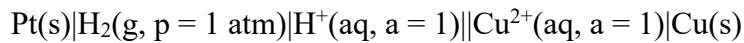


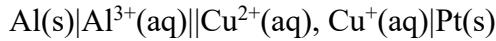
## Electrochemistry and the Nernst Equation Problem

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



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

2. For the following hypothetical cell,



at 298 K:

- (i) State the cell reaction.
- (ii) Give the Nernst equation for the cell.
- (iii) Calculate the cell EMF when
  - (a)  $a_{\text{Al}^{3+}} = a_{\text{Cu}^{2+}} = a_{\text{Cu}^+} = 1.0$
  - (b)  $a_{\text{Al}^{3+}} = a_{\text{Cu}^{2+}} = a_{\text{Cu}^+} = 0.1$

The standard electrode potentials are:

$$E^\circ_{\text{Cu}^+|\text{Cu}^{2+}} = +0.15 \text{ V}$$

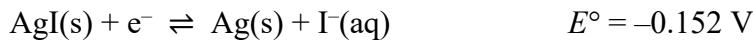
$$E^\circ_{\text{Al}|\text{Al}^{3+}} = -1.61 \text{ V}$$

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



- (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.



5. For the electrochemical cell

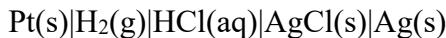


The EMF at temperatures near 298 K obeys the following equation:

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

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

6. Consider the cell



for which  $E^\circ = +0.2225$  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<sub>2</sub> gas is one atmosphere, what is the pH of the solution?

7. For the reduction of ClO<sub>4</sub><sup>-</sup> to ClO<sub>3</sub><sup>-</sup> the standard electrode potential under alkaline conditions is +0.37 V, while under acidic conditions it is +1.20 V.

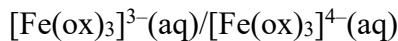
Write a balanced half-cell reaction for each reduction and deduce the value for the ionic product of water,  $K_w$ .

8. In a fuel cell, hydrazine, N<sub>2</sub>H<sub>4</sub>, is oxidized to nitrogen, and oxygen is reduced to water. The standard electrode potentials for the reduction of N<sub>2</sub> to N<sub>2</sub>H<sub>4</sub> and of O<sub>2</sub> to H<sub>2</sub>O at 298 K are -1.155 V and +0.401 V, respectively, both under alkaline conditions.

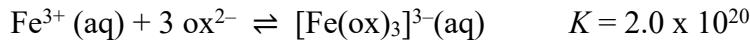
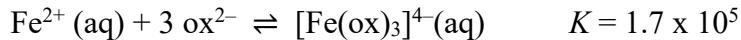
(i) Write a balanced equation for both of the half cell reactions under alkaline conditions. For the cell reaction where the hydrazine electrode is on the left, calculate the standard EMF of the cell at 298 K.

(ii) In a practical cell the concentrations of N<sub>2</sub>H<sub>4</sub> and OH<sup>-</sup> are 0.5 M and 1.0 M, respectively, and the pressure of O<sub>2</sub> and N<sub>2</sub> 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



from the following data (298 K), where ox<sup>2-</sup> refers to the oxalate anion, C<sub>2</sub>O<sub>4</sub><sup>2-</sup>:



**Table 1** Standard Reduction Potentials(Harvey, D. 2000. *Modern Analytical Chemistry*, USA : McGraw-Hill.)Standard Reduction Potentials<sup>a</sup>

Aluminum	$E^\circ$ (V)	$E^{\circ'}$ (V)	Bromine	$E^\circ$ (V)	$E^{\circ'}$ (V)																																																																																																									
$\text{Al}^{3+} + 3\text{e}^- \rightleftharpoons \text{Al}(s)$	-1.676		$\text{Br}_2 + 2\text{e}^- \rightleftharpoons 2\text{Br}^-$	1.087																																																																																																										
$\text{Al}(\text{OH})_4^- + 3\text{e}^- \rightleftharpoons \text{Al}(s) + 4\text{OH}^-$	-2.310		$\text{HOBr} + \text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Br}^- + \text{H}_2\text{O}$	1.341																																																																																																										
$\text{AlF}_6^{3-} + 3\text{e}^- \rightleftharpoons \text{Al}(s) + 6\text{F}^-$	-2.07		$\text{HOBr} + \text{H}^+ + \text{e}^- \rightleftharpoons \frac{1}{2}\text{Br}_2(\ell) + \text{H}_2\text{O}$	1.604																																																																																																										
			$\text{BrO}^- + \text{H}_2\text{O} + 2\text{e}^- \rightleftharpoons \text{Br}^- + 2\text{OH}^-$	0.76	1 M NaOH																																																																																																									
			$\text{BrO}_3^- + 6\text{H}^+ + 5\text{e}^- \rightleftharpoons \frac{1}{2}\text{Br}_2(\ell) + 3\text{H}_2\text{O}$	1.5																																																																																																										
			$\text{BrO}_3^- + 6\text{H}^+ + 6\text{e}^- \rightleftharpoons \text{Br}^- + 3\text{H}_2\text{O}$	1.478																																																																																																										
Antimony	$E^\circ$ (V)	$E^{\circ'}$ (V)	Cadmium	$E^\circ$ (V)	$E^{\circ'}$ (V)																																																																																																									
$\text{Sb}(s) + 3\text{H}^+ + 3\text{e}^- \rightleftharpoons \text{SbH}_3(g)$	-0.510		$\text{Cd}^{2+} + 2\text{e}^- \rightleftharpoons \text{Cd}(s)$	-0.4030																																																																																																										
$\text{Sb}_2\text{O}_5(s) + 6\text{H}^+ + 4\text{e}^- \rightleftharpoons 2\text{SbO}^+ + 3\text{H}_2\text{O}$	0.605		$\text{Cd}(\text{CN})_4^{2-} + 2\text{e}^- \rightleftharpoons \text{Cd}(s) + 4\text{CN}^-$	-0.943																																																																																																										
$\text{SbO}^+ + 2\text{H}^+ + 3\text{e}^- \rightleftharpoons \text{Sb}(s) + \text{H}_2\text{O}$	0.212		$\text{Cd}(\text{NH}_3)_4^{2+} + 2\text{e}^- \rightleftharpoons \text{Cd}(s) + 4\text{NH}_3$	-0.622																																																																																																										
Arsenic	$E^\circ$ (V)	$E^{\circ'}$ (V)	Calcium	$E^\circ$ (V)	$E^{\circ'}$ (V)																																																																																																									
$\text{As}(s) + 3\text{H}^+ + 3\text{e}^- \rightleftharpoons \text{AsH}_3(g)$	-0.225		$\text{Ca}^{2+} + 2\text{e}^- \rightleftharpoons \text{Ca}(s)$	-2.84																																																																																																										
$\text{H}_3\text{AsO}_4 + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{HAsO}_2 + 2\text{H}_2\text{O}$	0.560		Carbon	$E^\circ$ (V)	$E^{\circ'}$ (V)																																																																																																									
$\text{HAsO}_2 + 3\text{H}^+ + 3\text{e}^- \rightleftharpoons \text{As}(s) + 2\text{H}_2\text{O}$	0.240					$\text{CO}_2(g) + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{CO}(g) + \text{H}_2\text{O}$	-0.106		Barium	$E^\circ$ (V)	$E^{\circ'}$ (V)	$\text{CO}_2(g) + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{HCO}_2\text{H}$	-0.20		$\text{Ba}^{2+} + 2\text{e}^- \rightleftharpoons \text{Ba}(s)$	-2.92		$2\text{CO}_2(g) + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_2\text{C}_2\text{O}_4$	-0.481		$\text{BaO}(s) + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Ba}(s) + \text{H}_2\text{O}$	2.365		$\text{HCHO} + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{CH}_3\text{OH}$	0.2323		Beryllium	$E^\circ$ (V)	$E^{\circ'}$ (V)	Cerium	$E^\circ$ (V)	$E^{\circ'}$ (V)	$\text{Be}^{2+} + 2\text{e}^- \rightleftharpoons \text{Be}(s)$	-1.99		$\text{Ce}^{3+} + 3\text{e}^- \rightleftharpoons \text{Ce}(s)$	-2.336		Bismuth	$E^\circ$ (V)	$E^{\circ'}$ (V)	$\text{Ce}^{4+} + \text{e}^- \rightleftharpoons \text{Ce}^{3+}$	1.72	1.70	$\text{Bi}^{3+} + 3\text{e}^- \rightleftharpoons \text{Bi}(s)$	0.317			1.44	1 M HClO <sub>4</sub>	$\text{BiCl}_4^- + 3\text{e}^- \rightleftharpoons \text{Bi}(s) + 4\text{Cl}^-$	0.199			1.61	1 M H <sub>2</sub> SO <sub>4</sub>	Boron	$E^\circ$ (V)	$E^{\circ'}$ (V)			1.28	$\text{B}(\text{OH})_3 + 3\text{H}^+ + 3\text{e}^- \rightleftharpoons \text{B}(s) + 3\text{H}_2\text{O}$	-0.890		Chlorine	$E^\circ$ (V)	$E^{\circ'}$ (V)	$\text{B}(\text{OH})_4^- + 3\text{e}^- \rightleftharpoons \text{B}(s) + 4\text{OH}^-$	-1.811		$\text{Cl}_2(g) + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-$	1.396					$\text{ClO}^- + \text{H}_2\text{O} + \text{e}^- \rightleftharpoons \frac{1}{2}\text{Cl}_2(g) + 2\text{OH}^-$	0.421	1 M NaOH				$\text{ClO}^- + \text{H}_2\text{O} + 2\text{e}^- \rightleftharpoons \text{Cl}^- + 2\text{OH}^-$	0.890	1 M NaOH				$\text{HClO}_2 + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{HOCl} + \text{H}_2\text{O}$	1.64					$\text{ClO}_3^- + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{ClO}_2(g) + \text{H}_2\text{O}$	1.175					$\text{ClO}_3^- + 3\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{HClO}_2 + \text{H}_2\text{O}$	1.181					$\text{ClO}_4^- + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{ClO}_3^- + \text{H}_2\text{O}$	1.201	
			$\text{CO}_2(g) + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{CO}(g) + \text{H}_2\text{O}$	-0.106																																																																																																										
Barium	$E^\circ$ (V)	$E^{\circ'}$ (V)	$\text{CO}_2(g) + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{HCO}_2\text{H}$	-0.20																																																																																																										
$\text{Ba}^{2+} + 2\text{e}^- \rightleftharpoons \text{Ba}(s)$	-2.92		$2\text{CO}_2(g) + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_2\text{C}_2\text{O}_4$	-0.481																																																																																																										
$\text{BaO}(s) + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Ba}(s) + \text{H}_2\text{O}$	2.365		$\text{HCHO} + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{CH}_3\text{OH}$	0.2323																																																																																																										
Beryllium	$E^\circ$ (V)	$E^{\circ'}$ (V)	Cerium	$E^\circ$ (V)	$E^{\circ'}$ (V)																																																																																																									
$\text{Be}^{2+} + 2\text{e}^- \rightleftharpoons \text{Be}(s)$	-1.99		$\text{Ce}^{3+} + 3\text{e}^- \rightleftharpoons \text{Ce}(s)$	-2.336																																																																																																										
Bismuth	$E^\circ$ (V)	$E^{\circ'}$ (V)	$\text{Ce}^{4+} + \text{e}^- \rightleftharpoons \text{Ce}^{3+}$	1.72	1.70																																																																																																									
$\text{Bi}^{3+} + 3\text{e}^- \rightleftharpoons \text{Bi}(s)$	0.317			1.44	1 M HClO <sub>4</sub>																																																																																																									
$\text{BiCl}_4^- + 3\text{e}^- \rightleftharpoons \text{Bi}(s) + 4\text{Cl}^-$	0.199			1.61	1 M H <sub>2</sub> SO <sub>4</sub>																																																																																																									
Boron	$E^\circ$ (V)	$E^{\circ'}$ (V)			1.28																																																																																																									
$\text{B}(\text{OH})_3 + 3\text{H}^+ + 3\text{e}^- \rightleftharpoons \text{B}(s) + 3\text{H}_2\text{O}$	-0.890		Chlorine	$E^\circ$ (V)	$E^{\circ'}$ (V)																																																																																																									
$\text{B}(\text{OH})_4^- + 3\text{e}^- \rightleftharpoons \text{B}(s) + 4\text{OH}^-$	-1.811		$\text{Cl}_2(g) + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-$	1.396																																																																																																										
			$\text{ClO}^- + \text{H}_2\text{O} + \text{e}^- \rightleftharpoons \frac{1}{2}\text{Cl}_2(g) + 2\text{OH}^-$	0.421	1 M NaOH																																																																																																									
			$\text{ClO}^- + \text{H}_2\text{O} + 2\text{e}^- \rightleftharpoons \text{Cl}^- + 2\text{OH}^-$	0.890	1 M NaOH																																																																																																									
			$\text{HClO}_2 + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{HOCl} + \text{H}_2\text{O}$	1.64																																																																																																										
			$\text{ClO}_3^- + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{ClO}_2(g) + \text{H}_2\text{O}$	1.175																																																																																																										
			$\text{ClO}_3^- + 3\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{HClO}_2 + \text{H}_2\text{O}$	1.181																																																																																																										
			$\text{ClO}_4^- + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{ClO}_3^- + \text{H}_2\text{O}$	1.201																																																																																																										

continued

**Table 1** Standard Reduction Potentials – *continued*(Harvey, D. 2000. *Modern Analytical Chemistry*, USA : McGraw-Hill.)**Standard Reduction Potentials<sup>a</sup>—*continued***

Chromium	$E^\circ$ (V)	$E^{\circ'}$ (V)	Iron	$E^\circ$ (V)	$E^{\circ'}$ (V)
$\text{Cr}^{3+} + e^- \rightleftharpoons \text{Cr}^{2+}$	-0.424		$\text{Fe}^{2+} + 2e^- \rightleftharpoons \text{Fe}(s)$	-0.44	
$\text{Cr}^{2+} + 2e^- \rightleftharpoons \text{Cr}(s)$	-0.90		$\text{Fe}^{3+} + 3e^- \rightleftharpoons \text{Fe}(s)$	-0.037	
$\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6e^- \rightleftharpoons 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$	1.36		$\text{Fe}^{3+} + e^- \rightleftharpoons \text{Fe}^{2+}$	0.771	0.70 1 M HCl
$\text{CrO}_4^{2-} + 4\text{H}_2\text{O} + 3e^- \rightleftharpoons \text{Cr}(\text{OH})_4^- + 4\text{OH}^-$	-0.13	1 M NaOH			0.767 1 M $\text{HClO}_4$
					0.746 1 M $\text{HNO}_3$
					0.68 1 M $\text{H}_2\text{SO}_4$
					0.44 0.3 M $\text{H}_3\text{PO}_4$
Cobalt	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{Co}^{2+} + 2e^- \rightleftharpoons \text{Co}(s)$	-0.277		$\text{Fe}(\text{CN})_6^{3-} + e^- \rightleftharpoons \text{Fe}(\text{CN})_6^{4-}$	0.356	0.71 1 M HCl
$\text{Co}^{3+} + e^- \rightleftharpoons \text{Co}^{2+}$	1.92		$\text{Fe}(\text{phen})_3^{3+} + e^- \rightleftharpoons \text{Fe}(\text{phen})_3^{2+}$	1.147	
$\text{Co}(\text{NH}_3)_6^{3+} + e^- \rightleftharpoons \text{Co}(\text{NH}_3)_6^{2+}$	0.1		$\text{Fe}(\text{CN})_6^{3-} + e^- \rightleftharpoons \text{Fe}(\text{CN})_6^{4-}$	0.356	
$\text{Co}(\text{OH})_3(s) + e^- \rightleftharpoons \text{Co}(\text{OH})_2(s) + \text{OH}^-$	0.17		Lanthanum	$E^\circ$ (V)	$E^{\circ'}$ (V)
$\text{Co}(\text{OH})_2(s) + 2e^- \rightleftharpoons \text{Co}(s) + 2\text{OH}^-$	-0.746		$\text{La}^{3+} + 3e^- \rightleftharpoons \text{La}(s)$	-2.38	
Copper	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{Cu}^+ + e^- \rightleftharpoons \text{Cu}(s)$	0.520		Lead	$E^\circ$ (V)	$E^{\circ'}$ (V)
$\text{Cu}^{2+} + e^- \rightleftharpoons \text{Cu}^+$	0.159		$\text{Pb}^{2+} + 2e^- \rightleftharpoons \text{Pb}(s)$	-0.126	
$\text{Cu}^{2+} + 2e^- \rightleftharpoons \text{Cu}(s)$	0.3419		$\text{PbO}_2(s) + 4\text{H}^+ + 2e^- \rightleftharpoons \text{Pb}^{2+} + 2\text{H}_2\text{O}$	1.46	
$\text{Cu}^{2+} + \text{I}^- + e^- \rightleftharpoons \text{CuI}(s)$	0.86		$\text{PbO}_2(s) + \text{SO}_4^{2-} + 4\text{H}^+ + 2e^- \rightleftharpoons \text{PbSO}_4(s) + 2\text{H}_2\text{O}$	1.690	
$\text{Cu}^{2+} + \text{Cl}^- + e^- \rightleftharpoons \text{CuCl}(s)$	0.559		$\text{PbSO}_4(s) + 2e^- \rightleftharpoons \text{Pb}(s) + \text{SO}_4^{2-}$	-0.356	
Fluorine	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{F}_2(g) + 2\text{H}^+ + 2e^- \rightleftharpoons 2\text{HF}$	3.053		Lithium	$E^\circ$ (V)	$E^{\circ'}$ (V)
$\text{F}_2(g) + 2e^- \rightleftharpoons 2\text{F}^-$	2.87		$\text{Li}^+ + e^- \rightleftharpoons \text{Li}(s)$	-3.040	
Gallium	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{Ga}^{3+} + 3e^- \rightleftharpoons \text{Ga}(s)$	-0.529		Magnesium	$E^\circ$ (V)	$E^{\circ'}$ (V)
Gold	$E^\circ$ (V)	$E^{\circ'}$ (V)	$\text{Mg}^{2+} + 2e^- \rightleftharpoons \text{Mg}(s)$	-2.356	
$\text{Au}^+ + e^- \rightleftharpoons \text{Au}(s)$	1.83		$\text{Mg}(\text{OH})_2(s) + 2e^- \rightleftharpoons \text{Mg}(s) + 2\text{OH}^-$	-2.687	
$\text{Au}^{3+} + 2e^- \rightleftharpoons \text{Au}^+$	1.36		Manganese	$E^\circ$ (V)	$E^{\circ'}$ (V)
$\text{Au}^{3+} + 3e^- \rightleftharpoons \text{Au}(s)$	1.52		$\text{Mn}^{2+} + 2e^- \rightleftharpoons \text{Mn}(s)$	-1.17	
$\text{AuCl}_4^- + 3e^- \rightleftharpoons \text{Au}(s) + 4\text{Cl}^-$	1.002		$\text{M}^{3+} + e^- \rightleftharpoons \text{Mn}^{2+}$	1.5	
Hydrogen	$E^\circ$ (V)	$E^{\circ'}$ (V)	$\text{MnO}_2(s) + 4\text{H}^+ + 2e^- \rightleftharpoons \text{Mn}^{2+} + 2\text{H}_2\text{O}$	1.23	
$2\text{H}^+ + 2e^- \rightleftharpoons \text{H}_2(g)$	0.00000		$\text{MnO}_4^- + 4\text{H}^+ + 3e^- \rightleftharpoons \text{MnO}_2(s) + 2\text{H}_2\text{O}$	1.70	
$\text{H}_2\text{O} + e^- \rightleftharpoons \frac{1}{2}\text{H}_2(g) + \text{OH}^-$	-0.828		$\text{MnO}_4^- + 8\text{H}^+ + 5e^- \rightleftharpoons \text{Mn}^{2+} + 4\text{H}_2\text{O}$	1.51	
Iodine	$E^\circ$ (V)	$E^{\circ'}$ (V)	$\text{MnO}_4^- + 2\text{H}_2\text{O} + 3e^- \rightleftharpoons \text{MnO}_2(s) + 4\text{OH}^-$	0.60	
$\text{I}_2(s) + 2e^- \rightleftharpoons 2\text{I}^-$	0.5355		Mercury	$E^\circ$ (V)	$E^{\circ'}$ (V)
$\text{I}_3^- + 2e^- \rightleftharpoons 3\text{I}^-$	0.536		$\text{Hg}^{2+} + 2e^- \rightleftharpoons \text{Hg}(\ell)$	0.8535	
$\text{HIO} + \text{H}^+ + 2e^- \rightleftharpoons \text{I}^- + \text{H}_2\text{O}$	0.985		$2\text{Hg}^{2+} + 2e^- \rightleftharpoons \text{Hg}_2^{2+}$	0.911	
$\text{IO}_3^- + 6\text{H}^+ + 5e^- \rightleftharpoons \frac{1}{2}\text{I}_2(s) + 3\text{H}_2\text{O}$	1.195		$\text{Hg}_2^{2+} + 2e^- \rightleftharpoons 2\text{Hg}(\ell)$	0.7960	
$\text{IO}_3^- + 3\text{H}_2\text{O} + 6e^- \rightleftharpoons \text{I}^- + 6\text{OH}^-$	0.257		$\text{Hg}_2\text{Cl}_2(s) + 2e^- \rightleftharpoons 2\text{Hg}(\ell) + 2\text{Cl}^-$	0.2682	
			$\text{HgO}(s) + 2\text{H}^+ + 2e^- \rightleftharpoons \text{Hg}(\ell) + \text{H}_2\text{O}$	0.926	
			$\text{Hg}_2\text{Br}_2(s) + 2e^- \rightleftharpoons 2\text{Hg}(\ell) + 2\text{Br}^-$	0.1392	
			$\text{Hg}_2\text{I}_2(s) + 2e^- \rightleftharpoons 2\text{Hg}(\ell) + 2\text{I}^-$	-0.0405	

**Table 1** Standard Reduction Potentials – *continued*(Harvey, D. 2000. *Modern Analytical Chemistry*, USA : McGraw-Hill.)

Molybdenum	$E^\circ$ (V)	$E^{\circ'}$ (V)	Selenium	$E^\circ$ (V)	$E^{\circ'}$ (V)
$\text{Mo}^{3+} + 3e^- \rightleftharpoons \text{Mo}(s)$	-0.2		$\text{Se}(s) + 2e^- \rightleftharpoons \text{Se}^{2-}$		-0.670 1 M NaOH
$\text{MoO}_2(s) + 4\text{H}^+ + 4e^- \rightleftharpoons \text{Mo}(s) + 2\text{H}_2\text{O}$	-0.152		$\text{Se}(s) + 2\text{H}^+ + 2e^- \rightleftharpoons \text{H}_2\text{Se}(g)$	-0.115	
$\text{MoO}_4^{2-} + 4\text{H}_2\text{O} + 6e^- \rightleftharpoons \text{Mo}(s) + 8\text{OH}^-$	-0.913		$\text{H}_2\text{SeO}_3 + 4\text{H}^+ + 4e^- \rightleftharpoons \text{Se}(s) + 3\text{H}_2\text{O}$	0.74	
Nickel	$E^\circ$ (V)	$E^{\circ'}$ (V)	$\text{SeO}_4^{3-} + 4\text{H}^+ + e^- \rightleftharpoons \text{H}_2\text{SeO}_3 + \text{H}_2\text{O}$	1.151	
$\text{Ni}^{2+} + 2e^- \rightleftharpoons \text{Ni}(s)$	-0.257				
$\text{Ni}(\text{OH})_2(s) + 2e^- \rightleftharpoons \text{Ni}(s) + 2\text{OH}^-$	-0.72				
$\text{Ni}(\text{NH}_3)_6^{2+} + 2e^- \rightleftharpoons \text{Ni}(s) + 6\text{NH}_3$	-0.49				
Nitrogen	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{N}_2(g) + 5\text{H}^+ + 4e^- \rightleftharpoons \text{N}_2\text{H}_5^+$	-0.23				
$\text{N}_2\text{O}(g) + 2\text{H}^+ + 2e^- \rightleftharpoons \text{N}_2(g) + \text{H}_2\text{O}$	1.77				
$2\text{NO}(g) + 2\text{H}^+ + 2e^- \rightleftharpoons \text{N}_2\text{O}(g) + \text{H}_2\text{O}$	1.59				
$\text{HNO}_2 + \text{H}^+ + e^- \rightleftharpoons \text{NO}(g) + \text{H}_2\text{O}$	0.996				
$2\text{HNO}_2 + 4\text{H}^+ + 4e^- \rightleftharpoons \text{N}_2\text{O}(g) + 3\text{H}_2\text{O}$	1.297				
$\text{NO}_3^- + 3\text{H}^+ + 2e^- \rightleftharpoons \text{HNO}_2 + \text{H}_2\text{O}$	0.94				
Oxygen	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{O}_2(g) + 2\text{H}^+ + 2e^- \rightleftharpoons \text{H}_2\text{O}_2$	0.695				
$\text{O}_2(g) + 4\text{H}^+ + 4e^- \rightleftharpoons 2\text{H}_2\text{O}$	1.229				
$\text{H}_2\text{O}_2 + 2\text{H}^+ + 2e^- \rightleftharpoons 2\text{H}_2\text{O}$	1.763				
$\text{O}_2(g) + 2\text{H}_2\text{O} + 4e^- \rightleftharpoons 4\text{OH}^-$	0.401				
$\text{O}_3(g) + 2\text{H}^+ + 2e^- \rightleftharpoons \text{O}_2(g) + \text{H}_2\text{O}$	2.07				
Phosphorus	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{P}(s, \text{white}) + 3\text{H}^+ + 3e^- \rightleftharpoons \text{PH}_3(g)$	-0.063				
$\text{H}_3\text{PO}_3 + 2\text{H}^+ + 2e^- \rightleftharpoons \text{H}_3\text{PO}_2 + \text{H}_2\text{O}$	-0.499				
$\text{H}_3\text{PO}_4 + 2\text{H}^+ + 2e^- \rightleftharpoons \text{H}_3\text{PO}_3 + \text{H}_2\text{O}$	-0.276				
Platinum	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{Pt}^{2+} + 2e^- \rightleftharpoons \text{Pt}(s)$	1.188				
$\text{PtCl}_4^{2-} + 2e^- \rightleftharpoons \text{Pt}(s) + 4\text{Cl}^-$	0.758				
Potassium	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{K}^+ + e^- \rightleftharpoons \text{K}(s)$	-2.924				
Ruthenium	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{Ru}^{3+} + e^- \rightleftharpoons \text{Ru}^{2+}$	0.249				
$\text{RuO}_2(s) + 4\text{H}^+ + 4e^- \rightleftharpoons \text{Ru}(s) + 2\text{H}_2\text{O}$	0.68				
$\text{Ru}(\text{NH}_3)_6^{3+} + e^- \rightleftharpoons \text{Ru}(\text{NH}_3)_6^{2+}$	0.10				
$\text{Ru}(\text{CN})_6^{3-} + e^- \rightleftharpoons \text{Ru}(\text{CN})_6^{4-}$	0.86				
Selenium	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{Se}(s) + 2e^- \rightleftharpoons \text{Se}^{2-}$					
$\text{Se}(s) + 2\text{H}^+ + 2e^- \rightleftharpoons \text{H}_2\text{Se}(g)$			-0.115		
$\text{H}_2\text{SeO}_3 + 4\text{H}^+ + 4e^- \rightleftharpoons \text{Se}(s) + 3\text{H}_2\text{O}$			0.74		
$\text{SeO}_4^{3-} + 4\text{H}^+ + e^- \rightleftharpoons \text{H}_2\text{SeO}_3 + \text{H}_2\text{O}$			1.151		
Silicon	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{SiF}_6^{2-} + 4e^- \rightleftharpoons \text{Si}(s) + 6\text{F}^-$	-1.37				
$\text{SiO}_2(s) + 4\text{H}^+ + 4e^- \rightleftharpoons \text{Si}(s) + 2\text{H}_2\text{O}$	-0.909				
$\text{SiO}_2(s) + 8\text{H}^+ + 8e^- \rightleftharpoons \text{SiH}_4(g) + 2\text{H}_2\text{O}$	-0.516				
Silver	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{Ag}^+ + e^- \rightleftharpoons \text{Ag}(s)$	0.7996				
$\text{AgBr}(s) + e^- \rightleftharpoons \text{Ag}(s) + \text{Br}^-$	0.071				
$\text{Ag}_2\text{C}_2\text{O}_4(s) + 2e^- \rightleftharpoons 2\text{Ag}(s) + \text{C}_2\text{O}_4^{2-}$	0.47				
$\text{AgCl}(s) + e^- \rightleftharpoons \text{Ag}(s) + \text{Cl}^-$	0.2223				
$\text{AgI}(s) + e^- \rightleftharpoons \text{Ag}(s) + \text{I}^-$	-0.152				
$\text{Ag}_2\text{S}(s) + 2e^- \rightleftharpoons 2\text{Ag}(s) + \text{S}^{2-}$	-0.71				
$\text{Ag}(\text{NH}_3)_2^+ + e^- \rightleftharpoons \text{Ag}(s) + 2\text{NH}_3$	0.373				
Sodium	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{Na}^+ + e^- \rightleftharpoons \text{Na}(s)$	-2.713				
Strontium	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{Sr}^{2+} + 2e^- \rightleftharpoons \text{Sr}(s)$	-2.89				
Sulfur	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{S}(s) + 2e^- \rightleftharpoons \text{S}^{2-}$	-0.407				
$\text{S}(s) + 2\text{H}^+ + 2e^- \rightleftharpoons \text{H}_2\text{S}$	0.144				
$\text{S}_2\text{O}_6^{2-} + 4\text{H}^+ + 2e^- \rightleftharpoons 2\text{H}_2\text{SO}_3$	0.569				
$\text{S}_2\text{O}_8^{2-} + 2e^- \rightleftharpoons 2\text{SO}_4^{2-}$	1.96				
$\text{S}_4\text{O}_6^{2-} + 2e^- \rightleftharpoons 2\text{S}_2\text{O}_3^{2-}$	0.080				
$2\text{SO}_3^{2-} + 2\text{H}_2\text{O} + 2e^- \rightleftharpoons \text{S}_2\text{O}_4^{2-} + 4\text{OH}^-$	-1.13				
$2\text{SO}_3^{2-} + 3\text{H}_2\text{O} + 4e^- \rightleftharpoons \text{S}_2\text{O}_3^{2-} + 6\text{OH}^-$			-0.576 1 M NaOH		
$2\text{SO}_4^{2-} + 4\text{H}^+ + 2e^- \rightleftharpoons \text{S}_2\text{O}_6^{2-} + 2\text{H}_2\text{O}$	-0.25				
$\text{SO}_4^{2-} + \text{H}_2\text{O} + 2e^- \rightleftharpoons \text{SO}_3^{2-} + 2\text{OH}^-$	-0.936				
$\text{SO}_4^{2-} + 4\text{H}^+ + 2e^- \rightleftharpoons \text{H}_2\text{SO}_3 + \text{H}_2\text{O}$	+0.172				
Thallium	$E^\circ$ (V)	$E^{\circ'}$ (V)			
$\text{Ti}^{3+} + 2e^- \rightleftharpoons \text{Ti}^+$	1.25				
			0.77	1 M HCl	
$\text{Ti}^3 + 3e^- \rightleftharpoons \text{Ti}(s)$	0.742				

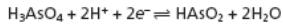
continued

**Table 1** Standard Reduction Potentials – *continued*(Harvey, D. 2000. *Modern Analytical Chemistry*, USA : McGraw-Hill.)**Standard Reduction Potentials<sup>a</sup>—*continued***

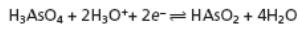
Tin	$E^\circ$ (V)	$E^\circ'$ (V)	Uranium	$E^\circ$ (V)	$E^\circ'$ (V)
$\text{Sn}^{2+} + 2e^- \rightleftharpoons \text{Sn}(s)$		-0.19	1 M HCl	$\text{U}^{3+} + 3e^- \rightleftharpoons \text{U}(s)$	-1.66
$\text{Sn}^{4+} + 2e^- \rightleftharpoons \text{Sn}^{2+}$	0.154	0.139	1 M HCl	$\text{U}^{4+} + e^- \rightleftharpoons \text{U}^{3+}$	-0.52
				$\text{UO}_2^{2+} + 4\text{H}^+ + e^- \rightleftharpoons \text{U}^{4+} + 2\text{H}_2\text{O}$	0.27
				$\text{UO}_2^{2+} + e^- \rightleftharpoons \text{UO}_2^{+}$	0.16
				$\text{UO}_2^{2+} + 4\text{H}^+ + 2e^- \rightleftharpoons \text{U}^{4+} + 2\text{H}_2\text{O}$	0.327
Titanium	$E^\circ$ (V)	$E^\circ'$ (V)	Vanadium	$E^\circ$ (V)	$E^\circ'$ (V)
$\text{Ti}^{2+} + 2e^- \rightleftharpoons \text{Ti}(s)$	-1.63		$\text{V}^{2+} + 2e^- \rightleftharpoons \text{V}(s)$	-1.13	
$\text{Ti}^{3+} + e^- \rightleftharpoons \text{Ti}^{2+}$	-0.37		$\text{V}^{3+} + e^- \rightleftharpoons \text{V}^{2+}$	-0.255	
			$\text{VO}^{2+} + 2\text{H}^+ + e^- \rightleftharpoons \text{V}^{3+} + \text{H}_2\text{O}$	0.337	
			$\text{VO}_2^{+} + 2\text{H}^+ + e^- \rightleftharpoons \text{VO}^{2+} + \text{H}_2\text{O}$	1.000	
Tungsten	$E^\circ$ (V)	$E^\circ'$ (V)	Zinc	$E^\circ$ (V)	$E^\circ'$ (V)
$\text{WO}_2(s) + 4\text{H}^+ + 4e^- \rightleftharpoons \text{W}(s) + 2\text{H}_2\text{O}$	-0.119		$\text{Zn}^{2+} + 2e^- \rightleftharpoons \text{Zn}(s)$	-0.7618	
$\text{WO}_3(s) + 6\text{H}^+ + 6e^- \rightleftharpoons \text{W}(s) + 3\text{H}_2\text{O}$	-0.090		$\text{Zn}(\text{OH})_4^{2-} + 2e^- \rightleftharpoons \text{Zn}(s) + 4\text{OH}^-$	-1.285	
			$\text{Zn}(\text{NH}_3)_4^{2+} + 2e^- \rightleftharpoons \text{Zn}(s) + 4\text{NH}_3$	-1.04	
			$\text{Zn}(\text{CN})_4^{2-} + 2e^- \rightleftharpoons \text{Zn}(s) + 4\text{CN}^-$	-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.

<sup>a</sup>Solids, gases, and liquids are identified; all other species are aqueous. Reduction reactions in acidic solution are written using  $\text{H}^+$  instead of  $\text{H}_3\text{O}^+$ . Reactions may be rewritten by replacing  $\text{H}^+$  with  $\text{H}_3\text{O}^+$  and adding one molecule of  $\text{H}_2\text{O}$  to the opposite side of the reaction for each  $\text{H}^+$ ; thus



becomes

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