Electrochemistry and the Nernst Equation Problem

1. The measured electromotive force (EMF) for the cell

$$Pt(s)|H_2(g, p = 1\ atm)|H^+(aq, a = 1)||Cu^{2+}(aq, a = 1)|Cu(s)$$

is +0.337 V. Write down the cell reaction and calculate the value of $\Delta G°$ for this reaction.

2. For the following hypothetical cell,

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

at 298 K:

(i) State the cell reaction.

(ii) Give the Nernst equation for the cell.

(iii) Calculate the cell EMF when

(a) $a_{Al^{3+}} = a_{Cu^{2+}} = a_{Cu^+} = 1.0$

(b) $a_{Al^{3+}} = a_{Cu^{2+}} = a_{Cu^+} = 0.1$

The standard electrode potentials are:

$E°_{Cu^+|Cu^{2+}} = +0.15$ V

$E°_{Al|Al^{3+}} = -1.61$ V

3. At 298 K, the EMF of the cell shown below is +0.84 V.

$$Pt(s)|Fe^{2+}(aq, a = 1), Fe^{3+}(aq, a = 1)|| Ce^{4+}(aq, a = 1), Ce^{3+}(aq, a = 1)|Pt(s)$$

(i) Define what is meant by the standard EMF of the cell.

(ii) Write down the cell reaction and the Nernst equation for the cell.

(iii) Calculate the equilibrium constant for the cell reaction at 298 K.

4. From the following standard electrode potential data, calculate the solubility product (K_{sp}) of AgI at 298 K.

$AgI(s) + e^- \rightleftharpoons Ag(s) + I^-(aq)$ $E° = -0.152$ V

$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$ $E° = +0.800$ V

5. For the electrochemical cell

$$Pt(s)|H_2(g, p = 1\ atm)|HCl(aq, a = 1)|AgCl(s)$$

The EMF at temperatures near 298 K obeys the following equation:

$E°/V = -0.00558 + 2.6967 \times 10^{-3}T - 8.2299 \times 10^{-6}T^2 + 5.869 \times 10^{-9}T^3$

Where T is the absolute temperature measured in K. Calculate $\Delta G°$, $\Delta H°$ and $\Delta S°$ for the reaction at 298 K

6. Consider the cell

$$Pt(s)|H_2(g)|HCl(aq)|AgCl(s)|Ag(s)$$

for which $E° = +0.2225$ V at 298 K. If the concentration of HCl is such that the measured cell potential is +0.385 V when the pressure of H_2 gas is one atmosphere, what is the pH of the solution?

7. For the reduction of ClO_4^- to ClO_3^- the standard electrode potential under alkaline conditions is +0.37 V, while under acidic conditions it is +1.20 V.
Write a balanced half-cell reaction for each reduction and deduce the value for the ionic product of water, K_w.

8. In a fuel cell, hydrazine, N_2H_4, is oxidized to nitrogen, and oxygen is reduced to water. The standard electrode potentials for the reduction of N_2 to N_2H_4 and of O_2 to H_2O at 298 K are –1.155 V and +0.401 V, respectively, both under alkaline conditions.

(i) Write a balanced equation for both of the half cell reactions under alkaline conditions. For the cell reaction where the hydrazine electrode is on the left, calculate the standard EMF of the cell at 298 K.

(ii) In a practical cell the concentrations of N_2H_4 and OH^- are 0.5 M and 1.0 M, respectively, and the pressure of O_2 and N_2 are 0.2 bar and 0.8 bar, respectively. Use the Nernst equation to estimate the cell EMF at 298 K, assuming all activity coefficients are unity.

9. Calculate the standard electrode potential for the aqueous couple

$$[Fe(ox)_3]^{3-}(aq)/[Fe(ox)_3]^{4-}(aq)$$

from the following data (298 K), where ox^{2-} refers to the oxalate anion, $C_2O_4^{2-}$:

$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$ $\quad E° = +0.770$ V

$Fe^{2+}(aq) + 3\ ox^{2-} \rightleftharpoons [Fe(ox)_3]^{4-}(aq)$ $\quad K = 1.7 \times 10^5$

$Fe^{3+}(aq) + 3\ ox^{2-} \rightleftharpoons [Fe(ox)_3]^{3-}(aq)$ $\quad K = 2.0 \times 10^{20}$

Table 1 Standard Reduction Potentials

(Harvey, D. 2000. *Modern Analytical Chemistry*, USA : McGraw-Hill.)

Standard Reduction Potentials[a]

Aluminum	E° (V)	$E^{\circ\prime}$ (V)
$Al^{3+} + 3e^- \rightleftharpoons Al(s)$	−1.676	
$Al(OH)_4^- + 3e^- \rightleftharpoons Al(s) + 4OH^-$	−2.310	
$AlF_6^{3-} + 3e^- \rightleftharpoons Al(s) + 6F^-$	−2.07	

Antimony	E° (V)	$E^{\circ\prime}$ (V)
$Sb(s) + 3H^+ + 3e^- \rightleftharpoons SbH_3(g)$	−0.510	
$Sb_2O_5(s) + 6H^+ + 4e^- \rightleftharpoons 2SbO^+ + 3H_2O$	0.605	
$SbO^+ + 2H^+ + 3e^- \rightleftharpoons Sb(s) + H_2O$	0.212	

Arsenic	E° (V)	$E^{\circ\prime}$ (V)
$As(s) + 3H^+ + 3e^- \rightleftharpoons AsH_3(g)$	−0.225	
$H_3AsO_4 + 2H^+ + 2e^- \rightleftharpoons HAsO_2 + 2H_2O$	0.560	
$HAsO_2 + 3H^+ + 3e^- \rightleftharpoons As(s) + 2H_2O$	0.240	

Barium	E° (V)	$E^{\circ\prime}$ (V)
$Ba^{2+} + 2e^- \rightleftharpoons Ba(s)$	−2.92	
$BaO(s) + 2H^+ + 2e^- \rightleftharpoons Ba(s) + H_2O$	2.365	

Beryllium	E° (V)	$E^{\circ\prime}$ (V)
$Be^{2+} + 2e^- \rightleftharpoons Be(s)$	−1.99	

Bismuth	E° (V)	$E^{\circ\prime}$ (V)
$Bi^{3+} + 3e^- \rightleftharpoons Bi(s)$	0.317	
$BiCl_4^- + 3e^- \rightleftharpoons Bi(s) + 4Cl^-$	0.199	

Boron	E° (V)	$E^{\circ\prime}$ (V)
$B(OH)_3 + 3H^+ + 3e^- \rightleftharpoons B(s) + 3H_2O$	−0.890	
$B(OH)_4^- + 3e^- \rightleftharpoons B(s) + 4OH^-$	−1.811	

Bromine	E° (V)	$E^{\circ\prime}$ (V)
$Br_2 + 2e^- \rightleftharpoons 2Br^-$	1.087	
$HOBr + H^+ + 2e^- \rightleftharpoons Br^- + H_2O$	1.341	
$HOBr + H^+ + e^- \rightleftharpoons \frac{1}{2}Br_2(\ell) + H_2O$	1.604	
$BrO^- + H_2O + 2e^- \rightleftharpoons Br^- + 2OH^-$		0.76 1 M NaOH
$BrO_3^- + 6H^+ + 5e^- \rightleftharpoons \frac{1}{2}Br_2(\ell) + 3H_2O$	1.5	
$BrO_3^- + 6H^+ + 6e^- \rightleftharpoons Br^- + 3H_2O$	1.478	

Cadmium	E° (V)	$E^{\circ\prime}$ (V)
$Cd^{2+} + 2e^- \rightleftharpoons Cd(s)$	−0.4030	
$Cd(CN)_4^{2-} + 2e^- \rightleftharpoons Cd(s) + 4CN^-$	−0.943	
$Cd(NH_3)_4^{2+} + 2e^- \rightleftharpoons Cd(s) + 4NH_3$	−0.622	

Calcium	E° (V)	$E^{\circ\prime}$ (V)
$Ca^{2+} + 2e^- \rightleftharpoons Ca(s)$	−2.84	

Carbon	E° (V)	$E^{\circ\prime}$ (V)
$CO_2(g) + 2H^+ + 2e^- \rightleftharpoons CO(g) + H_2O$	−0.106	
$CO_2(g) + 2H^+ + 2e^- \rightleftharpoons HCO_2H$	−0.20	
$2CO_2(g) + 2H^+ + 2e^- \rightleftharpoons H_2C_2O_4$	−0.481	
$HCHO + 2H^+ + 2e^- \rightleftharpoons CH_3OH$	0.2323	

Cerium	E° (V)	$E^{\circ\prime}$ (V)
$Ce^{3+} + 3e^- \rightleftharpoons Ce(s)$	−2.336	
$Ce^{4+} + e^- \rightleftharpoons Ce^{3+}$	1.72	1.70 1 M $HClO_4$
		1.44 1 M H_2SO_4
		1.61 1 M HNO_3
		1.28 1 M HCl

Chlorine	E° (V)	$E^{\circ\prime}$ (V)
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-$	1.396	
$ClO^- + H_2O + e^- \rightleftharpoons \frac{1}{2}Cl_2(g) + 2OH^-$		0.421 1 M NaOH
$ClO^- + H_2O + 2e^- \rightleftharpoons Cl^- + 2OH^-$		0.890 1 M NaOH
$HClO_2 + 2H^+ + 2e^- \rightleftharpoons HOCl + H_2O$	1.64	
$ClO_3^- + 2H^+ + e^- \rightleftharpoons ClO_2(g) + H_2O$	1.175	
$ClO_3^- + 3H^+ + 2e^- \rightleftharpoons HClO_2 + H_2O$	1.181	
$ClO_4^- + 2H^+ + 2e^- \rightleftharpoons ClO_3^- + H_2O$	1.201	

continued

Table 1 Standard Reduction Potentials – *continued*

(Harvey, D. 2000. *Modern Analytical Chemistry*, USA : McGraw-Hill.)

Standard Reduction Potentials[a]—*continued*

Chromium	E° (V)	$E^{\circ\prime}$ (V)
$Cr^{3+} + e^- \rightleftharpoons Cr^{2+}$	−0.424	
$Cr^{2+} + 2e^- \rightleftharpoons Cr(s)$	−0.90	
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O$	1.36	
$CrO_4^{2-} + 4H_2O + 3e^- \rightleftharpoons Cr(OH)_4^- + 4OH^-$		−0.13 1 M NaOH

Cobalt	E° (V)	$E^{\circ\prime}$ (V)
$Co^{2+} + 2e^- \rightleftharpoons Co(s)$	−0.277	
$Co^{3+} + e^- \rightleftharpoons Co^{2+}$	1.92	
$Co(NH_3)_6^{3+} + e^- \rightleftharpoons Co(NH_3)_6^{2+}$	0.1	
$Co(OH)_3(s) + e^- \rightleftharpoons Co(OH)_2(s) + OH^-$	0.17	
$Co(OH)_2(s) + 2e^- \rightleftharpoons Co(s) + 2OH^-$	−0.746	

Copper	E° (V)	$E^{\circ\prime}$ (V)
$Cu^+ + e^- \rightleftharpoons Cu(s)$	0.520	
$Cu^{2+} + e^- \rightleftharpoons Cu^+$	0.159	
$Cu^{2+} + 2e^- \rightleftharpoons Cu(s)$	0.3419	
$Cu^{2+} + I^- + e^- \rightleftharpoons CuI(s)$	0.86	
$Cu^{2+} + Cl^- + e^- \rightleftharpoons CuCl(s)$	0.559	

Fluorine	E° (V)	$E^{\circ\prime}$ (V)
$F_2(g) + 2H^+ + 2e^- \rightleftharpoons 2HF$	3.053	
$F_2(g) + 2e^- \rightleftharpoons 2F^-$	2.87	

Gallium	E° (V)	$E^{\circ\prime}$ (V)
$Ga^{3+} + 3e^- \rightleftharpoons Ga(s)$	−0.529	

Gold	E° (V)	$E^{\circ\prime}$ (V)
$Au^+ + e^- \rightleftharpoons Au(s)$	1.83	
$Au^{3+} + 2e^- \rightleftharpoons Au^+$	1.36	
$Au^{3+} + 3e^- \rightleftharpoons Au(s)$	1.52	
$AuCl_4^- + 3e^- \rightleftharpoons Au(s) + 4Cl^-$	1.002	

Hydrogen	E° (V)	$E^{\circ\prime}$ (V)
$2H^+ + 2e^- \rightleftharpoons H_2(g)$	0.00000	
$H_2O + e^- \rightleftharpoons \frac{1}{2}H_2(g) + OH^-$	−0.828	

Iodine	E° (V)	$E^{\circ\prime}$ (V)
$I_2(s) + 2e^- \rightleftharpoons 2I^-$	0.5355	
$I_3^- + 2e^- \rightleftharpoons 3I^-$	0.536	
$HIO + H^+ + 2e^- \rightleftharpoons I^- + H_2O$	0.985	
$IO_3^- + 6H^+ + 5e^- \rightleftharpoons \frac{1}{2}I_2(s) + 3H_2O$	1.195	
$IO_3^- + 3H_2O + 6e^- \rightleftharpoons I^- + 6OH^-$	0.257	

Iron	E° (V)	$E^{\circ\prime}$ (V)
$Fe^{2+} + 2e^- \rightleftharpoons Fe(s)$	−0.44	
$Fe^{3+} + 3e^- \rightleftharpoons Fe(s)$	−0.037	
$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	0.771	0.70 1 M HCl
		0.767 1 M $HClO_4$
		0.746 1 M HNO_3
		0.68 1 M H_2SO_4
		0.44 0.3 M H_3PO_4
$Fe(CN)_6^{3-} + e^- \rightleftharpoons Fe(CN)_6^{4-}$	0.356	0.71 1 M HCl
$Fe(phen)_3^{3+} + e^- \rightleftharpoons Fe(phen)_3^{2+}$	1.147	
$Fe(CN)_6^{3-} + e^- \rightleftharpoons Fe(CN)_6^{4-}$	0.356	

Ianthanum	E° (V)	$E^{\circ\prime}$ (V)
$La^{3+} + 3e^- \rightleftharpoons La(s)$	−2.38	

Lead	E° (V)	$E^{\circ\prime}$ (V)
$Pb^{2+} + 2e^- \rightleftharpoons Pb(s)$	−0.126	
$PbO_2(s) + 4H^+ + 2e^- \rightleftharpoons Pb^{2+} + 2H_2O$	1.46	
$PbO_2(s) + SO_4^{2-} + 4H^+ + 2e^- \rightleftharpoons PbSO_4(s) + 2H_2O$	1.690	
$PbSO_4(s) + 2e^- \rightleftharpoons Pb(s) + SO_4^{2-}$	−0.356	

Lithium	E° (V)	$E^{\circ\prime}$ (V)
$Li^+ + e^- \rightleftharpoons Li(s)$	−3.040	

Magnesium	E° (V)	$E^{\circ\prime}$ (V)
$Mg^{2+} + 2e^- \rightleftharpoons Mg(s)$	−2.356	
$Mg(OH)_2(s) + 2e^- \rightleftharpoons Mg(s) + 2OH^-$	−2.687	

Manganese	E° (V)	$E^{\circ\prime}$ (V)
$Mn^{2+} + 2e^- \rightleftharpoons Mn(s)$	−1.17	
$M^{3+} + e^- \rightleftharpoons Mn^{2+}$	1.5	
$MnO_2(s) + 4H^+ + 2e^- \rightleftharpoons Mn^{2+} + 2H_2O$	1.23	
$MnO_4^- + 4H^+ + 3e^- \rightleftharpoons MnO_2(s) + 2H_2O$	1.70	
$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O$	1.51	
$MnO_4^- + 2H_2O + 3e^- \rightleftharpoons MnO_2(s) + 4OH^-$	0.60	

Mercury	E° (V)	$E^{\circ\prime}$ (V)
$Hg^{2+} + 2e^- \rightleftharpoons Hg(\ell)$	0.8535	
$2Hg^{2+} + 2e^- \rightleftharpoons Hg_2^{2+}$	0.911	
$Hg_2^{2+} + 2e^- \rightleftharpoons 2Hg(\ell)$	0.7960	
$Hg_2Cl_2(s) + 2e^- \rightleftharpoons 2Hg(\ell) + 2Cl^-$	0.2682	
$HgO(s) + 2H^+ + 2e^- \rightleftharpoons Hg(\ell) + H_2O$	0.926	
$Hg_2Br_2(s) + 2e^- \rightleftharpoons 2Hg(\ell) + 2Br^-$	0.1392	
$Hg_2I_2(s) + 2e^- \rightleftharpoons 2Hg(\ell) + 2I^-$	−0.0405	

Table 1 Standard Reduction Potentials – *continued*

(Harvey, D. 2000. *Modern Analytical Chemistry*, USA : McGraw-Hill.)

Molybdenum	E° (V)	$E^{\circ\prime}$ (V)
$Mo^{3+} + 3e^- \rightleftharpoons Mo(s)$	–0.2	
$MoO_2(s) + 4H^+ + 4e^- \rightleftharpoons Mo(s) + 2H_2O$	–0.152	
$MoO_4^{2-} + 4H_2O + 6e^- \rightleftharpoons Mo(s) + 8OH^-$	–0.913	

Nickel	E° (V)	$E^{\circ\prime}$ (V)
$Ni^{2+} + 2e^- \rightleftharpoons Ni(s)$	–0.257	
$Ni(OH)_2(s) + 2e^- \rightleftharpoons Ni(s) + 2OH^-$	–0.72	
$Ni(NH_3)_6^{2+} + 2e^- \rightleftharpoons Ni(s) + 6NH_3$	–0.49	

Nitrogen	E° (V)	$E^{\circ\prime}$ (V)
$N_2(g) + 5H^+ + 4e^- \rightleftharpoons N_2H_5^+$	–0.23	
$N_2O(g) + 2H^+ + 2e^- \rightleftharpoons N_2(g) + H_2O$	1.77	
$2NO(g) + 2H^+ + 2e^- \rightleftharpoons N_2O(g) + H_2O$	1.59	
$HNO_2 + H^+ + e^- \rightleftharpoons NO(g) + H_2O$	0.996	
$2HNO_2 + 4H^+ + 4e^- \rightleftharpoons N_2O(g) + 3H_2O$	1.297	
$NO_3^- + 3H^+ + 2e^- \rightleftharpoons HNO_2 + H_2O$	0.94	

Oxygen	E° (V)	$E^{\circ\prime}$ (V)
$O_2(g) + 2H^+ + 2e^- \rightleftharpoons H_2O_2$	0.695	
$O_2(g) + 4H^+ + 4e^- \rightleftharpoons 2H_2O$	1.229	
$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O$	1.763	
$O_2(g) + 2H_2O + 4e^- \rightleftharpoons 4OH^-$	0.401	
$O_3(g) + 2H^+ + 2e^- \rightleftharpoons O_2(g) + H_2O$	2.07	

Phosphorus	E° (V)	$E^{\circ\prime}$ (V)
$P(s, \text{white}) + 3H^+ + 3e^- \rightleftharpoons PH_3(g)$	–0.063	
$H_3PO_3 + 2H^+ + 2e^- \rightleftharpoons H_3PO_2 + H_2O$	–0.499	
$H_3PO_4 + 2H^+ + 2e^- \rightleftharpoons H_3PO_3 + H_2O$	–0.276	

Platinum	E° (V)	$E^{\circ\prime}$ (V)
$Pt^{2+} + 2e^- \rightleftharpoons Pt(s)$	1.188	
$PtCl_4^{2-} + 2e^- \rightleftharpoons Pt(s) + 4Cl^-$	0.758	

Potassium	E° (V)	$E^{\circ\prime}$ (V)
$K^+ + e^- \rightleftharpoons K(s)$	–2.924	

Ruthenium	E° (V)	$E^{\circ\prime}$ (V)
$Ru^{3+} + e^- \rightleftharpoons Ru^{2+}$	0.249	
$RuO_2(s) + 4H^+ + 4e^- \rightleftharpoons Ru(s) + 2H_2O$	0.68	
$Ru(NH_3)_6^{3+} + e^- \rightleftharpoons Ru(NH_3)_6^{2+}$	0.10	
$Ru(CN)_6^{3-} + e^- \rightleftharpoons Ru(CN)_6^{4-}$	0.86	

Selenium	E° (V)	$E^{\circ\prime}$ (V)
$Se(s) + 2e^- \rightleftharpoons Se^{2-}$		–0.670 1 M NaOH
$Se(s) + 2H^+ + 2e^- \rightleftharpoons H_2Se(g)$	–0.115	
$H_2SeO_3 + 4H^+ + 4e^- \rightleftharpoons Se(s) + 3H_2O$	0.74	
$SeO_4^{3-} + 4H^+ + e^- \rightleftharpoons H_2SeO_3 + H_2O$	1.151	

Silicon	E° (V)	$E^{\circ\prime}$ (V)
$SiF_6^{2-} + 4e^- \rightleftharpoons Si(s) + 6F^-$	–1.37	
$SiO_2(s) + 4H^+ + 4e^- \rightleftharpoons Si(s) + 2H_2O$	–0.909	
$SiO_2(s) + 8H^+ + 8e^- \rightleftharpoons SiH_4(g) + 2H_2O$	–0.516	

Silver	E° (V)	$E^{\circ\prime}$ (V)
$Ag^+ + e^- \rightleftharpoons Ag(s)$	0.7996	
$AgBr(s) + e^- \rightleftharpoons Ag(s) + Br^-$	0.071	
$Ag_2C_2O_4(s) + 2e^- \rightleftharpoons 2Ag(s) + C_2O_4^{2-}$	0.47	
$AgCl(s) + e^- \rightleftharpoons Ag(s) + Cl^-$	0.2223	
$AgI(s) + e^- \rightleftharpoons Ag(s) + I^-$	–0.152	
$Ag_2S(s) + 2e^- \rightleftharpoons 2Ag(s) + S^{2-}$	–0.71	
$Ag(NH_3)_2^+ + e^- \rightleftharpoons Ag(s) + 2NH_3$	0.373	

Sodium	E° (V)	$E^{\circ\prime}$ (V)
$Na^+ + e^- \rightleftharpoons Na(s)$	–2.713	

Strontium	E° (V)	$E^{\circ\prime}$ (V)
$Sr^{2+} + 2e^- \rightleftharpoons Sr(s)$	–2.89	

Sulfur	E° (V)	$E^{\circ\prime}$ (V)
$S(s) + 2e^- \rightleftharpoons S^{2-}$	–0.407	
$S(s) + 2H^+ + 2e^- \rightleftharpoons H_2S$	0.144	
$S_2O_6^{2-} + 4H^+ + 2e^- \rightleftharpoons 2H_2SO_3$	0.569	
$S_2O_8^{2-} + 2e^- \rightleftharpoons 2SO_4^{2-}$	1.96	
$S_4O_6^{2-} + 2e^- \rightleftharpoons 2S_2O_3^{2-}$	0.080	
$2SO_3^{2-} + 2H_2O + 2e^- \rightleftharpoons S_2O_4^{2-} + 4OH^-$	–1.13	
$2SO_3^{2-} + 3H_2O + 4e^- \rightleftharpoons S_2O_3^{2-} + 6OH^-$		–0.576 1 M NaOH
$2SO_4^{2-} + 4H^+ + 2e^- \rightleftharpoons S_2O_6^{2-} + 2H_2O$	–0.25	
$SO_4^{2-} + H_2O + 2e^- \rightleftharpoons SO_3^{2-} + 2OH^-$	–0.936	
$SO_4^{2-} + 4H^+ + 2e^- \rightleftharpoons H_2SO_3 + H_2O$	+0.172	

Thallium	E° (V)	$E^{\circ\prime}$ (V)
$Tl^{3+} + 2e^- \rightleftharpoons Tl^+$		1.25 1 M $HClO_4$
		0.77 1 M HCL
$Tl^3 + 3e^- \rightleftharpoons Tl(s)$	0.742	

continued

Table 1 Standard Reduction Potentials – *continued*

(Harvey, D. 2000. *Modern Analytical Chemistry*, USA : McGraw-Hill.)

Standard Reduction Potentials[a]—*continued*

Tin	E° (V)	$E^{\circ\prime}$ (V)	Conditions
$Sn^{2+} + 2e^- \rightleftharpoons Sn(s)$		−0.19	1 M HCl
$Sn^{4+} + 2e^- \rightleftharpoons Sn^{2+}$	0.154	0.139	1 M HCl

Titanium	E° (V)	$E^{\circ\prime}$ (V)
$Ti^{2+} + 2e^- \rightleftharpoons Ti(s)$	−1.63	
$Ti^{3+} + e^- \rightleftharpoons Ti^{2+}$	−0.37	

Tungsten	E° (V)	$E^{\circ\prime}$ (V)
$WO_2(s) + 4H^+ + 4e^- \rightleftharpoons W(s) + 2H_2O$	−0.119	
$WO_3(s) + 6H^+ + 6e^- \rightleftharpoons W(s) + 3H_2O$	−0.090	

Uranium	E° (V)	$E^{\circ\prime}$ (V)
$U^{3+} + 3e^- \rightleftharpoons U(s)$	−1.66	
$U^{4+} + e^- \rightleftharpoons U^{3+}$	−0.52	
$UO_2^+ + 4H^+ + e^- \rightleftharpoons U^{4+} + 2H_2O$	0.27	
$UO_2^{2+} + e^- \rightleftharpoons UO_2^+$	0.16	
$UO_2^{2+} + 4H^+ + 2e^- \rightleftharpoons U^{4+} + 2H_2O$	0.327	

Vanadium	E° (V)	$E^{\circ\prime}$ (V)
$V^{2+} + 2e^- \rightleftharpoons V(s)$	−1.13	
$V^{3+} + e^- \rightleftharpoons V^{2+}$	−0.255	
$VO^{2+} + 2H^+ + e^- \rightleftharpoons V^{3+} + H_2O$	0.337	
$VO_2^+ + 2H^+ + e^- \rightleftharpoons VO^{2+} + H_2O$	1.000	

Zinc	E° (V)	$E^{\circ\prime}$ (V)
$Zn^{2+} + 2e^- \rightleftharpoons Zn(s)$	−0.7618	
$Zn(OH)_4^{2-} + 2e^- \rightleftharpoons Zn(s) + 4OH^-$	−1.285	
$Zn(NH_3)_4^{2+} + 2e^- \rightleftharpoons Zn(s) + 4NH_3$	−1.04	
$Zn(CN)_4^{2-} + 2e^- \rightleftharpoons Zn(s) + 4CN^-$	−1.34	

Source: Values are compiled from the following sources: Bard, A. J.; Parsons, R.; Jordon, J., eds. *Standard Potentials in Aqueous Solutions.* Dekker: New York, 1985; Milazzo, G.; Caroli, S.; Sharma, V. K. *Tables of Standard Electrode Potentials.* Wiley: London, 1978; Swift, E. H.; Butler, E. A. *Quantitative Measurements and Chemical Equilibria.* Freeman: New York, 1972.

[a]Solids, gases, and liquids are identified; all other species are aqueous. Reduction reactions in acidic solution are written using H^+ instead of H_3O^+. Reactions may be rewritten by replacing H^+ with H_3O^+ and adding one molecule of H_2O to the opposite side of the reaction for each H^+; thus

$$H_3AsO_4 + 2H^+ + 2e^- \rightleftharpoons HAsO_2 + 2H_2O$$

becomes

$$H_3AsO_4 + 2H_3O^+ + 2e^- \rightleftharpoons HAsO_2 + 4H_2O$$

Conditions for formal potentials ($E^{\circ\prime}$) are listed next to the potential.