

17.10: Electromotive Force of Galvanic Cells

Using a voltmeter to measure the **electrical potential difference** (commonly called voltage) between two electrodes provides a quantitative indication of just how spontaneous a redox reaction is. The potential difference is measured in **volts** (V), an SI unit which corresponds to one joule per ampere-second ($1V = 1 \text{ J A}^{-1} \text{ s}^{-1}$). The voltage indicates the tendency for current to flow in the external circuit, that is, it shows how strongly the anode reaction can push electrons into the circuit and how strongly the cathode reaction can pull them out. The potential difference is greatest when a large electrical resistance in the external circuit prevents any current from flowing. The maximum potential difference which can be measured for a given cell is called the **electromotive force**, abbreviated emf and represented by the symbol E.

By convention, when a cell is written in shorthand notation, its *emf* is *given* a positive value if the cell reaction is spontaneous. That is, if the electrode on the left forces electrons into the external circuit and the electrode on the right withdraws them, then the dial on the voltmeter gives the cell emf. On the other hand, if the half-cell on the right side of the shorthand cell notation is releasing electrons, making the right-hand terminal of the voltmeter negative, the cell emf is minus the reading of the meter. This corresponds to a nonspontaneous cell reaction, written in the conventional way.

✓ Example 17.10.1 : Galvanic Cell EMF

When the galvanic cell shown in Figure 2 from Galvanic Cells is connected to a voltmeter, the reading is 0.59 V. The shorthand notation for this cell is

$$Pt, Cl_2(g) \mid Cl^-(1 M) \parallel Fe^{2+}(1 M), Fe^{3+}(1 M) \mid Pt$$

What is the value of the cell emf?

Solution:

We have already seen that this cell as written corresponds to a nonspontaneous reaction. Therefore the emf must be negative and E = -0.59 V.

Example 17.10.2 : Voltmeter Readings

If the voltmeter in Figure 17.5 reads 1.10 V, what is the emf for the cell

$$Cu|Cu^{2}+(1 M) \parallel Zn^{2}+(1 M)|Zn$$

Solution

In this case the shorthand notation corresponds to the reverse of Eq. (1) in Galvanic Cells; that is, it refers to the nonspontaneous cell reaction

$$\mathrm{Cu} + \mathrm{Zn}^{2\;+} \to \mathrm{Cu}^{2\;+} + \mathrm{Zn}$$

Consequently the emf for this cell must be negative and E = -1.10 V.

Example 17.10.2shows that if the cell notation is written in reverse, the cell emf changes sign, since for the spontaneous reaction shown in Eq. (2) from Galvanic Cells the emf would have been +1.10 V.

Experimentally measured cell emf's are found to depend on the concentrations of species in solution and on the pressures of gases involved in the cell reaction. Consequently it is necessary to specify concentrations and pressures when reporting an emf, and we shall only consider cells in which all concentrations are 1mol dm⁻³ and all pressures are 1 atm (101.3 kPa).

The emf of such a cell is said to be its **standard electromotive force** and is given the symbol E° .

The electromotive forces of galvanic cells are found to be additive. That is, if we measure the emf's of the two cells

$$Z_{n}|Z^{2}+(1 M)||H^{+}(1 M)|H_{2}(1 atm), Pt$$
 (17.10.1)

 $E^{\circ} = 0.76 \text{ V}$

$$Pt, H_2(1 atm) | H^+(1 M) | Cu^{2+}(1 M) | Cu$$
 (17.10.2)



 $E^{\circ} = 0.34 \text{ V}$

the sum of the *E*° values corresponds to the measured emf for a third cell with which we discuss in the section on Cell Notation and Conventions:

$$Zn|Zn^{2}+(1 M) \parallel Cu^{2}+(1 M) \mid CuE^{o}=1 \cdot 10$$
 (17.10.3)

Whenever the right-hand electrode of one cell is identical to the left-hand electrode of another, we can add the emf's in this way, canceling the electrode which appears twice. This additivity makes it possible to store a large amount of emf data in a small table. By convention such data are tabulated as **standard reduction potentials**. These refer to the emf of a cell whose left-hand electrode is the hydrogen-gas electrode and whose right-hand electrode is the electrode whose emf is being sought. Table 17.10.1contains a number of useful standard reduction potentials.

As an example of the use of the table, the entry corresponding to the electrode $Cu^{2+}(1M) \mid Cuis + 0.34V$. Thus when this electrode is written

TABLE 17.10.1: Standard Reduction Potentials at 298.15 K.

Acidic Solution	Standard Reduction Potential, E° (volts)
${\rm F_2(g)} + 2e^-/{\rm rightarrow2F^-(aq)}$	2.87
$\mathrm{Co}^{3+}(\mathrm{aq}) + e^-/\mathrm{rightarrowCo}^{2+}(\mathrm{aq})$	1.92
$\mathrm{Au}^+(\mathrm{aq}) + e^- o \mathrm{Au}(\mathrm{s})$	1.83
${\rm H_2O_2(aq)} + 2{\rm H_3O^+(aq)} + 2e^- \rightarrow 4{\rm H_2O(l)}$	1.763
$\mathrm{Ce}^{4+}(\mathrm{aq}) + e^- ightarrow \mathrm{Ce}^{3+}(\mathrm{aq})$	1.72
$\mathrm{Pb}^{4+}(\mathrm{aq}) + 2e^- ightarrow \mathrm{Pb}^{2+}(\mathrm{aq})$	1.69
${\rm PbO_2(s) + SO_4^{2-}(aq) + 4H_3O^+(aq) + 2}e^- \rightarrow {\rm PbSO_4(s) + 6H_2O(l)}$	1.690
${\rm NiO_2(s)} + 4{\rm H_3O^+(aq)} + 2e^- \rightarrow {\rm Ni^2}^+({\rm aq}) + 6{\rm H_2O(l)}$	1.68
$2\mathrm{HClO(aq)} + 2\mathrm{H3}\mathrm{O} + (\mathrm{aq}) + 2e^- \rightarrow \mathrm{Cl}_2(\mathrm{g}) + 4\mathrm{H}_2\mathrm{O(l)}$	1.63
$\mathrm{Au^3}^+(\mathrm{aq}) + 3e^- o \mathrm{Au(s)}$	1.52
${\rm MnO_4^-(aq)} + 8{\rm H_3O^+(aq)} + 5e^- \rightarrow {\rm Mn^2^+(aq)} + 12{\rm H_2O(l)}$	1.51
${\rm BrO}_3^-({\rm aq}) + 6{\rm H}_3{\rm O}^+({\rm aq}) + 5e^- \to {\textstyle \frac{1}{2}}{\rm Br}_2({\rm aq}) + 9{\rm H}_2{\rm O}({\rm l})$	1.478
$2{\rm ClO}_3^-({\rm aq}) + 12{\rm H}_3^{}{\rm O}^+({\rm aq}) + 10e^- \rightarrow {\rm Cl}_2^{}({\rm g}) + 18{\rm H}_2^{}{\rm O}({\rm l})$	1.47
$\mathrm{Cr}_2\mathrm{O}_7^{2-}(\mathrm{aq}) + 14\mathrm{H}_3\mathrm{O}^+(\mathrm{aq}) + 6e^- \rightarrow 2\mathrm{Cr}^{3+}(\mathrm{aq}) + 21\mathrm{H}_2\mathrm{O}(\mathrm{l})$	1.36
$ ext{Cl}_2(ext{g}) + 2e^- ightarrow 2 ext{Cl}^-(ext{aq})$	1.358
${\rm N_2H_5^+(aq)} + 3{\rm H_3O^+(aq)} + 2e^- \rightarrow 2{\rm NH_4^+(aq)} + 3{\rm H_2O(l)}$	1.275
${\rm MnO}_2({\rm s}) + 4{\rm H}_3{\rm O}^+({\rm aq}) + 2e^- \rightarrow {\rm Mn}^{2+}({\rm aq}) + 6{\rm H}_2{\rm O}({\rm l})$	1.23
${ m O_2(g)} + 4{ m H_3O^+(aq)} + 4e^- o 6{ m H_2O(l)}$	1.229
$\mathrm{ClO}_{4}^{-}(\mathrm{aq}) + 2\mathrm{H}_{3}\mathrm{O}^{+}(\mathrm{aq}) + 2e^{-} \rightarrow \mathrm{ClO}_{3}^{-}(\mathrm{aq}) + 3\mathrm{H}_{2}\mathrm{O}(\mathrm{l})$	1.201
${\rm IO}_{3}^{-}({\rm aq}) + 6{\rm H}_{3}{\rm O}^{+}({\rm aq}) + 5e^{-} \rightarrow {\textstyle \frac{1}{2}}{\rm I}_{2}({\rm aq}) + 9{\rm H}_{2}{\rm O}({\rm l})$	1.195
$\mathrm{Pt}^{2+}(\mathrm{aq}) + 2e^- ightarrow \mathrm{Pt}(\mathrm{s})$	1.188
$\mathrm{Br}_2(\mathrm{l}) + 2e^- ightarrow 2\mathrm{Br}^-(\mathrm{aq})$	1.066
$\mathrm{AuCl}_4^-(\mathrm{aq}) + 3e^- \to \mathrm{Au}(\mathrm{s}) + 4\mathrm{Cl}^-(\mathrm{aq})$	1.00
${\rm NO_3^-(aq)} + 4{\rm H_3O^+(aq)} + 3e^- \rightarrow {\rm NO(g)} + 6{\rm H_2O(l)}$	0.96
${\rm NO_3^-(aq)} + 3{\rm H_3O^+(aq)} + 2e^- \rightarrow {\rm HNO_2(aq)} + 4{\rm H_2O(l)}$	0.94
$\mathrm{Pd}^{2+}(\mathrm{aq}) + 2e^- o \mathrm{Pd}(\mathrm{s})$	0.915
$2{ m Hg}^{2+}({ m aq}) + 2e^- ightarrow { m Hg}_2^{2+}({ m aq})$	0.9110



$\begin{array}{lll} H_g^{2^+}(aq) + 2e^- \to Hg(l) & 0.8535 \\ SbCl_6^-(aq) + e^- \to SbCl_4^-(aq) + 2 Cl^-(aq) & 0.84 \\ Ag^-(aq) + e^- \to Ag(s) & 0.7991 \\ Hg_3^{2^+}(aq) + e^- \to Pe^{2^+}(aq) & 0.7960 \\ Fe^{3^+}(aq) + e^- \to Fe^{2^+}(aq) & 0.771 \\ [PtCl_4]^2^-(aq) + 2e^- \to Pt(s) + 4 Cl^-(aq) & 0.726 \\ O_2(g) + 2 H_3 O^+(aq) + 2e^- \to H_2 O_2(aq) + 2 H_2 O(l) & 0.695 \\ TeCl_2(g)^2 + 2 H_3 O^+(aq) + 2e^- \to H_2 O_2(aq) + 2 H_2 O(l) & 0.604 \\ H_3 AsO_4(aq) + 2H_2 O^+(aq) + 2e^- \to HAsO_2(aq) + 4 H_2 O(l) & 0.560 \\ I_2(s) + 2e^- \to 2 I^-(aq) & 0.535 \\ Cu^+(aq) + e^- \to Cu(s) & 0.521 \\ [RhCl_6]^3^-(aq) + 3e^- \to Rh(s) + 6 Cl^-(aq) & 0.5 \\ Cu^2^+(aq) + e^- \to Cu(s) & 0.340 \\ Hg_2 Cl_2(s) + 2e^- \to 2 Hg(l) + 2 Cl^-(aq) & 0.27 \\ AgCl(s) + e^- \to Ag(s) + Cl^-(aq) & 0.222 \\ Cu^3^+(aq) + e^- \to Cu^+(aq) & 0.158 \\ Sol_4^4^-(aq) + e^- \to Cu^+(aq) & 0.158 \\ Sol_4^4^-(aq) + e^- \to Cu^+(aq) & 0.158 \\ Sol_4^4^-(aq) + 2e^- \to H_3 Sol_3(aq) + 5 H_3 O(l) & 0.144 \\ AgBr(s) + e^- \to Ag(s) + Br^-(aq) & 0.0713 \\ 2H_3 O^+(aq) + 2e^- \to 2H_2(g) + 2H_2 O(l) & 0.044 \\ HgS(s) hack) + 2H_3 O^+(aq) + 2e^- \to H_3 Sol_4 O(l) & 0.041 \\ HgS(s) hack) + 2H_3 O^+(aq) + 2e^- \to H_3 O(l) + 2H_2 O(l) & 0.015 \\ Sol_2^2^-(aq) + 2e^- \to 2H_2(g) + 2H_2 O(l) & 0.144 \\ AgBr(s) + e^- \to Ag(s) + Br^-(aq) & 0.0713 \\ 2H_3 O^+(aq) + 2e^- \to H_3 O(l) + 2e^- \to H_3 O(l) & 0.000 \\ N_2 O(g) + 6H_3 O^+(aq) + 2e^- \to H_3 O(l) + 2H_2 O(l) & 0.015 \\ HgS(s) hack) + 2H_3 O^+(aq) + 2e^- \to H_2 Sol_4 + 2H_2 O(l) & 0.015 \\ HgS(s) hack) + 2H_3 O^+(aq) + 2e^- \to H_2 Sol_4 + 2H_2 O(l) & 0.015 \\ Sol_2^2^+(aq) + 2e^- \to Pb(s) & -0.125 \\ Sol_2^2^+(aq) + 2e^- \to Pb(s) & -0.125 \\ Sol_2^2^+(aq) + 2e^- \to Pb(s) & -0.125 \\ Sol_2^2^+(aq) + 2e^- \to Sol_3 + 6F^-(aq) & -0.200 \\ Nl^{1+}(aq) + 2e^- \to Ni(s) & -0.25 \\ Co^-(aq) + 2e^- \to Ni(s) & -0.25 \\ Co^-(aq) + 2e^- \to Pb(s) + Sol_4^2^-(aq) & -0.3505 \\ Col_2^2^+(aq) + 2e^- \to Col(s) & -0.403 \\ \end{array}$	Standard Reduction Potential, E° (volts)
$\begin{array}{llllllllllllllllllllllllllllllllllll$	$ ightarrow ext{Hg(l)}$
$\begin{array}{llllllllllllllllllllllllllllllllllll$	$ ho ightarrow \mathrm{SbCl}_4^-(\mathrm{aq}) + 2\mathrm{Cl}^-(\mathrm{aq}) $ 0.84
$\begin{array}{llllllllllllllllllllllllllllllllllll$	Ag(s) 0.7991
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	$ ightarrow 2\mathrm{Hg}(\mathrm{l})$ 0.7960
$\begin{split} & [\operatorname{PtCl}_{6}]^{2} - (\operatorname{aq}) + 2e^{-} \to [\operatorname{PtCl}_{4}]^{2} - (\operatorname{aq}) + 2\operatorname{CI}(\operatorname{aq}) & 0.726 \\ O_{2}(\operatorname{g}) + 2\operatorname{H}_{3}\operatorname{O}^{+}(\operatorname{aq}) + 2e^{-} \to \operatorname{H}_{2}\operatorname{O}_{2}(\operatorname{aq}) + 2\operatorname{H}_{2}\operatorname{O}(1) & 0.695 \\ & \operatorname{TeO}_{2}(\operatorname{s}) + 4\operatorname{H}_{3}\operatorname{O}^{-}(\operatorname{aq}) + 4e^{-} \to \operatorname{Te}(\operatorname{s}) + 6\operatorname{H}_{2}\operatorname{O}(1) & 0.604 \\ & \operatorname{H}_{3}\operatorname{ASO}_{4}(\operatorname{aq}) + 2\operatorname{H}_{3}\operatorname{O}^{+}(\operatorname{aq}) + 2e^{-} \to \operatorname{HAsO}_{2}(\operatorname{aq}) + 4\operatorname{H}_{2}\operatorname{O}(1) & 0.560 \\ & \operatorname{I}_{2}(\operatorname{s}) + 2e^{-} \to 2\operatorname{I}^{-}(\operatorname{aq}) & 0.535 \\ & \operatorname{Cu}^{+}(\operatorname{aq}) + e^{-} \to \operatorname{Cu}(\operatorname{s}) & 0.521 \\ & [\operatorname{RbCI}_{6}]^{3} - (\operatorname{aq}) + 3e^{-} \to \operatorname{Rh}(\operatorname{s}) + 6\operatorname{CI}^{-}(\operatorname{aq}) & 0.5 \\ & \operatorname{Cu}^{2}^{+}(\operatorname{aq}) + 2e^{-} \to \operatorname{Cu}(\operatorname{s}) & 0.340 \\ & \operatorname{Hg}_{2}\operatorname{Cl}_{2}(\operatorname{s}) + 2e^{-} \to 2\operatorname{Hg}(1) + 2\operatorname{CI}^{-}(\operatorname{aq}) & 0.27 \\ & \operatorname{AgCI}_{3}(\operatorname{s}) + e^{-} \to \operatorname{Cu}^{+}(\operatorname{aq}) & 0.222 \\ & \operatorname{Cu}^{2}^{+}(\operatorname{aq}) + e^{-} \to \operatorname{Cu}^{+}(\operatorname{aq}) & 0.159 \\ & \operatorname{SO}_{4}^{2} - (\operatorname{aq}) + e^{-} \to \operatorname{Cu}^{+}(\operatorname{aq}) & 0.158 \\ & \operatorname{Sn}^{4}^{+}(\operatorname{aq}) + 2e^{-} \to \operatorname{H}_{2}\operatorname{SO}_{3}(\operatorname{aq}) + 5\operatorname{H}_{2}\operatorname{O}(1) & 0.158 \\ & \operatorname{Sn}^{4}^{+}(\operatorname{aq}) + 2e^{-} \to \operatorname{Sn}^{2}^{+}(\operatorname{aq}) & 0.15 \\ & \operatorname{S(s)} + 2\operatorname{H}_{3}\operatorname{O}^{+}(\operatorname{aq}) + 2e^{-} \to \operatorname{H}_{2}\operatorname{SO}_{3}(\operatorname{aq}) + 5\operatorname{H}_{2}\operatorname{O}(1) & 0.144 \\ & \operatorname{AgBr}(\operatorname{s}) + e^{-} \to \operatorname{Ag}(\operatorname{s}) + \operatorname{Br}^{-}(\operatorname{aq}) & 0.0713 \\ & 2\operatorname{H}_{3}\operatorname{O}^{+}(\operatorname{aq}) + 2e^{-} \to \operatorname{H}_{2}\operatorname{SO}_{4} + 2\operatorname{Hg}(1) + \operatorname{Hg}_{2}\operatorname{S}(\operatorname{g}) + 2\operatorname{Hg}_{2}\operatorname{O}(1) & -0.05 \\ & \operatorname{HgS}(\operatorname{s},\operatorname{black}) + 2\operatorname{H}_{3}\operatorname{O}^{+}(\operatorname{aq}) + 2e^{-} \to \operatorname{Hg}(\operatorname{O}) + 2e^{-} \to \operatorname{Hg}(\operatorname{O}) + 2e^{-} \to \operatorname{Hg}(\operatorname{O}) & -0.15 \\ & \operatorname{Se}(\operatorname{s}) + 2\operatorname{H}_{3}\operatorname{O}^{+}(\operatorname{aq}) + 2e^{-} \to \operatorname{Hg}(\operatorname{Se}(\operatorname{aq}) + 2\operatorname{Hg}(\operatorname{O}) & -0.15 \\ & \operatorname{Se}(\operatorname{s}) + 2\operatorname{Hg}(\operatorname{O}) + 2e^{-} \to \operatorname{Hg}(\operatorname{Se}(\operatorname{aq}) + 2\operatorname{Hg}(\operatorname{O}) & -0.05 \\ & \operatorname{Se}(\operatorname{s}) + 2\operatorname{Hg}(\operatorname{O}) + 2e^{-} \to \operatorname{Hg}(\operatorname{Se}(\operatorname{aq}) + 2\operatorname{Hg}(\operatorname{O}) & -0.15 \\ & \operatorname{Se}(\operatorname{s}) + 2\operatorname{Hg}(\operatorname{O}) + 2e^{-} \to \operatorname{Hg}(\operatorname{Se}(\operatorname{A}) + 2\operatorname{Hg}(\operatorname{O}) & -0.15 \\ & \operatorname{Se}(\operatorname{Se}(\operatorname{Se}) + 2\operatorname{Hg}(\operatorname{O}) + 2e^{-} \to \operatorname{Hg}(\operatorname{Se}(\operatorname{A}) + 2e^{-} \to \operatorname{Hg}(\operatorname{O}) & -0.15 \\ & \operatorname{Se}(\operatorname{Se}(\operatorname{Se}(\operatorname{A}) + 2e^{-} \to \operatorname{Se}(\operatorname{Se}(\operatorname{A}) + 2e^{-} \to \operatorname{Hg}(\operatorname{O}) & -0.15 \\ & \operatorname{Se}(\operatorname{Se}(\operatorname{A}) + 2e^{-$	ightarrow Fe ²⁺ (aq) 0.771
$\begin{array}{llll} O_2(g) + 2H_3O^+(aq) + 2e^- \to H_2O_2(aq) + 2H_2O(1) & 0.695 \\ TeO_2(g) + 4H_3O^+(aq) + 4e^- \to Te(g) + 6H_2O(1) & 0.604 \\ H_3AsO_4(aq) + 2H_3O^+(aq) + 2e^- \to HAsO_2(aq) + 4H_2O(1) & 0.560 \\ I_2(g) + 2e^- \to 2I^-(aq) & 0.535 \\ Cu^+(aq) + e^- \to Cu(g) & 0.521 \\ [RhCl_6]^3 - (aq) + 3e^- \to Rh(s) + 6Cl^-(aq) & 0.5 \\ Cu^2^+(aq) + 2e^- \to Cu(s) & 0.340 \\ Hg_2Cl_2(s) + 2e^- \to 2Hg(1) + 2Cl^-(aq) & 0.27 \\ AgCl(s) + e^- \to Ag(s) + Cl^-(aq) & 0.222 \\ Cu^2^+(aq) + e^- \to Cu^+(aq) & 0.159 \\ SO_4^2 - (aq) + 4H_3O^+(aq) + 2e^- \to H_2SO_3(aq) + 5H_2O(1) & 0.158 \\ Sn^4^+(aq) + 2e^- \to Sn^2^+(aq) & 0.15 \\ S(s) + 2H_3O^+(aq) + 2e^- \to H_2S(aq) + 2H_2O(1) & 0.144 \\ AgBr(s) + e^- \to Ag(s) + Br^-(aq) & 0.0713 \\ 2H_3O^+(aq) + 2e^- \to 2H_2(g) + 2H_2O(1) & condo \\ N_2O(g) + 6H_3O^+(aq) + 2e^- \to H_2S(aq) + 2H_2O(1) & -0.05 \\ HgS(s,black) + 2H_3O^+(aq) + 2e^- \to H_2S(aq) + 2H_2O(1) & -0.05 \\ Se(s) + 2H_3O^+(aq) + 2e^- \to H_2S(aq) + 2H_2O(1) & -0.115 \\ Pb^2^+(aq) + 2e^- \to Sn(s) & -0.1375 \\ AgI(s) + e^- \to Ag(s) + \Gamma^-(aq) & -0.1522 \\ [SnF_6]^2^-(aq) + 4e^- \to Sn(s) + 6F^-(aq) & -0.25 \\ Co^2^+(aq) + 2e^- \to Ni(s) & -0.25 \\ Co^2^+(aq) + 2e^- \to Ni(s) & -0.25 \\ Co^2^+(aq) + 2e^- \to Tl(s) & -0.3363 \\ PbSO_4(s) + 2e^- \to Pb(s) + SO_4^2^-(aq) & -0.3505 \\ Cd^2^+(aq) + 2e^- \to D(d(s) & -0.403 \\ \end{array}$	$2e^- ightarrow \mathrm{Pt(s)} + 4\mathrm{Cl^-(aq)}$
$\begin{array}{llll} TeO_2(s) + 4H_3O^+(aq) + 4e^- \to Te(s) + 6H_2O(l) & 0.604 \\ H_3AsO_4(aq) + 2H_3O^+(aq) + 2e^- \to HAsO_2(aq) + 4H_2O(l) & 0.560 \\ I_2(s) + 2e^- \to 2I^-(aq) & 0.535 \\ Cu^+(aq) + e^- \to Cu(s) & 0.521 \\ [RhCI_6]^3 - (aq) + 3e^- \to Rh(s) + 6Cl^-(aq) & 0.5 \\ Cu^2 + (aq) + 2e^- \to Cu(s) & 0.340 \\ Hg_2Cl_2(s) + 2e^- \to 2Hg(l) + 2Cl^-(aq) & 0.27 \\ AgCl(s) + e^- \to Ag(s) + Cl^-(aq) & 0.159 \\ SO_4^2 - (aq) + 4H_3O^+(aq) + 2e^- \to H_2SO_3(aq) + 5H_2O(l) & 0.158 \\ Sn^4 + (aq) + 2e^- \to Sn^2 + (aq) & 0.15 \\ S(s) + 2H_3O^+(aq) + 2e^- \to H_2S(aq) + 2H_2O(l) & 0.144 \\ AgBr(s) + e^- \to Ag(s) + Br^-(aq) & 0.0713 \\ 2H_3O^+(aq) + 2e^- \to 2H_2(g) + 2H_2O(l) & (reference electrode) & 0.0000 \\ N_2O(g) + 6H_3O^+(aq) + 2e^- \to H_2S(aq) + 2H_2O(l) & -0.05 \\ HgS(s,black) + 2H_3O^+(aq) + 2e^- \to H_2S(aq) + 2H_2O(l) & -0.05 \\ Se(s) + 2H_3O^+(aq) + 2e^- \to H_2S(aq) + 2H_2O(l) & -0.115 \\ Pb^2 + (aq) + 2e^- \to Pb(s) & -0.125 \\ Sn^2 + (aq) + 2e^- \to Sn(s) & -0.1375 \\ AgI(s) + e^- \to Ag(s) + I^-(aq) & -0.200 \\ Ni^2 + (aq) + 2e^- \to Ni(s) & -0.25 \\ Co^2 + (aq) + 2e^- \to Ni(s) & -0.25 \\ Co^2 + (aq) + 2e^- \to Tl(s) & -0.363 \\ PbSO_4(s) + 2e^- \to Pb(s) + SO_4^2 - (aq) & -0.3505 \\ Cd^2 + (aq) + 2e^- \to Pb(s) + SO_4^2 - (aq) & -0.3505 \\ Cd^2 + (aq) + 2e^- \to Cd(s) & -0.403 \\ \end{array}$	$2e^- o [{ m PtCl}_4]^{2-}({ m aq}) + 2{ m Cl}^-({ m aq})$ 0.726
$\begin{array}{lll} H_3 A s O_4(aq) + 2 H_3 O^+(aq) + 2 e^- & \rightarrow H A s O_2(aq) + 4 H_2 O(l) & 0.560 \\ I_2(s) + 2 e^- & \rightarrow 2 \Gamma^-(aq) & 0.535 \\ Cu^+(aq) + e^- & \rightarrow Cu(s) & 0.521 \\ [RhCl_6]^3^-(aq) + 3 e^- & \rightarrow Rh(s) + 6 C\Gamma^-(aq) & 0.5 \\ Cu^2^+(aq) + 2 e^- & \rightarrow Cu(s) & 0.340 \\ Hg_2 Cl_2(s) + 2 e^- & \rightarrow 2 Hg(l) + 2 C\Gamma^-(aq) & 0.27 \\ Ag Cl(s) + e^- & \rightarrow Ag(s) + C\Gamma^-(aq) & 0.222 \\ Cu^2^+(aq) + e^- & \rightarrow Cu^+(aq) & 0.159 \\ SO_4^2^-(aq) + 4 H_3 O^+(aq) + 2 e^- & \rightarrow H_2 SO_3(aq) + 5 H_2 O(l) & 0.158 \\ Sn^{1+}(aq) + 2 e^- & \rightarrow Sn^2^+(aq) & 0.15 \\ S(s) + 2 H_3 O^+(aq) + 2 e^- & \rightarrow H_2 S(aq) + 2 H_2 O(l) & 0.144 \\ AgBr(s) + e^- & \rightarrow Ag(s) + Br^-(aq) & 0.0713 \\ 2 H_3 O^+(aq) + 2 e^- & \rightarrow 2 H_2(g) + 2 H_2 O(l) (reference\ electrode) & 0.0000 \\ N_2 O(g) + 6 H_3 O^+(aq) + 4 e^- & \rightarrow 2 NH_3 OH^+(aq) + 5 H_2 O(l) & -0.05 \\ HgS(s, black) + 2 H_3 O^+(aq) + 2 e^- & \rightarrow H_2 S(aq) + 2 H_2 O(l) & -0.115 \\ Pb^2^+(aq) + 2 e^- & \rightarrow Pb(s) & -0.125 \\ Sn^2^+(aq) + 2 e^- & \rightarrow Sn(s) & -0.1375 \\ AgI(s) + e^- & \rightarrow Ag(s) + \Gamma^-(aq) & -0.1522 \\ [SnF_6]^2^-(aq) + 4 e^- & \rightarrow Sn(s) + 6 F^-(aq) & -0.25 \\ Co^2^+(aq) + 2 e^- & \rightarrow Co(s) & -0.277 \\ Tl^+(aq) + e^- & \rightarrow Tl(s) & -0.3363 \\ PbSO_4(s) + 2 e^- & \rightarrow Cd(s) & -0.403 \\ \end{array}$	${ m (aq)} + 2e^- ightarrow { m H_2O_2(aq)} + 2 { m H_2O(l)}$ 0.695
$\begin{array}{lll} I_2(s) + 2e^- \to 2\Gamma(aq) & 0.535 \\ Cu^+(aq) + e^- \to Cu(s) & 0.521 \\ [RhCl_6]^3 - (aq) + 3e^- \to Rh(s) + 6C\Gamma(aq) & 0.5 \\ Cu^2 + (aq) + 2e^- \to Cu(s) & 0.340 \\ Hg_2(l_2(s) + 2e^- \to 2Hg(l)) + 2Cl^-(aq) & 0.27 \\ AgCl(s) + e^- \to Ag(s) + Cl^-(aq) & 0.222 \\ Cu^2 + (aq) + e^- \to Cu^+(aq) & 0.159 \\ SO_4^2 - (aq) + 4H_3O^+(aq) + 2e^- \to H_2SO_3(aq) + 5H_2O(l) & 0.158 \\ Sn^4 + (aq) + 2e^- \to Sn^2 + (aq) & 0.15 \\ S(s) + 2H_3O^+(aq) + 2e^- \to H_2S(aq) + 2H_2O(l) & 0.144 \\ AgBr(s) + e^- \to Ag(s) + Br^-(aq) & 0.0713 \\ 2H_3O^+(aq) + 2e^- \to 2H_2(g) + 2H_2O(l) (reference\ electrode) & 0.0000 \\ N_2O(g) + 6H_3O^+(aq) + 4e^- \to 2NH_3OH^+(aq) + 5H_2O(l) & -0.05 \\ HgS(s, black) + 2H_3O^+(aq) + 2e^- \to Hg(l) + H_2S(g) + 2H_2O(l) & -0.015 \\ Se(s) + 2H_3O^+(aq) + 2e^- \to H_2Se(aq) + 2H_2O(l) & -0.115 \\ Pb^2 + (aq) + 2e^- \to Sn(s) & -0.1375 \\ AgI(s) + e^- \to Ag(s) + \Gamma^-(aq) & -0.1522 \\ Sn^2 + (aq) + 2e^- \to Ni(s) & -0.25 \\ Co^2 + (aq) + 2e^- \to Ni(s) & -0.25 \\ Co^2 + (aq) + 2e^- \to Co(s) & -0.277 \\ Tl^+(aq) + e^- \to Tl(s) & -0.3363 \\ PbSO_4(s) + 2e^- \to Cd(s) & -0.403 \\ \end{array}$	$\mathrm{O}^{+}(\mathrm{aq}) + 4e^{-} ightarrow \mathrm{Te(s)} + 6\mathrm{H_2O(l)}$ 0.604
$\begin{array}{llllllllllllllllllllllllllllllllllll$	${\rm H_{3}O^{+}(aq)} + 2e^{-} \rightarrow {\rm HAsO_{2}(aq)} + 4{\rm H_{2}O(l)} \qquad \qquad 0.560$
$\begin{array}{llllllllllllllllllllllllllllllllllll$	$I^-(aq)$ 0.535
$\begin{array}{llll} Cu^{2^{+}}(aq) + 2e^{-} \rightarrow Cu(s) & 0.340 \\ Hg_{2}Cl_{2}(s) + 2e^{-} \rightarrow 2Hg(l) + 2Cl^{-}(aq) & 0.27 \\ AgCl(s) + e^{-} \rightarrow Ag(s) + Cl^{-}(aq) & 0.222 \\ Cu^{2^{+}}(aq) + e^{-} \rightarrow Cu^{+}(aq) & 0.159 \\ SO_{4}^{2^{-}}(aq) + 4H_{3}O^{+}(aq) + 2e^{-} \rightarrow H_{2}SO_{3}(aq) + 5H_{2}O(l) & 0.158 \\ Sn^{4^{+}}(aq) + 2e^{-} \rightarrow Sn^{2^{+}}(aq) & 0.15 \\ S(s) + 2H_{3}O^{+}(aq) + 2e^{-} \rightarrow H_{2}S(aq) + 2H_{2}O(l) & 0.144 \\ AgBr(s) + e^{-} \rightarrow Ag(s) + Br^{-}(aq) & 0.0713 \\ 2H_{3}O^{+}(aq) + 2e^{-} \rightarrow 2H_{2}(g) + 2H_{2}O(l) (referenceelectrode) & 0.0000 \\ N_{2}O(g) + 6H_{3}O^{+}(aq) + 4e^{-} \rightarrow 2NH_{3}OH^{+}(aq) + 5H_{2}O(l) & -0.05 \\ HgS(s,black) + 2H_{3}O^{+}(aq) + 2e^{-} \rightarrow Hg(l) + H_{2}S(g) + 2H_{2}O(l) & -0.115 \\ Se(s) + 2H_{3}O^{+}(aq) + 2e^{-} \rightarrow H_{2}Se(aq) + 2H_{2}O(l) & -0.125 \\ Sn^{2^{+}}(aq) + 2e^{-} \rightarrow Sn(s) & -0.1375 \\ AgI(s) + e^{-} \rightarrow Ag(s) + I^{-}(aq) & -0.522 \\ [SnF_{6}]^{2^{-}}(aq) + 4e^{-} \rightarrow Sn(s) + 6F^{-}(aq) & -0.200 \\ Ni^{2^{+}}(aq) + 2e^{-} \rightarrow Ni(s) & -0.25 \\ Co^{2^{+}}(aq) + 2e^{-} \rightarrow Pb(s) + SO_{4}^{2^{-}}(aq) & -0.3363 \\ PbSO_{4}(s) + 2e^{-} \rightarrow Pb(s) + SO_{4}^{2^{-}}(aq) & -0.3505 \\ Cd^{2^{+}}(aq) + 2e^{-} \rightarrow Cd(s) & -0.403 \\ \end{array}$	m Cu(s) 0.521
$\begin{array}{llllllllllllllllllllllllllllllllllll$	$-3e^- ightarrow ext{Rh(s)} + 6 ext{ Cl}^-(ext{aq})$
$\begin{array}{llllllllllllllllllllllllllllllllllll$	$ ightarrow \mathrm{Cu(s)}$ 0.340
$\begin{array}{lll} Cu^{2+}(aq) + e^{-} \rightarrow Cu^{+}(aq) & 0.159 \\ SO_{4}^{2-}(aq) + 4H_{3}O^{+}(aq) + 2e^{-} \rightarrow H_{2}SO_{3}(aq) + 5H_{2}O(l) & 0.158 \\ Sn^{4+}(aq) + 2e^{-} \rightarrow Sn^{2+}(aq) & 0.15 \\ S(s) + 2H_{3}O^{+}(aq) + 2e^{-} \rightarrow H_{2}S(aq) + 2H_{2}O(l) & 0.144 \\ AgBr(s) + e^{-} \rightarrow Ag(s) + Br^{-}(aq) & 0.0713 \\ 2H_{3}O^{+}(aq) + 2e^{-} \rightarrow 2H_{2}(g) + 2H_{2}O(l) & (reference\ electrode) & 0.0000 \\ N_{2}O(g) + 6H_{3}O^{+}(aq) + 4e^{-} \rightarrow 2NH_{3}OH^{+}(aq) + 5H_{2}O(l) & -0.05 \\ HgS(s, black) + 2H_{3}O^{+}(aq) + 2e^{-} \rightarrow Hg(l) + H_{2}S(g) + 2H_{2}O(l) & -0.015 \\ Se(s) + 2H_{3}O^{+}(aq) + 2e^{-} \rightarrow H_{2}Se(aq) + 2H_{2}O(l) & -0.115 \\ Pb^{2+}(aq) + 2e^{-} \rightarrow Pb(s) & -0.125 \\ Sn^{2+}(aq) + 2e^{-} \rightarrow Sn(s) & -0.1375 \\ AgI(s) + e^{-} \rightarrow Ag(s) + I^{-}(aq) & -0.522 \\ [SnF_{6}]^{2-}(aq) + 4e^{-} \rightarrow Sn(s) + 6F^{-}(aq) & -0.200 \\ Ni^{2+}(aq) + 2e^{-} \rightarrow Ni(s) & -0.25 \\ Co^{2+}(aq) + 2e^{-} \rightarrow Co(s) & -0.277 \\ Tl^{+}(aq) + e^{-} \rightarrow Tl(s) & -0.3363 \\ PbSO_{4}(s) + 2e^{-} \rightarrow Pb(s) + SO_{4}^{2-}(aq) & -0.3505 \\ Cd^{2+}(aq) + 2e^{-} \rightarrow Cd(s) & -0.403 \\ \end{array}$	$ ightarrow 2\mathrm{Hg}(\mathrm{l}) + 2\mathrm{Cl}^-(\mathrm{aq})$ 0.27
$\begin{array}{llllllllllllllllllllllllllllllllllll$	$\mathrm{Ag}(\mathrm{s}) + \mathrm{Cl}^-(\mathrm{aq})$ 0.222
$\begin{array}{llllllllllllllllllllllllllllllllllll$	$ ightarrow { m Cu}^+({ m aq})$ 0.159
$\begin{array}{llllllllllllllllllllllllllllllllllll$	$_3{ m O}^+({ m aq}) + 2e^- ightarrow { m H}_2{ m SO}_3({ m aq}) + 5{ m H}_2{ m O}({ m l})$ 0.158
$\begin{array}{llllllllllllllllllllllllllllllllllll$	ightarrow Sn ²⁺ (aq) 0.15
$\begin{array}{llllllllllllllllllllllllllllllllllll$	$\mathrm{q}) + 2e^- \rightarrow \mathrm{H_2S(aq)} + 2\mathrm{H_2O(l)} \qquad \qquad 0.144$
$\begin{array}{llll} N_2 O(g) + 6 H_3 O^+(aq) + 4e^- &\rightarrow 2 N H_3 O H^+(aq) + 5 H_2 O(l) & -0.05 \\ Hg S(s, black) + 2 H_3 O^+(aq) + 2e^- &\rightarrow Hg(l) + H_2 S(g) + 2 H_2 O(l) & -0.085 \\ Se(s) + 2 H_3 O^+(aq) + 2e^- &\rightarrow H_2 Se(aq) + 2 H_2 O(l) & -0.115 \\ Pb^2 + (aq) + 2e^- &\rightarrow Pb(s) & -0.125 \\ Sn^2 + (aq) + 2e^- &\rightarrow Sn(s) & -0.1375 \\ Ag I(s) + e^- &\rightarrow Ag(s) + I^-(aq) & -0.1522 \\ [SnF_6]^2 - (aq) + 4e^- &\rightarrow Sn(s) + 6 F^-(aq) & -0.200 \\ Ni^2 + (aq) + 2e^- &\rightarrow Ni(s) & -0.25 \\ Co^2 + (aq) + 2e^- &\rightarrow Co(s) & -0.277 \\ Tl^+(aq) + e^- &\rightarrow Tl(s) & -0.3363 \\ Pb SO_4(s) + 2e^- &\rightarrow Pb(s) + SO_4^2 - (aq) & -0.3505 \\ Cd^2 + (aq) + 2e^- &\rightarrow Cd(s) & -0.403 \\ \end{array}$	$\mathrm{Ag(s)} + \mathrm{Br^-(aq)}$
$\begin{array}{lllll} & & & & & & & \\ & & & & \\ & & & & \\ & & & \\ & & & \\ & & & \\ &$	${ m e}^- ightarrow 2{ m H}_2^{}({ m g}) + 2{ m H}_2^{}{ m O}({ m l})$ (reference electrode) 0.0000
$\begin{array}{llllllllllllllllllllllllllllllllllll$	$^{+}({ m aq}) + 4e^{-} ightarrow 2{ m NH_{3}OH^{+}(aq)} + 5{ m H_{2}O(l)}$ -0.05
$\begin{array}{llllllllllllllllllllllllllllllllllll$	$2{ m H_3O^+(aq)} + 2e^- ightarrow { m Hg(l)} + { m H_2S(g)} + 2{ m H_2O(l)} \hspace{0.5cm} -0.085$
$\begin{array}{llll} & Sn^{2+}(aq) + 2e^{-} \rightarrow Sn(s) & -0.1375 \\ & AgI(s) + e^{-} \rightarrow Ag(s) + I^{-}(aq) & -0.1522 \\ & [SnF_{6}]^{2-}(aq) + 4e^{-} \rightarrow Sn(s) + 6 \ F^{-}(aq) & -0.200 \\ & Ni^{2+}(aq) + 2e^{-} \rightarrow Ni(s) & -0.25 \\ & Co^{2+}(aq) + 2e^{-} \rightarrow Co(s) & -0.277 \\ & Tl^{+}(aq) + e^{-} \rightarrow Tl(s) & -0.3363 \\ & PbSO_{4}(s) + 2e^{-} \rightarrow Pb(s) + SO_{4}^{2-}(aq) & -0.3505 \\ & Cd^{2+}(aq) + 2e^{-} \rightarrow Cd(s) & -0.403 \\ \end{array}$	$\mathrm{aq}) + 2e^- ightarrow \mathrm{H_2Se(aq)} + 2\mathrm{H_2O(l)}$
$\begin{array}{lll} {\rm AgI(s)} + e^- \to {\rm Ag(s)} + {\rm I^-(aq)} & -0.1522 \\ & [{\rm SnF_6}]^{2^-}({\rm aq}) + 4e^- \to {\rm Sn(s)} + 6{\rm F^-(aq)} & -0.200 \\ & {\rm Ni^2}^+({\rm aq}) + 2e^- \to {\rm Ni(s)} & -0.25 \\ & {\rm Co^2}^+({\rm aq}) + 2e^- \to {\rm Co(s)} & -0.277 \\ & {\rm Tl^+(aq)} + e^- \to {\rm Tl(s)} & -0.3363 \\ & {\rm PbSO_4(s)} + 2e^- \to {\rm Pb(s)} + {\rm SO_4^2}^-({\rm aq}) & -0.3505 \\ & {\rm Cd^2}^+({\rm aq}) + 2e^- \to {\rm Cd(s)} & -0.403 \\ \end{array}$	$ ightarrow ext{Pb(s)}$
$\begin{split} & [\operatorname{SnF}_6]^{2^-}(\operatorname{aq}) + 4e^- \to \operatorname{Sn}(\operatorname{s}) + 6\operatorname{F}^-(\operatorname{aq}) & -0.200 \\ & \operatorname{Ni}^{2^+}(\operatorname{aq}) + 2e^- \to \operatorname{Ni}(\operatorname{s}) & -0.25 \\ & \operatorname{Co}^{2^+}(\operatorname{aq}) + 2e^- \to \operatorname{Co}(\operatorname{s}) & -0.277 \\ & \operatorname{Tl}^+(\operatorname{aq}) + e^- \to \operatorname{Tl}(\operatorname{s}) & -0.3363 \\ & \operatorname{PbSO}_4(\operatorname{s}) + 2e^- \to \operatorname{Pb}(\operatorname{s}) + \operatorname{SO}_4^{2^-}(\operatorname{aq}) & -0.3505 \\ & \operatorname{Cd}^{2^+}(\operatorname{aq}) + 2e^- \to \operatorname{Cd}(\operatorname{s}) & -0.403 \end{split}$	$ ightarrow \mathrm{Sn(s)}$ -0.1375
$\begin{array}{lll} {\rm Ni^2}^+({\rm aq}) + 2e^- \to {\rm Ni(s)} & -0.25 \\ {\rm Co^2}^+({\rm aq}) + 2e^- \to {\rm Co(s)} & -0.277 \\ {\rm Tl^+(aq)} + e^- \to {\rm Tl(s)} & -0.3363 \\ {\rm PbSO_4(s)} + 2e^- \to {\rm Pb(s)} + {\rm SO_4^2}^-({\rm aq}) & -0.3505 \\ {\rm Cd^2}^+({\rm aq}) + 2e^- \to {\rm Cd(s)} & -0.403 \\ \end{array}$	-0.1522
$\begin{array}{lll} & & & & & & & & & & & & \\ & & & & & & $	$e^- ightarrow \mathrm{Sn}(\mathrm{s}) + 6\mathrm{F}^-(\mathrm{aq})$ -0.200
$\begin{array}{ll} {\rm Tl}^{+}({\rm aq}) + e^{-} \to {\rm Tl(s)} & -0.3363 \\ {\rm PbSO}_4({\rm s}) + 2e^{-} \to {\rm Pb(s)} + {\rm SO}_4^{2-}({\rm aq}) & -0.3505 \\ {\rm Cd}^{2+}({\rm aq}) + 2e^{-} \to {\rm Cd(s)} & -0.403 \end{array}$	$ ightarrow \mathrm{Ni(s)}$
$\begin{array}{ll} {\rm PbSO_4(s) + 2}e^- \to {\rm Pb(s) + SO_4^2^-(aq)} & -0.3505 \\ {\rm Cd^2^+(aq) + 2}e^- \to {\rm Cd(s)} & -0.403 \end{array}$	$ ightarrow ext{Co(s)}$
$\mathrm{Cd}^{2+}(\mathrm{aq}) + 2e^- ightarrow \mathrm{Cd}(\mathrm{s})$ -0.403	-0.3363
$\mathrm{Cr}^{3+}(\mathrm{aq}) + e^- ightarrow \mathrm{Cr}^{2+}(\mathrm{aq})$	ightarrow Cr ²⁺ (aq)
$\mathrm{Fe^{2}}^{+}(\mathrm{aq}) + 2e^{-} ightarrow \mathrm{Fe(s)}$	$ ightarrow { m Fe(s)}$
$2 \operatorname{CO_2(g)} + 2 \operatorname{H_3O^+(aq)} + 2 e^- \to (\operatorname{COOH})_2(\operatorname{aq}) + 2 \operatorname{H_2O(l)} \\ -0.481$	$\mathrm{O^+(aq)} + 2e^- ightarrow \mathrm{(COOH)}_2\mathrm{(aq)} + 2\mathrm{H}_2\mathrm{O(l)}$ -0.481



Acidic Solution	Standard Reduction Potential, E° (volts)
$\mathrm{Ga^3}^+(\mathrm{aq}) + 3e^- ightarrow \mathrm{Ga(s)}$	-0.53
$\mathrm{Cr}^{3+}(\mathrm{aq}) + 3e^- ightarrow \mathrm{Cr}(\mathrm{s})$	-0.74
$\mathrm{Zn^{2}}^{+}(\mathrm{aq}) + 2e^{-} ightarrow \mathrm{Zn(s)}$	-0.763
$\mathrm{Cr}^{2+}(\mathrm{aq}) + 2e^- o \mathrm{Cr}(\mathrm{s})$	-0.90
$\mathrm{V}^{2+}(\mathrm{aq}) + 2e^- ightarrow \mathrm{V(s)}$	-1.13
$\mathrm{Mn}^{2+}(\mathrm{aq}) + 2e^- ightarrow \mathrm{Mn}(\mathrm{s})$	-1.18
$\mathrm{Zr}^{4+}(\mathrm{aq}) + 4e^- ightarrow \mathrm{Zr}(\mathrm{s})$	-1.55
$\mathrm{Al}^{3}{}^{+}(\mathrm{aq}) + 3e^{-} ightarrow \mathrm{Al}(\mathrm{s})$	-1.676
$\mathrm{H_2(g)} + 2e^- ightarrow 2\mathrm{H^-(aq)}$	-2.25
$\mathrm{Mg}^{2+}(\mathrm{aq}) + 2e^- ightarrow \mathrm{Mg}(\mathrm{s})$	-2.356
${ m Na^+(aq)} + e^- ightarrow { m Na(s)}$	-2.714
$\mathrm{Ca^2}^+(\mathrm{aq}) + 2e^- ightarrow \mathrm{Ca(s)}$	-2.84
$\mathrm{Sr}^{2+}(\mathrm{aq}) + 2e^- ightarrow \mathrm{Sr}(\mathrm{s})$	-2.89
$\mathrm{Ba^2}^+(\mathrm{aq}) + 2e^- o \mathrm{Ba}(\mathrm{s})$	-2.92
${ m Rb}^+({ m aq}) + e^- ightarrow { m Rb}({ m s})$	-2.925
$\mathrm{K}^+(\mathrm{aq}) + e^- ightarrow \mathrm{K}(\mathrm{s})$	-2.925
$\mathrm{Li}^+(\mathrm{aq}) + e^- o \mathrm{Li}(\mathrm{s})$	-3.045

Basic Solution	Standard Reduction Potential, E° (volts)
$ ext{ClO}^-(ext{aq}) + ext{H}_2 ext{O(l)} + 2e^- ightarrow ext{Cl}^-(ext{aq}) + 2 ext{OH}^-(ext{aq})$	0.89
$\mathrm{OOH^-(aq)} + \mathrm{H_2O(l)} + 2e^- \rightarrow 3\mathrm{OH^-(aq)}$	0.867
$2\mathrm{NH_2OH(aq)} + 2e^- \rightarrow \mathrm{N_2H_4(aq)} + 2\mathrm{OH^-(aq)}$	0.73
$\mathrm{ClO_3^-(aq)} + 3\mathrm{H_2O(l)} + 6e^- \rightarrow \mathrm{Cl^-(aq)} + 6\mathrm{OH^-(aq)}$	0.622
$\mathrm{ClO_3^-(aq)} + 3\mathrm{H_2O(l)} + 6e^- \rightarrow \mathrm{Cl^-(aq)} + 6\mathrm{OH^-(aq)}$	0.622
$\mathrm{MnO}_{4}^{-}(\mathrm{aq}) + 2\mathrm{H}_{2}\mathrm{O}(\mathrm{l}) + 3e^{-} \rightarrow \mathrm{MnO}_{2}(\mathrm{s}) + 4\mathrm{OH}^{-}(\mathrm{aq})$	0.60
$\mathrm{MnO_4^-(aq)} + e^- ightarrow \mathrm{MnO_4^2^-(aq)}$	0.56
$\mathrm{NiO}_2(\mathrm{s}) + 2\mathrm{H}_2\mathrm{O}(\mathrm{l}) + 2e^- \rightarrow \mathrm{Ni}(\mathrm{OH})_2(\mathrm{s}) + 2\mathrm{OH}^-(\mathrm{aq})$	0.49
${ m Ag_2CrO_4^-(s)} + 2e^- ightarrow 2{ m Ag(s)} + { m CrO_4^{2-}(aq)}$	0.4491
$\mathrm{O_2(g)} + 2\mathrm{H_2O(l)} + 4e^- ightarrow 4\mathrm{OH^-(aq)}$	0.401
$\text{ClO}_4^-(\text{aq}) + \text{H}_2\text{O(l)} + 2e^- \rightarrow \text{ClO}_3^-(\text{aq}) + 2\text{OH}^-(\text{aq})$	0.374
$\mathrm{Ag_2O(s)} + \mathrm{H_2O(l)} + 2e^- \rightarrow 2\mathrm{Ag(s)} + 2\mathrm{OH^-(aq)}$	0.342
$2{\rm NO_2^-(aq)} + 3{\rm H_2O(l)} + 4e^- \rightarrow {\rm N_2O(g)} + 6{\rm OH^-(aq)}$	0.15
${\rm [Co(NH_3)_6]^{3}}^{+}{\rm (aq)} + e^{-} \rightarrow {\rm [Co(NH_3)_6]^{3}}^{+}{\rm (aq)}$	0.058
$\mathrm{HgO}(\mathrm{s}) + \mathrm{H_2O}(\mathrm{l}) + 2e^- ightarrow \mathrm{Hg}(\mathrm{l}) + 2\mathrm{OH^-}(\mathrm{aq})$	0.0977
$\mathrm{O_2(g)} + \mathrm{H_2O(l)} + 2e^- \rightarrow \mathrm{OOH^-(aq)} + \mathrm{OH^-(aq)}$	0.0649
$\mathrm{NO_3^-(aq)} + \mathrm{H_2O(l)} + 2e^- ightarrow \mathrm{NO_2^-(aq)} + 2\mathrm{OH^-(aq)}$	0.01
$\mathrm{MnO}_2(\mathbf{s}) + 2\mathrm{H}_2\mathrm{O}(\mathbf{l}) + 2e^- \rightarrow \mathrm{Mn}(\mathrm{OH})_2(\mathbf{s}) + 2\mathrm{OH}^-(\mathbf{aq})$	-0.05
${ m CrO}_4^{2-}({ m aq}) + 4{ m H}_2{ m O}({ m l}) + 3e^- ightarrow { m Cr}({ m OH})_3({ m s}) + 5{ m OH}^-({ m aq})$	-0.11



$\mathrm{Cu_2O(s)} + \mathrm{H_2O(l)} + 2e^- ightarrow 2\mathrm{Cu(s)} + 2\mathrm{OH^-(aq)}$	-0.365
$\mathrm{FeO}_2(\mathrm{aq}) + \mathrm{H}_2\mathrm{O}(\mathrm{l}) + 2e^- \rightarrow \mathrm{HFeO}_2^-(\mathrm{aq}) + \mathrm{OH}^-(\mathrm{aq})$	-0.69
$2\mathrm{H_2O(l)} + 2e^- \rightarrow \mathrm{H_2(g)} + 2\mathrm{OH^-(aq)}$	-0.8277
$2{\rm NO_3^-(aq)} + 2{\rm H_2O(l)} + 2e^- \rightarrow {\rm N_2O_4(g)} + 4{\rm OH^-(aq)}$	-0.86
$\mathrm{HFeO_2^-(aq)} + 2e^- ightarrow \mathrm{Fe(s)} + 3~\mathrm{OH^-(aq)}$	-0.8
$\mathrm{SO}_4^{2-}(\mathrm{aq}) + \mathrm{H}_2\mathrm{O}(\mathrm{l}) + 2e^- \rightarrow \mathrm{SO}_3^{2-}(\mathrm{aq}) + 2\mathrm{OH}^-(\mathrm{aq})$	-0.936
${\rm N_2(g)} + 4{\rm H_2O(l)} + 4e^- \rightarrow {\rm N_2H_4(aq)} + 4{\rm OH^-(aq)}$	-1.16
$[\mathrm{Zn(OH)}_4]^{2-}(\mathrm{aq}) + 2e^- \rightarrow \mathrm{Zn(s)} + 4\mathrm{OH^-(aq)}$	-1.285
$\mathrm{Zn}(\mathrm{OH})_2(\mathrm{s}) + 2e^- ightarrow \mathrm{Zn}(\mathrm{s}) + 2\mathrm{OH}^-(\mathrm{aq})$	-1.246
$\left[\mathrm{Zn(CN)}_4 ight]^{2-}(\mathrm{aq}) + 2e^- ightarrow \mathrm{Zn(s)} + 4\mathrm{CN^-(aq)}$	-1.34
$\mathrm{Cr}(\mathrm{OH})_3(\mathrm{s}) + 3e^- ightarrow \mathrm{Cr}(\mathrm{s}) + 3\mathrm{OH}^-(\mathrm{aq})$	-1.33
$\mathrm{SiO_3^{2-}(aq)} + 3\mathrm{H_2O(l)} + 4e^- \rightarrow \mathrm{Si(s)} + 6\mathrm{OH^-(aq)}$	-1.69

contacts here

to the right of Pt, $H_2(1 \text{ atm}) \mid H^+(1 M)$, as in Eq. 17.10.2 above, the E° is + 0.34 V. For the $Zn^{2+} \mid Zn$ redox couple, we find $E^{\circ} = -0.76 \text{ V}$ in Table 17.1. This means that for the cell

$$Pt, H_2(1 \text{ atm}) \mid H^+(1 \text{ M}) \parallel Zn^{2 +}(1 \text{ M}) \mid ZnE^o = -0.76 \text{ V}$$

Since Eq. 17.10.1 shows this cell in reverse, we change the sign of E° , obtaining + 0.76 V. Thus we can combine standard reduction potentials from Table 1 to obtain emf's for cells like Eq. 17.10.3so long as both electrodes are given in the table.

Example 17.10.3: Find the standard emf for the cell

$$Hg(l) | Hg^{2+}(1 M) | Br^{-} | Br_{2}(l), Pt$$

Solution

From Table 17.10.1we have;

$$Pt, H_2(1\:atm) \mid H^+(1\:M) \parallel Hg^2 + (1\:M) \mid Hg(l)E^o = + \ 0 \cdot 85\:V$$

Since we want to be the left-hand electrode, this must be reversed and the sign of E° must be changed:

$$Hg(l) \mid Hg^{2} + (1 M) \mid H^{+}(1 M) \mid H_{2}(1atm), PtE^{o} = -0.85V$$
 (17.10.4)

For the other electrode Table 17.10.1 gives

$$Pt, H_{2}(1 \text{ atm}) \mid H^{+}(1 \text{ M}) \parallel Br^{-}(1 \text{ M}) \mid Br_{2}(1), PtE^{0} = +1 \cdot 07 \text{ V}$$
 (17.10.5)

Adding the cells of Eqs. 17.10.4 and 17.10.5, we obtain

$${\rm Hg(l)} \mid {\rm Hg^2}^+(1\,{\rm M}) \parallel {\rm Br}^-(1\,{\rm M}) \mid {\rm Br}_2(l), {\rm PtE^o} = (1\,\cdot 07 - 0\,\cdot 85\,) \\ {\rm V} = +\,0\,\cdot 22\,{\rm V}$$

The positive value of the standard emf obtained in Example 17.10.3 indicates that the corresponding cell reaction is spontaneous:

$$Hg(l) + Br_2(l) \rightarrow Hg^{2+}(1 M) + 2 Br^{-}(1 M)$$

In other words, bromine is a strong enough oxidizing agent to convert mercury metal to mercury(II) ions in aqueous solution, assuming the concentrations of mercury(II) and bromide ions to be 1 mol dm⁻³. This corresponds to the observations made where liquid mercury combined with liquid bromine to form mercury(II) bromide. Thus the standard reduction potentials in Table 17.10.1 can be used to predict whether a particular reaction will take place, just as Table 1 in Redox Couples was used in our earlier discussion of redox reactions. The advantage of Table 17.10.1 is that it gives quantitative as well as qualitative information. It not



only tells us that $Br_2(l)$ is a stronger oxidizing agent than Hg^{2+} (1 M) [because $Br_2(l)$ is above Hg^{2+} (1 M), but it also tells us how much stronger, in terms of the cell emf of + 0.22 V.

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