow \boxed{\Delta S \approx +\text{ve}}$

$2AlBr_3(l) \longrightarrow 2Al(l) + 3Br_2(l)$

$35A = 35\ C/s$

Q8. [10 pts.] Molten aluminum bromide is electrolyzed for 24 hours using an electric current of 35 A. Predict the mass of aluminum formed in the electrolytic cell.

$3e^- + Al^{3+} \longrightarrow Al$

$$\Rightarrow \frac{35C}{1s} \left| \frac{24h}{} \right| \frac{3600s}{1h} \left| \frac{1\ mole^-}{96{,}500C} \right| \frac{1\ mol\ Al}{3\ mol\ e^-} \left| \frac{26.98g}{1\ mol\ Al} \right. = 282g\ Al$$

$= 280g\ Al$

BONUS Question

[5 pts.] CH_3OH has a boiling point of 65 °C. Predict the sign of $\Delta G°$, $\Delta H°$, and $\Delta S°$ for the process: $CH_3OH(g) \longrightarrow CH_3OH(l)$ at a temperature of 63 °C. Explain your answer.

(g) → (l) = Condensation.

below bp, condensation is spont ⇒ $\Delta G° = -ve$.

$\Delta H° = -ve$ (absorb heat when vap, release heat when condens)

- or... we form IMFs ⇒ give off energy (heat)

$\Delta S° = -ve$ (liquids are more 'ordered' than gases)

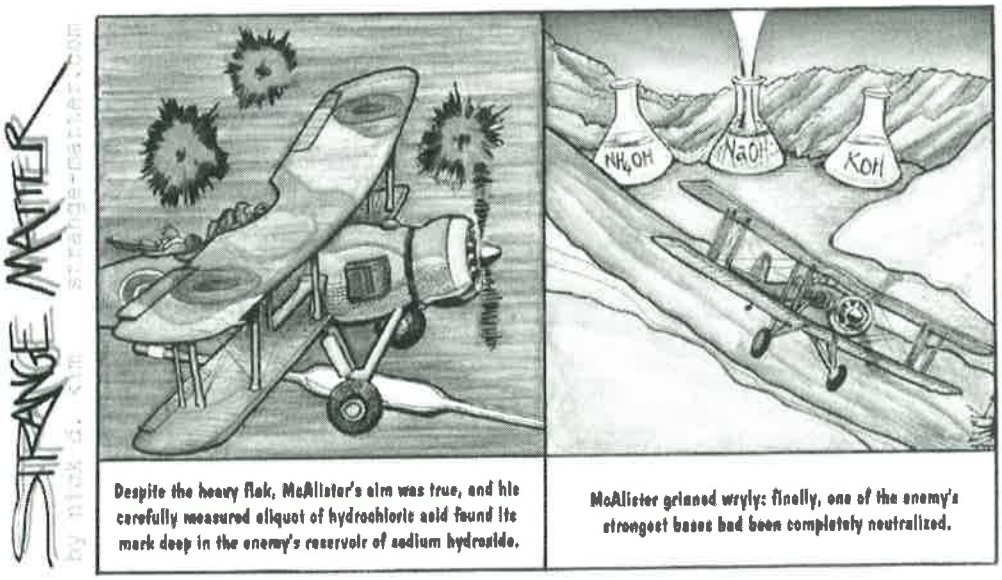
Chemistry 1142
Spring 2013
Exam 4b

Name: KEY

Take a deep breath, and relax! First, answer the questions you know how to do and then work on the more difficult problems. Don't forget to show all your work, so I can give you as much credit as possible.

Good Luck!

Andy



Show all work to receive credit. Be sure to include units, and express answers to the correct number of significant figures / decimal places.

Q1. [20 pts.] Balance the following redox reactions using the half-reaction method.

a) $Zn(s) + ClO^-(aq) \rightarrow Zn(OH)_2(s) + Cl^-(aq)$ (BASIC Conditions)

See Exam A

b) $MnO_2(s) + Cl^-(aq) \rightarrow Mn^{2+}(aq) + Cl_2(g)$ (ACIDIC Conditions)

See Exam A

Q2. [12 pts.] Calculate $\Delta G°$ at 15 °C and 105 °C for the reaction:

$$2CH_3CH_2OH(l) + 2O_2(g) \rightarrow 2CH_3CO_2H(l) + 2H_2O(l)$$

given the following data:

Compound	$\Delta H°_f$ / kJ·mol^{-1}	$S°$ / J·mol^{-1}·K^{-1}
$CH_3CH_2OH(l)$	–276.98	161.04
$O_2(g)$	0	205.0
$CH_3CO_2H(l)$	–484.2	159.83
$H_2O(l)$	–285.8	69.9

See exam A

Q3. [8 pts.] Calculate $\Delta G°$ for the process:

$Ag^+(aq) + NH_3(aq) \rightleftharpoons Ag(NH_3)_2^+(aq)$, if $K = 1.5 \times 10^7$ at 25 °C.

See exam A

Q4. [12 pts.] Using the standard electrode potentials given on the back page of this exam, calculate E°_{cell} for the following cells:

a) $Zn(s)\,|\,Zn^{2+}(aq)\;||\;Cu^{2+}(aq)\,|\,Cu(s)$

b) $Cr(s)\,|\,Cr^{3+}(aq)\;||\;Cd^{2+}(aq)\,|\,Cd(s)$

c) $Al(s)\,|\,Al^{3+}(aq)\;||\;Cu^{2+}(aq)\,|\,Cu(s)$

See exam A

Q5. [12 pts.] Predict whether the following reactions have a positive, negative, or ≈0 value of ΔS.

a) $C_3H_8(g) + 7O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)$

See exam A

b) $C_2H_5OH(g) \rightarrow C_2H_5OH(l)$

c) $Fe_2O_3(s) + C(s) \rightarrow 2Fe(s) + \frac{3}{2}\,CO_2(g)$

d) $N_2O_4(g) + CO_2(g) \rightarrow N_2O_5(g) + CO(g)$

"Now, in the second law of thermodynamics..."

Q6. [16 pts.] Calculate E_{cell} for the following cell:

$Al(s) \,|\, Al^{3+}(aq, 0.010\ M) \,||\, Zn^{2+}(aq, 3.50\ M) \,|\, Zn(s)$

Be sure to write out the overall balanced equation for the cell reaction as part of your answer. The cell operates at a temperature of 298 K.

See exam A.

$$Q = \frac{[Al^{3+}]^2}{[Zn^{2+}]^3}$$

$E_{cell} = \boxed{0.96V}$

Q7. [10 pts.] A particular chemical reaction is spontaneous at low temperatures, but becomes non-spontaneous at high temperatures. What can you say about the signs (+ve or –ve) of ΔS and ΔH? Be sure to explain your answer.

ΔG = -ve (low T)
= +ve (high T)

$\Delta G = \Delta H - T\Delta S$

@ low T, $\Delta G \approx \Delta H$

$\Rightarrow \boxed{\Delta H = -ve}$

@ high T, $\Delta G \approx -T\Delta S$

$\Rightarrow \boxed{\Delta S = -ve}$

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

Q8. [10 pts.] Molten aluminum oxide is electrolyzed for 24 hours using an electric current of 35 A. Predict the mass of aluminum formed in the electrolytic cell.

$35\ A = 35\ C/s$

$Al^{3+} + 3e^- \longrightarrow Al$.

$$\frac{35\ C}{s} \left| \frac{24\ h}{} \right| \frac{3600\ s}{1\ h} \left| \frac{1\ mole^-}{96{,}500\ C} \right| \frac{1\ mol\ Al}{3\ mol\ e^-} \left| \frac{26.98\ g\ Al}{1\ mol\ Al} \right. = 280\ g\ Al$$

BONUS Question

[5 pts.] CH_3OH has a boiling point of 65 °C. Predict the sign of $\Delta G°$, $\Delta H°$, and $\Delta S°$ for the process: $CH_3OH(g) \longrightarrow CH_3OH(l)$ at a temperature of 63 °C. Explain your answer.

See exam A

le 19.1 Standard Reduction Potentials at 25°C*

Half-Reaction	$E°$(V)
$F_2(g) + 2e^- \longrightarrow 2F^-(aq)$	+2.87
$O_3(g) + 2H^+(aq) + 2e^- \longrightarrow O_2(g) + H_2O$	+2.07
$Co^{3+}(aq) + e^- \longrightarrow Co^{2+}(aq)$	+1.82
$H_2O_2(aq) + 2H^+(aq) + 2e^- \longrightarrow 2H_2O$	+1.77
$PbO_2(s) + 4H^+(aq) + SO_4^{2-}(aq) + 2e^- \longrightarrow PbSO_4(s) + 2H_2O$	+1.70
$Ce^{4+}(aq) + e^- \longrightarrow Ce^{3+}(aq)$	+1.61
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \longrightarrow Mn^{2+}(aq) + 4H_2O$	+1.51
$Au^{3+}(aq) + 3e^- \longrightarrow Au(s)$	+1.50
$Cl_2(g) + 2e^- \longrightarrow 2Cl^-(aq)$	+1.36
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \longrightarrow 2Cr^{3+}(aq) + 7H_2O$	+1.33
$MnO_2(s) + 4H^+(aq) + 2e^- \longrightarrow Mn^{2+}(aq) + 2H_2O$	+1.23
$O_2(g) + 4H^+(aq) + 4e^- \longrightarrow 2H_2O$	+1.23
$Br_2(l) + 2e^- \longrightarrow 2Br^-(aq)$	+1.07
$NO_3^-(aq) + 4H^+(aq) + 3e^- \longrightarrow NO(g) + 2H_2O$	+0.96
$2Hg^{2+}(aq) + 2e^- \longrightarrow Hg_2^{2+}(aq)$	+0.92
$Hg_2^{2+}(aq) + 2e^- \longrightarrow 2Hg(l)$	+0.85
$Ag^+(aq) + e^- \longrightarrow Ag(s)$	+0.80
$Fe^{3+}(aq) + e^- \longrightarrow Fe^{2+}(aq)$	+0.77
$O_2(g) + 2H^+(aq) + 2e^- \longrightarrow H_2O_2(aq)$	+0.68
$MnO_4^-(aq) + 2H_2O + 3e^- \longrightarrow MnO_2(s) + 4OH^-(aq)$	+0.59
$I_2(s) + 2e^- \longrightarrow 2I^-(aq)$	+0.53
$O_2(g) + 2H_2O + 4e^- \longrightarrow 4OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$	+0.34
$AgCl(s) + e^- \longrightarrow Ag(s) + Cl^-(aq)$	+0.22
$SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \longrightarrow SO_2(g) + 2H_2O$	+0.20
$Cu^{2+}(aq) + e^- \longrightarrow Cu^+(aq)$	+0.15
$Sn^{4+}(aq) + 2e^- \longrightarrow Sn^{2+}(aq)$	+0.13
$2H^+(aq) + 2e^- \longrightarrow H_2(g)$	0.00
$Pb^{2+}(aq) + 2e^- \longrightarrow Pb(s)$	−0.13
$Sn^{2+}(aq) + 2e^- \longrightarrow Sn(s)$	−0.14
$Ni^{2+}(aq) + 2e^- \longrightarrow Ni(s)$	−0.25
$Co^{2+}(aq) + 2e^- \longrightarrow Co(s)$	−0.28
$PbSO_4(s) + 2e^- \longrightarrow Pb(s) + SO_4^{2-}(aq)$	−0.31
$Cd^{2+}(aq) + 2e^- \longrightarrow Cd(s)$	−0.40
$Fe^{2+}(aq) + 2e^- \longrightarrow Fe(s)$	−0.44
$Cr^{3+}(aq) + 3e^- \longrightarrow Cr(s)$	−0.74
$Zn^{2+}(aq) + 2e^- \longrightarrow Zn(s)$	−0.76
$2H_2O + 2e^- \longrightarrow H_2(g) + 2OH^-(aq)$	−0.83
$Mn^{2+}(aq) + 2e^- \longrightarrow Mn(s)$	−1.18
$Al^{3+}(aq) + 3e^- \longrightarrow Al(s)$	−1.66
$Be^{2+}(aq) + 2e^- \longrightarrow Be(s)$	−1.85
$Mg^{2+}(aq) + 2e^- \longrightarrow Mg(s)$	−2.37
$Na^+(aq) + e^- \longrightarrow Na(s)$	−2.71
$Ca^{2+}(aq) + 2e^- \longrightarrow Ca(s)$	−2.87
$Sr^{2+}(aq) + 2e^- \longrightarrow Sr(s)$	−2.89
$Ba^{2+}(aq) + 2e^- \longrightarrow Ba(s)$	−2.90
$K^+(aq) + e^- \longrightarrow K(s)$	−2.93
$Li^+(aq) + e^- \longrightarrow Li(s)$	−3.05

Useful Information

$N_A = 6.022 \times 10^{23}\ mol^{-1}$

Given: $ax^2 + bx + c$, then $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

$K_w = [H_3O^+][OH^-] = 1.0 \times 10^{-14}$ at 25 °C.

$pH = -\log[H_3O^+]$ $\qquad$ $pH + pOH = 14.00$ (at 25 °C)

$K_aK_b = K_w$ $\qquad$ $R = 8.3145\ J/mol \cdot K = 0.08206\ L \cdot atm/mol \cdot K$

$$pH = pK_a + \log\frac{[Base]}{[Acid]} \qquad M_1V_1 = M_2V_2$$

$\Delta G = -nFE_{cell}$ $\qquad$ $\Delta G^\circ = -nFE^\circ_{cell}$ $\qquad$ $E^o_{cell} = \dfrac{RT}{nF}\ln K$

$E_{cell} = E^\circ_{cell} - \dfrac{RT}{nF}\ln Q$ $\qquad$ $E^\circ_{cell} = E^\circ_{cathode} - E^\circ_{anode}$ $\qquad$ $F = 96{,}500\ C/mol\ e^-$

$R = 8.3145\ J \cdot mol^{-1} \cdot K^{-1}$ $\qquad$ Q (charge) $= I \cdot t$ $\qquad$ $\Delta G = \Delta H - T\Delta S$

$\Delta S = q/T$ $\qquad$ $\Delta G = \Delta G^\circ + RT\ln Q$ $\qquad$ $\Delta G^\circ = -RT\ln K$

Periodic Table of the Elements

IA	IIA											IIIA	IVA	VA	VIA	VIIA	VIIIA
1																	2
1 H 1.01	2											13	14	15	16	17	He 4.00
3 Li 6.94	4 Be 9.01											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31	3	4	5	6	7	8	9	10	11	12	13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.61	33 As 74.92160	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc [98]	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
55 Cs 132.91	56 Ba* 137.33	71 Lu 174.97	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.20	83 Bi 208.98	84 Po [210]	85 At [210]	86 Rn [222]
87 Fr [223]	88 Ra** [226]	103 Lr [262]	104 Rf [261]	105 Db [262]	106 Sg [266]	107 Bh [264]	108 Hs [265]	109 Mt [268]	110 [269]	111 [272]	112 [277]	113	114 [285]	115	116 [289]	117	118 [293]

*	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm [145]	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04
**	89 Ac [227]	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np [237]	94 Pu [244]	95 Am [243]	96 Cm [247]	97 Bk [247]	98 Cf [251]	99 Es [252]	100 Fm [257]	101 Md [258]	102 No [259]

le 19.1 Standard Reduction Potentials at 25°C*

Half-Reaction	$E°$(V)
$F_2(g) + 2e^- \longrightarrow 2F^-(aq)$	+2.87
$O_3(g) + 2H^+(aq) + 2e^- \longrightarrow O_2(g) + H_2O$	+2.07
$Co^{3+}(aq) + e^- \longrightarrow Co^{2+}(aq)$	+1.82
$H_2O_2(aq) + 2H^+(aq) + 2e^- \longrightarrow 2H_2O$	+1.77
$PbO_2(s) + 4H^+(aq) + SO_4^{2-}(aq) + 2e^- \longrightarrow PbSO_4(s) + 2H_2O$	+1.70
$Ce^{4+}(aq) + e^- \longrightarrow Ce^{3+}(aq)$	+1.61
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \longrightarrow Mn^{2+}(aq) + 4H_2O$	+1.51
$Au^{3+}(aq) + 3e^- \longrightarrow Au(s)$	+1.50
$Cl_2(g) + 2e^- \longrightarrow 2Cl^-(aq)$	+1.36
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \longrightarrow 2Cr^{3+}(aq) + 7H_2O$	+1.33
$MnO_2(s) + 4H^+(aq) + 2e^- \longrightarrow Mn^{2+}(aq) + 2H_2O$	+1.23
$O_2(g) + 4H^+(aq) + 4e^- \longrightarrow 2H_2O$	+1.23
$Br_2(l) + 2e^- \longrightarrow 2Br^-(aq)$	+1.07
$NO_3^-(aq) + 4H^+(aq) + 3e^- \longrightarrow NO(g) + 2H_2O$	+0.96
$2Hg^{2+}(aq) + 2e^- \longrightarrow Hg_2^{2+}(aq)$	+0.92
$Hg_2^{2+}(aq) + 2e^- \longrightarrow 2Hg(l)$	+0.85
$Ag^+(aq) + e^- \longrightarrow Ag(s)$	+0.80
$Fe^{3+}(aq) + e^- \longrightarrow Fe^{2+}(aq)$	+0.77
$O_2(g) + 2H^+(aq) + 2e^- \longrightarrow H_2O_2(aq)$	+0.68
$MnO_4^-(aq) + 2H_2O + 3e^- \longrightarrow MnO_2(s) + 4OH^-(aq)$	+0.59
$I_2(s) + 2e^- \longrightarrow 2I^-(aq)$	+0.53
$O_2(g) + 2H_2O + 4e^- \longrightarrow 4OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$	+0.34
$AgCl(s) + e^- \longrightarrow Ag(s) + Cl^-(aq)$	+0.22
$SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \longrightarrow SO_2(g) + 2H_2O$	+0.20
$Cu^{2+}(aq) + e^- \longrightarrow Cu^+(aq)$	+0.15
$Sn^{4+}(aq) + 2e^- \longrightarrow Sn^{2+}(aq)$	+0.13
$2H^+(aq) + 2e^- \longrightarrow H_2(g)$	0.00
$Pb^{2+}(aq) + 2e^- \longrightarrow Pb(s)$	−0.13
$Sn^{2+}(aq) + 2e^- \longrightarrow Sn(s)$	−0.14
$Ni^{2+}(aq) + 2e^- \longrightarrow Ni(s)$	−0.25
$Co^{2+}(aq) + 2e^- \longrightarrow Co(s)$	−0.28
$PbSO_4(s) + 2e^- \longrightarrow Pb(s) + SO_4^{2-}(aq)$	−0.31
$Cd^{2+}(aq) + 2e^- \longrightarrow Cd(s)$	−0.40
$Fe^{2+}(aq) + 2e^- \longrightarrow Fe(s)$	−0.44
$Cr^{3+}(aq) + 3e^- \longrightarrow Cr(s)$	−0.74
$Zn^{2+}(aq) + 2e^- \longrightarrow Zn(s)$	−0.76
$2H_2O + 2e^- \longrightarrow H_2(g) + 2OH^-(aq)$	−0.83
$Mn^{2+}(aq) + 2e^- \longrightarrow Mn(s)$	−1.18
$Al^{3+}(aq) + 3e^- \longrightarrow Al(s)$	−1.66
$Be^{2+}(aq) + 2e^- \longrightarrow Be(s)$	−1.85
$Mg^{2+}(aq) + 2e^- \longrightarrow Mg(s)$	−2.37
$Na^+(aq) + e^- \longrightarrow Na(s)$	−2.71
$Ca^{2+}(aq) + 2e^- \longrightarrow Ca(s)$	−2.87
$Sr^{2+}(aq) + 2e^- \longrightarrow Sr(s)$	−2.89
$Ba^{2+}(aq) + 2e^- \longrightarrow Ba(s)$	−2.90
$K^+(aq) + e^- \longrightarrow K(s)$	−2.93
$Li^+(aq) + e^- \longrightarrow Li(s)$	−3.05

Useful Information

$N_A = 6.022 \times 10^{23}\ \text{mol}^{-1}$

Given: $ax^2 + bx + c$, then $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

$K_w = [H_3O^+][OH^-] = 1.0 \times 10^{-14}$ at 25 °C.

$pH = -\log[H_3O^+]$

$pH + pOH = 14.00$ (at 25 °C)

$K_aK_b = K_w$

$R = 8.3145\ \text{J/mol·K} = 0.08206\ \text{L·atm/mol·K}$

$$pH = pK_a + \log\frac{[\text{Base}]}{[\text{Acid}]}$$

$M_1V_1 = M_2V_2$

$\Delta G = -nFE_{cell}$ $\quad \Delta G° = -nFE°_{cell}$ $\quad E^o_{cell} = \dfrac{RT}{nF}\ln K$

$E_{cell} = E^\circ_{cell} - \dfrac{RT}{nF}\ln Q$ $\quad E°_{cell} = E°_{cathode} - E°_{anode}$ $\quad F = 96{,}500\ \text{C/mol e}^-$

$R = 8.3145\ \text{J·mol}^{-1}\text{·K}^{-1}$ $\quad Q\ (\text{charge}) = I \cdot t$ $\quad \Delta G = \Delta H - T\Delta S$

$\Delta S = q/T$ $\quad \Delta G = \Delta G° + RT\ln Q$ $\quad \Delta G° = -RT\ln K$

Periodic Table of the Elements

IA	IIA											IIIA	IVA	VA	VIA	VIIA	VIIIA
1																	2
H																	He
1.01	2											13	14	15	16	17	4.00
3	4											5	6	7	8	9	10
Li	Be											B	C	N	O	F	Ne
6.94	9.01											10.81	12.01	14.01	16.00	19.00	20.18
11	12											13	14	15	16	17	18
Na	Mg	3	4	5	6	7	8	9	10	11	12	Al	Si	P	S	Cl	Ar
22.99	24.31											26.98	28.09	30.97	32.07	35.45	39.95
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
39.10	40.08	44.96	47.87	50.94	52.00	54.94	55.85	58.93	58.69	63.55	65.39	69.72	72.61	74.92160	78.96	79.90	83.80
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
85.47	87.62	88.91	91.22	92.91	95.94	[98]	101.07	102.91	106.42	107.87	112.41	114.82	118.71	121.76	127.60	126.90	131.29
55	56	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cs	Ba*	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
132.91	137.33	174.97	178.49	180.95	183.84	186.21	190.23	192.22	195.08	196.97	200.59	204.38	207.20	208.98	[210]	[210]	[222]
87	88	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
Fr	Ra**	Lr	Rf	Db	Sg	Bh	Hs	Mt									
[223]	[226]	[262]	[261]	[262]	[266]	[264]	[265]	[268]	[269]	[272]	[277]		[285]		[289]		[293]

*	57	58	59	60	61	62	63	64	65	66	67	68	69	70
	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
	138.91	140.12	140.91	144.24	[145]	150.36	151.96	157.25	158.93	162.50	164.93	167.26	168.93	173.04
**	89	90	91	92	93	94	95	96	97	98	99	100	101	102
	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No
	[227]	232.04	231.04	238.03	[237]	[244]	[243]	[247]	[247]	[251]	[252]	[257]	[258]	[259]