

Topic 6M - Standard Potentials

Half-Cell Standard Potentials

Standard emf of an electrochemical cell is the difference between two half-cell standard potentials:

$$E^{\circ} = E^{\circ}_{\text{cathode hc (redn.)}} - E^{\circ}_{\text{anode hc (oxidn.)}}$$

With both half-cell reactions written as **reductions**.

The half-cell reaction with the more positive reduction potential will occur spontaneously as a reduction, while the other half-cell reaction will occur as an oxidation.

Hydrogen Electrode

Just as absolute energies cannot be determined in thermodynamics, but only energy differences, so also only differences in E° are relevant. Thus, we can arbitrarily select one half-cell reaction and assign it a value of $E^{\circ} = 0$ (analogous to $\Delta G^{\circ}_{\text{f elements}} = 0$). The half-cell reaction so designated is the **hydrogen electrode**:



Tabulated E° values of all other half-reactions are relative to that of the hydrogen electrode.

Standard Hydrogen Electrode

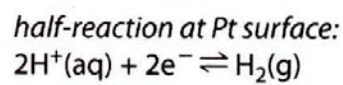
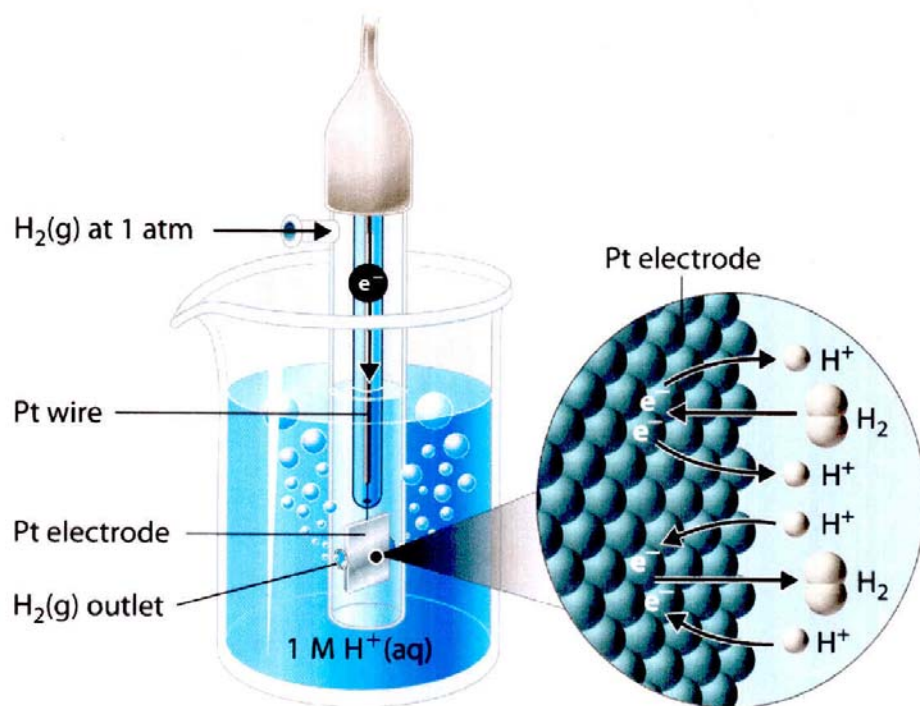


TABLE 6M.1 Standard Potentials at 25 °C*

Species	Reduction half-reaction	E°/V
Oxidized form is strongly oxidizing		
F_2/F^-	$\text{F}_2(\text{g}) + 2 \text{e}^- \longrightarrow 2 \text{F}^-(\text{aq})$	+2.87
Au^+/Au	$\text{Au}^+(\text{aq}) + \text{e}^- \longrightarrow \text{Au}(\text{s})$	+1.69
$\text{Ce}^{4+}/\text{Ce}^{3+}$	$\text{Ce}^{4+}(\text{aq}) + \text{e}^- \longrightarrow \text{Ce}^{3+}(\text{aq})$	+1.61
$\text{MnO}_4^-, \text{H}^+/\text{Mn}^{2+}, \text{H}_2\text{O}$	$\text{MnO}_4^-(\text{aq}) + 8 \text{H}^+(\text{aq}) + 5 \text{e}^- \longrightarrow \text{Mn}^{2+}(\text{aq}) + 4 \text{H}_2\text{O}(\text{l})$	+1.51
Cl_2/Cl^-	$\text{Cl}_2(\text{g}) + 2 \text{e}^- \longrightarrow 2 \text{Cl}^-(\text{aq})$	+1.36
$\text{Cr}_2\text{O}_7^{2-}, \text{H}^+/\text{Cr}^{3+}, \text{H}_2\text{O}$	$\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14 \text{H}^+(\text{aq}) + 6 \text{e}^- \longrightarrow 2 \text{Cr}^{3+}(\text{aq}) + 7 \text{H}_2\text{O}(\text{l})$	+1.33
$\text{O}_2, \text{H}^+/\text{H}_2\text{O}$	$\text{O}_2(\text{g}) + 4 \text{H}^+(\text{aq}) + 4 \text{e}^- \longrightarrow 2 \text{H}_2\text{O}(\text{l})$	+1.23; +0.82 at pH = 7
Br_2/Br^-	$\text{Br}_2(\text{l}) + 2 \text{e}^- \longrightarrow 2 \text{Br}^-(\text{aq})$	+1.09
$\text{NO}_3^-, \text{H}^+/\text{NO}, \text{H}_2\text{O}$	$\text{NO}_3^-(\text{aq}) + 4 \text{H}^+(\text{aq}) + 3 \text{e}^- \longrightarrow \text{NO}(\text{g}) + 2 \text{H}_2\text{O}(\text{l})$	+0.96
Ag^+/Ag	$\text{Ag}^+(\text{aq}) + \text{e}^- \longrightarrow \text{Ag}(\text{s})$	+0.80
$\text{Fe}^{3+}/\text{Fe}^{2+}$	$\text{Fe}^{3+}(\text{aq}) + \text{e}^- \longrightarrow \text{Fe}^{2+}(\text{aq})$	+0.77
I_2/I^-	$\text{I}_2(\text{s}) + 2 \text{e}^- \longrightarrow 2 \text{I}^-(\text{aq})$	+0.54
$\text{O}_2, \text{H}_2\text{O}/\text{OH}^-$	$\text{O}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{l}) + 4 \text{e}^- \longrightarrow 4 \text{OH}^-(\text{aq})$	+0.40; +0.82 at pH = 7
Cu^{2+}/Cu	$\text{Cu}^{2+}(\text{aq}) + 2 \text{e}^- \longrightarrow \text{Cu}(\text{s})$	+0.34
$\text{AgCl}/\text{Ag}, \text{Cl}^-$	$\text{AgCl}(\text{s}) + \text{e}^- \longrightarrow \text{Ag}(\text{s}) + \text{Cl}^-(\text{aq})$	+0.22
H^+/H_2	$2 \text{H}^+(\text{aq}) + 2 \text{e}^- \longrightarrow \text{H}_2(\text{g})$	0, by definition
Fe^{3+}/Fe	$\text{Fe}^{3+}(\text{aq}) + 3 \text{e}^- \longrightarrow \text{Fe}(\text{s})$	-0.04
$\text{O}_2, \text{H}_2\text{O}/\text{HO}_2^-, \text{OH}^-$	$\text{O}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) + 2 \text{e}^- \longrightarrow \text{HO}_2^-(\text{aq}) + \text{OH}^-(\text{aq})$	-0.08
Pb^{2+}/Pb	$\text{Pb}^{2+}(\text{aq}) + 2 \text{e}^- \longrightarrow \text{Pb}(\text{s})$	-0.13
Sn^{2+}/Sn	$\text{Sn}^{2+}(\text{aq}) + 2 \text{e}^- \longrightarrow \text{Sn}(\text{s})$	-0.14
Fe^{2+}/Fe	$\text{Fe}^{2+}(\text{aq}) + 2 \text{e}^- \longrightarrow \text{Fe}(\text{s})$	-0.44
Zn^{2+}/Zn	$\text{Zn}^{2+}(\text{aq}) + 2 \text{e}^- \longrightarrow \text{Zn}(\text{s})$	-0.76
$\text{H}_2\text{O}/\text{H}_2, \text{OH}^-$	$2 \text{H}_2\text{O}(\text{l}) + 2 \text{e}^- \longrightarrow \text{H}_2(\text{g}) + 2 \text{OH}^-(\text{aq})$	-0.83; -0.42 at pH = 7
Al^{3+}/Al	$\text{Al}^{3+}(\text{aq}) + 3 \text{e}^- \longrightarrow \text{Al}(\text{s})$	-1.66
Mg^{2+}/Mg	$\text{Mg}^{2+}(\text{aq}) + 2 \text{e}^- \longrightarrow \text{Mg}(\text{s})$	-2.36
Na^+/Na	$\text{Na}^+(\text{aq}) + \text{e}^- \longrightarrow \text{Na}(\text{s})$	-2.71
K^+/K	$\text{K}^+(\text{aq}) + \text{e}^- \longrightarrow \text{K}(\text{s})$	-2.93
Li^+/Li	$\text{Li}^+(\text{aq}) + \text{e}^- \longrightarrow \text{Li}(\text{s})$	-3.05
Reduced form is strongly reducing		

*For a more extensive table, see Appendix 2B.

Table 6M.1Atkins, *Chemical Principles: The Quest for Insight*, 7e

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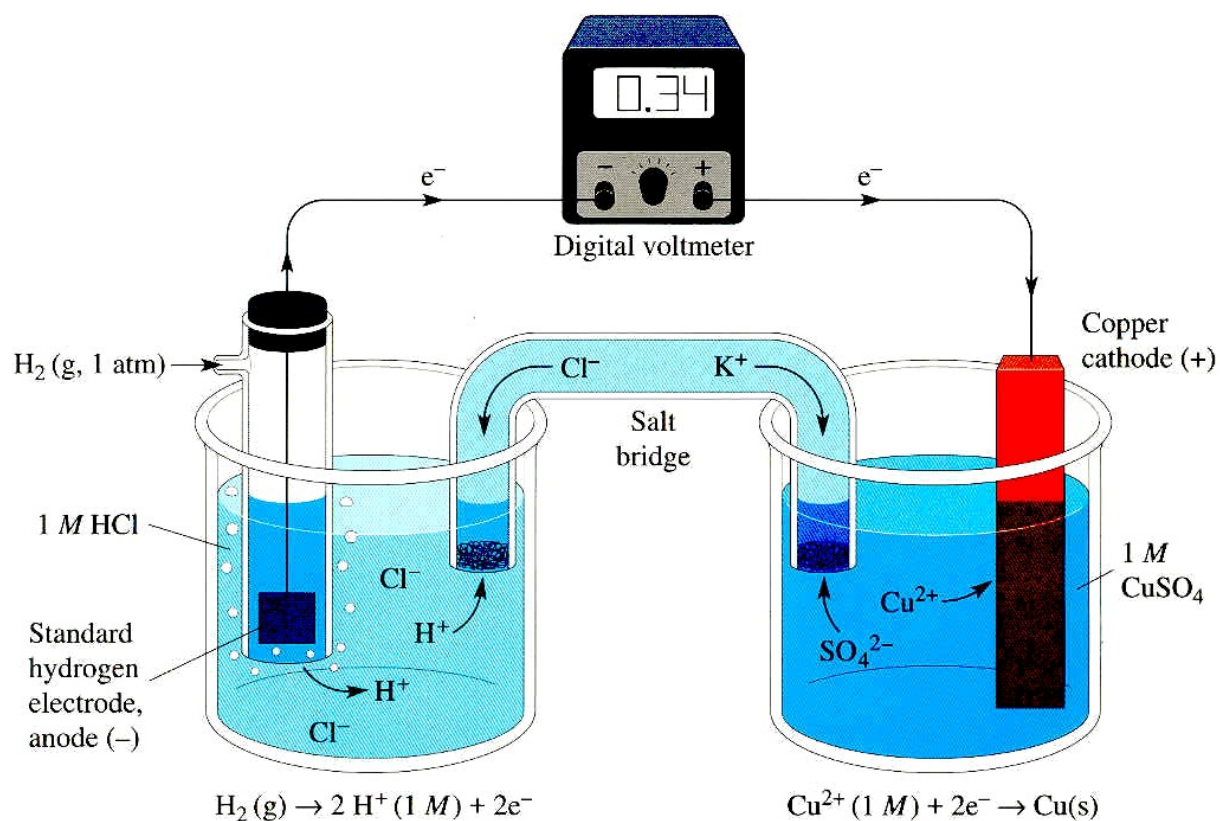
Tabulated by Decreasing Reduction Potential:

Reduction half-reaction	E° (V)	Reduction half-reaction	E° (V)
Strongly oxidizing		$\text{NO}_3^- + \text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{NO}_2^- + 2\text{OH}^-$	+0.01
$\text{H}_4\text{XeO}_6 + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{XeO}_3 + 3\text{H}_2\text{O}$	+3.0	$\text{Ti}^{4+} + \text{e}^- \rightarrow \text{Ti}^{3+}$	0.00
$\text{F}_2 + 2\text{e}^- \rightarrow 2\text{F}^-$	+2.87	$2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$	0, by definition
$\text{O}_3 + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{O}_2 + \text{H}_2\text{O}$	+2.07	$\text{Fe}^{3+} + 3\text{e}^- \rightarrow \text{Fe}$	-0.04
$\text{S}_2\text{O}_8^{2-} + 2\text{e}^- \rightarrow 2\text{SO}_4^{2-}$	+2.05	$\text{O}_2 + \text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{HO}_2^- + \text{OH}^-$	-0.08
$\text{Ag}^{2+} + \text{e}^- \rightarrow \text{Ag}^+$	+1.98	$\text{Pb}^{2+} + 2\text{e}^- \rightarrow \text{Pb}$	-0.13
$\text{Co}^{3+} + \text{e}^- \rightarrow \text{Co}^{2+}$	+1.81	$\text{In}^+ + \text{e}^- \rightarrow \text{In}$	-0.14
$\text{H}_2\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightarrow 2\text{H}_2\text{O}$	+1.78	$\text{Sn}^{2+} + 2\text{e}^- \rightarrow \text{Sn}$	-0.14
$\text{Au}^+ + \text{e}^- \rightarrow \text{Au}$	+1.69	$\text{AgI} + \text{e}^- \rightarrow \text{Ag} + \text{I}^-$	-0.15
$\text{Pb}^{4+} + 2\text{e}^- \rightarrow \text{Pb}^{2+}$	+1.67	$\text{Ni}^{2+} + 2\text{e}^- \rightarrow \text{Ni}$	-0.23
$2\text{HClO} + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{Cl}_2 + 2\text{H}_2\text{O}$	+1.63	$\text{V}^{3+} + \text{e}^- \rightarrow \text{V}^{2+}$	-0.26
$\text{Ce}^{4+} + \text{e}^- \rightarrow \text{Ce}^{3+}$	+1.61	$\text{Co}^{2+} + 2\text{e}^- \rightarrow \text{Co}$	-0.28
$2\text{HBrO} + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{Br}_2 + 2\text{H}_2\text{O}$	+1.60	$\text{In}^{3+} + 3\text{e}^- \rightarrow \text{In}$	-0.34
$\text{MnO}_4^- + 8\text{H}^+ + 5\text{e}^- \rightarrow \text{Mn}^{2+} + 4\text{H}_2\text{O}$	+1.51	$\text{Tl}^+ + \text{e}^- \rightarrow \text{Tl}$	-0.34
$\text{Mn}^{3+} + \text{e}^- \rightarrow \text{Mn}^{2+}$	+1.51	$\text{PbSO}_4 + 2\text{e}^- \rightarrow \text{Pb} + \text{SO}_4^{2-}$	-0.36
$\text{Au}^{3+} + 3\text{e}^- \rightarrow \text{Au}$	+1.40	$\text{Ti}^{3+} + \text{e}^- \rightarrow \text{Ti}^{2+}$	-0.37
$\text{Cl}_2 + 2\text{e}^- \rightarrow 2\text{Cl}^-$	+1.36	$\text{In}^{2+} + \text{e}^- \rightarrow \text{In}^+$	-0.40
$\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- \rightarrow 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$	+1.33	$\text{Cd}^{2+} + 2\text{e}^- \rightarrow \text{Cd}$	-0.40
$\text{O}_3 + \text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{O}_2 + 2\text{OH}^-$	+1.24	$\text{Cr}^{3+} + \text{e}^- \rightarrow \text{Cr}^{2+}$	-0.41
$\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}$	+1.23	$\text{Fe}^{2+} + 2\text{e}^- \rightarrow \text{Fe}$	-0.44
$\text{MnO}_2 + 4\text{H}^+ + 2\text{e}^- \rightarrow \text{Mn}^{2+} + 2\text{H}_2\text{O}$	+1.23	$\text{In}^{3+} + 2\text{e}^- \rightarrow \text{In}^+$	-0.44
$\text{ClO}_4^- + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{ClO}_3^- + \text{H}_2\text{O}$	+1.23	$\text{S} + 2\text{e}^- \rightarrow \text{S}^{2-}$	-0.48
$\text{Pt}^{2-} + 2\text{e}^- \rightarrow \text{Pt}$	+1.20	$\text{In}^{3+} + \text{e}^- \rightarrow \text{In}^{2+}$	-0.49
$\text{Br}_2 + 2\text{e}^- \rightarrow 2\text{Br}^-$	+1.09	$\text{Ga}^+ + \text{e}^- \rightarrow \text{Ga}$	-0.53
$\text{Pu}^{4+} + \text{e}^- \rightarrow \text{Pu}^{3+}$	+0.97	$\text{O}_2 + \text{e}^- \rightarrow \text{O}_2^-$	-0.56
$\text{NO}_3^- + 4\text{H}^+ + 3\text{e}^- \rightarrow \text{NO} + 2\text{H}_2\text{O}$	+0.96	$\text{U}^{4+} + \text{e}^- \rightarrow \text{U}^{3+}$	-0.61
$2\text{Hg}^{2+} + 2\text{e}^- \rightarrow \text{Hg}_2^{2+}$	+0.92	$\text{Se} + 2\text{e}^- \rightarrow \text{Se}^{2-}$	-0.67
$\text{ClO}^- + \text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{Cl}^- + 2\text{OH}^-$	+0.89	$\text{Cr}^{3+} + 3\text{e}^- \rightarrow \text{Cr}$	-0.74
$\text{Hg}_2^{2+} + 2\text{e}^- \rightarrow \text{Hg}$	+0.85	$\text{Zn}^{2+} + 2\text{e}^- \rightarrow \text{Zn}$	-0.76
$\text{NO}_3^- + 2\text{H}^+ + \text{e}^- \rightarrow \text{NO}_2 + \text{H}_2\text{O}$	+0.80	$\text{Cd}(\text{OH})_2 + 2\text{e}^- \rightarrow \text{Cd} + 2\text{OH}^-$	-0.81
$\text{Ag}^+ + \text{e}^- \rightarrow \text{Ag}$	+0.80	$2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$	-0.83
$\text{Hg}_2^{2+} + 2\text{e}^- \rightarrow 2\text{Hg}$	+0.79	$\text{Te} + 2\text{e}^- \rightarrow \text{Te}^{2-}$	-0.84
$\text{AgF} + \text{e}^- \rightarrow \text{Ag} + \text{F}^-$	+0.78	$\text{Cr}^{2+} + 2\text{e}^- \rightarrow \text{Cr}$	-0.91
$\text{Fe}^{3+} + \text{e}^- \rightarrow \text{Fe}^{2+}$	+0.77	$\text{Mn}^{2+} + 2\text{e}^- \rightarrow \text{Mn}$	-1.18
$\text{BrO}^- + \text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{Br}^- + 2\text{OH}^-$	+0.76	$\text{V}^{2+} + 2\text{e}^- \rightarrow \text{V}$	-1.19
$\text{MnO}_4^{2-} + 2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{MnO}_2 + 4\text{OH}^-$	+0.60	$\text{Ti}^{2+} + 2\text{e}^- \rightarrow \text{Ti}$	-1.63
$\text{MnO}_4^- + \text{e}^- \rightarrow \text{MnO}_4^{2-}$	+0.56	$\text{Al}^{3+} + 3\text{e}^- \rightarrow \text{Al}$	-1.66
$\text{I}_2 + 2\text{e}^- \rightarrow 2\text{I}^-$	+0.54	$\text{U}^{3+} + 3\text{e}^- \rightarrow \text{U}$	-1.79
$\text{I}_3^- + 2\text{e}^- \rightarrow 3\text{I}^-$	+0.53	$\text{Be}^{2+} + 2\text{e}^- \rightarrow \text{Be}$	-1.85
$\text{Cu}^+ + \text{e}^- \rightarrow \text{Cu}$	+0.52	$\text{Mg}^{2+} + 2\text{e}^- \rightarrow \text{Mg}$	-2.36
$\text{Ni}(\text{OH})_3 + \text{e}^- \rightarrow \text{Ni}(\text{OH})_2 + \text{OH}^-$	+0.49	$\text{Ce}^{3+} + 3\text{e}^- \rightarrow \text{Ce}$	-2.48
$\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^-$	+0.40	$\text{La}^{3+} + 3\text{e}^- \rightarrow \text{La}$	-2.52
$\text{ClO}_4^- + \text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{ClO}_3^- + 2\text{OH}^-$	+0.36	$\text{Na}^+ + \text{e}^- \rightarrow \text{Na}$	-2.71
$\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$	+0.34	$\text{Ca}^{2+} + 2\text{e}^- \rightarrow \text{Ca}$	-2.87
$\text{Hg}_2\text{Cl}_2 + 2\text{e}^- \rightarrow 2\text{Hg} + 2\text{Cl}^-$	+0.27	$\text{Sr}^{2+} + 2\text{e}^- \rightarrow \text{Sr}$	-2.89
$\text{AgCl} + \text{e}^- \rightarrow \text{Ag} + \text{Cl}^-$	+0.22	$\text{Ba}^{2+} + 2\text{e}^- \rightarrow \text{Ba}$	-2.91
$\text{Bi}^{3+} + 3\text{e}^- \rightarrow \text{Bi}$	+0.20	$\text{Ra}^{2+} + 2\text{e}^- \rightarrow \text{Ra}$	-2.92
$\text{SO}_4^{2-} + 4\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2\text{SO}_3 + \text{H}_2\text{O}$	+0.17	$\text{Cs}^+ + \text{e}^- \rightarrow \text{Cs}$	-2.92
$\text{Cu}^{2+} + \text{e}^- \rightarrow \text{Cu}^+$	+0.15	$\text{Rb}^+ + \text{e}^- \rightarrow \text{Rb}$	-2.93
$\text{Sn}^{4+} + 2\text{e}^- \rightarrow \text{Sn}^{2+}$	+0.15	$\text{K}^+ + \text{e}^- \rightarrow \text{K}$	-2.93
$\text{AgBr} + \text{e}^- \rightarrow \text{Ag} + \text{Br}^-$	+0.07	$\text{Li}^+ + \text{e}^- \rightarrow \text{Li}$	-3.05
		Strongly reducing	

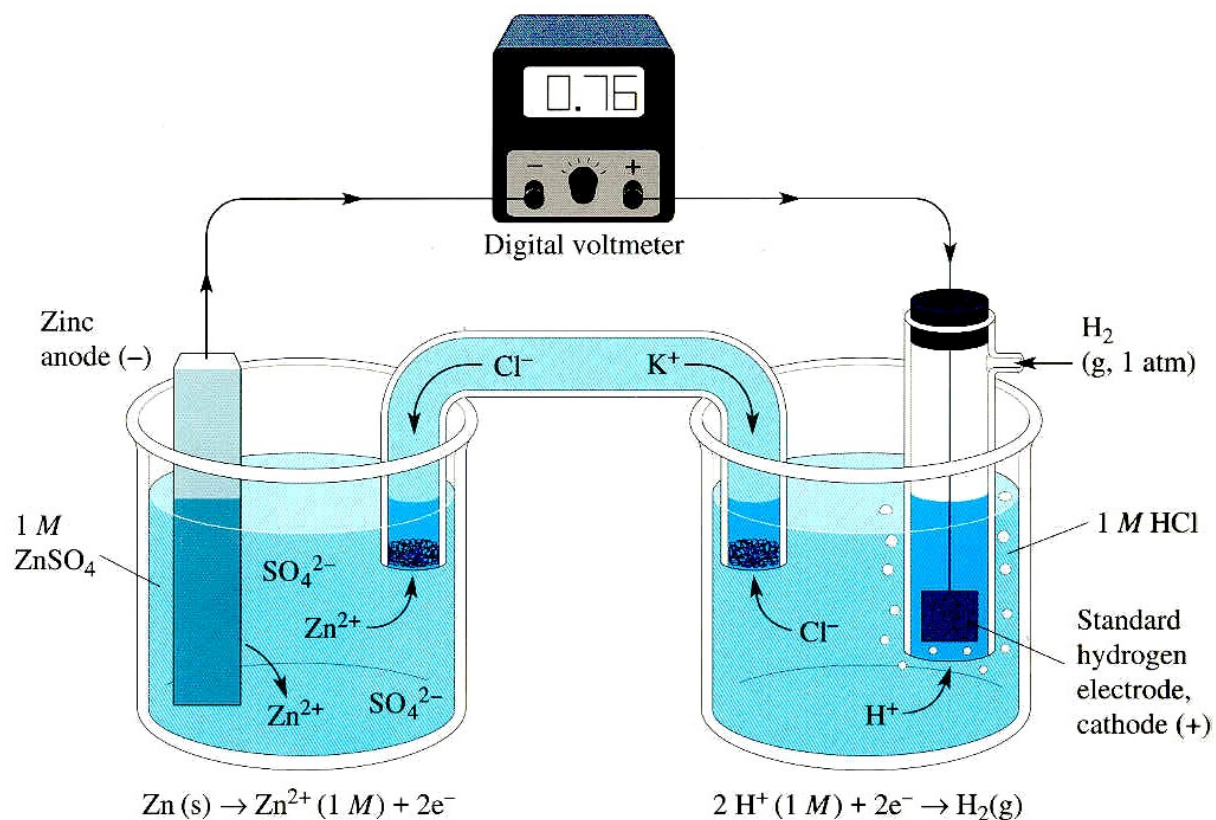
Tabulated in Alphabetical Order:

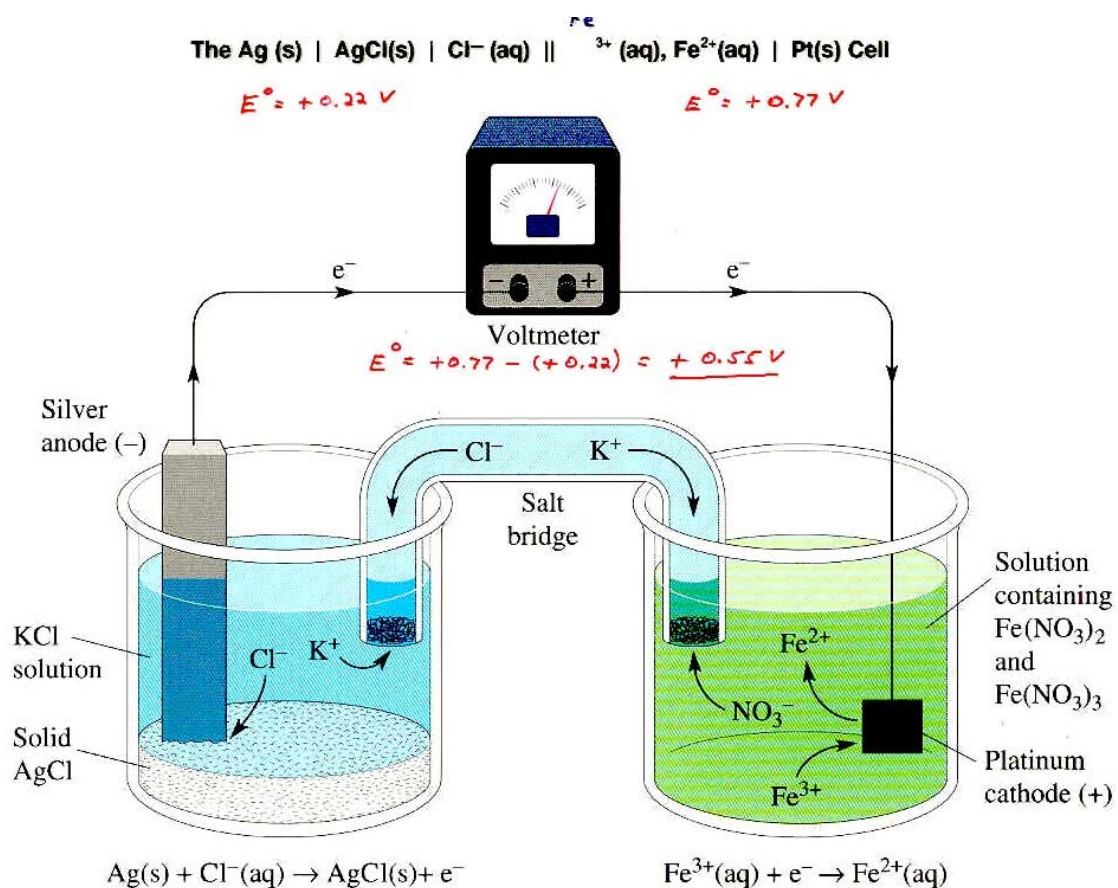
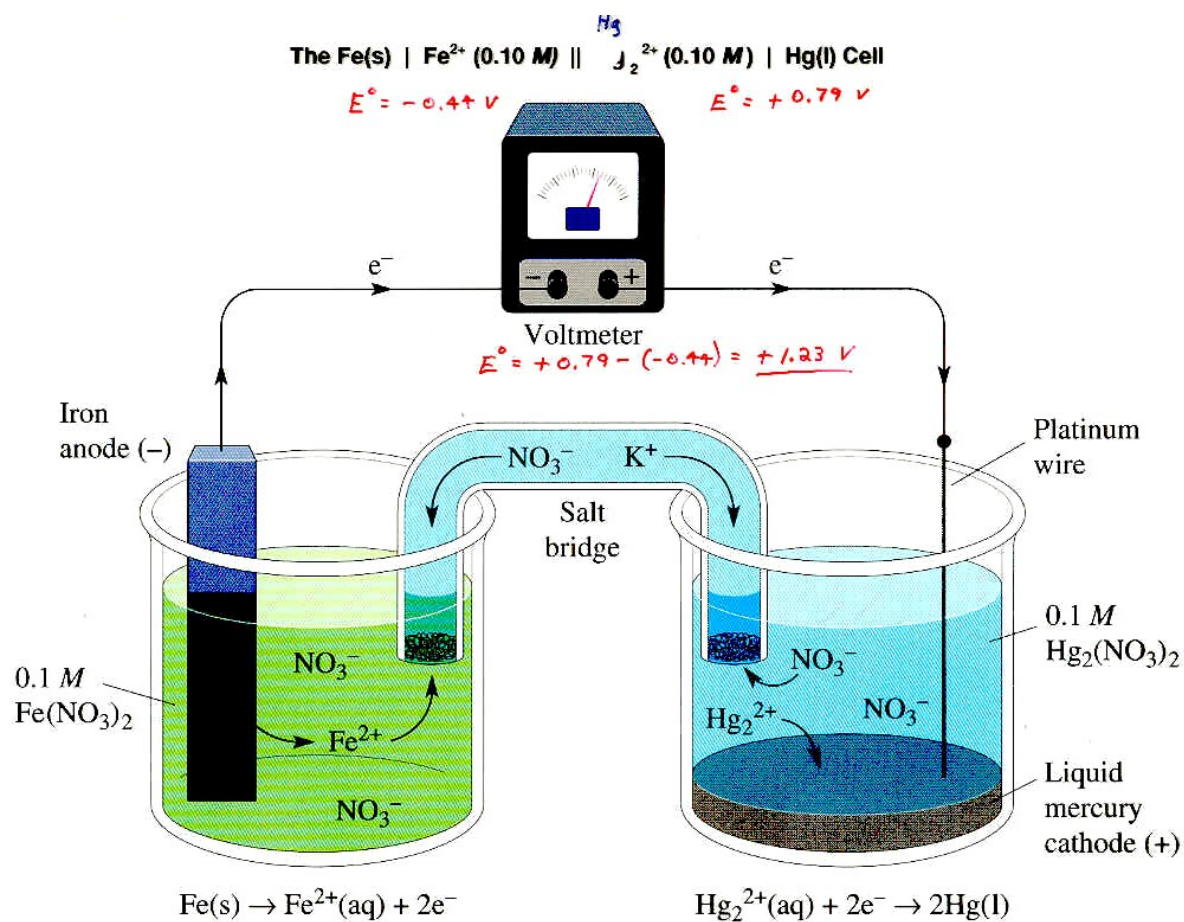
Reduction half-reaction	E° (V)	Reduction half-reaction	E° (V)
$\text{Ag}^+ + \text{e}^- \rightarrow \text{Ag}$	+0.80	$\text{In}^{2+} + \text{e}^- \rightarrow \text{In}^+$	-0.40
$\text{Ag}^{2+} + \text{e}^- \rightarrow \text{Ag}^+$	+1.98	$\text{In}^{3+} + \text{e}^- \rightarrow \text{In}^{2+}$	-0.49
$\text{AgBr} + \text{e}^- \rightarrow \text{Ag} + \text{Br}^-$	+0.07	$\text{In}^{3+} + 2 \text{e}^- \rightarrow \text{In}^+$	-0.44
$\text{AgCl} + \text{e}^- \rightarrow \text{Ag} + \text{Cl}^-$	+0.22	$\text{In}^{3+} + 3 \text{e}^- \rightarrow \text{In}$	-0.34
$\text{AgF} + \text{e}^- \rightarrow \text{Ag} + \text{F}^-$	+0.78	$\text{K}^+ + \text{e}^- \rightarrow \text{K}$	-2.93
$\text{AgI} + \text{e}^- \rightarrow \text{Ag} + \text{I}^-$	-0.15	$\text{La}^{3+} + 3 \text{e}^- \rightarrow \text{La}$	-2.52
$\text{Al}^{3+} + 3 \text{e}^- \rightarrow \text{Al}$	-1.66	$\text{Li}^+ + \text{e}^- \rightarrow \text{Li}$	-3.05
$\text{Au}^+ + \text{e}^- \rightarrow \text{Au}$	+1.69	$\text{Mg}^{2+} + 2 \text{e}^- \rightarrow \text{Mg}$	-2.36
$\text{Au}^{3+} + 3 \text{e}^- \rightarrow \text{Au}$	+1.40	$\text{Mn}^{2+} + 2 \text{e}^- \rightarrow \text{Mn}$	-1.18
$\text{Ba}^{2+} + 2 \text{e}^- \rightarrow \text{Ba}$	-2.91	$\text{Mn}^{3+} + \text{e}^- \rightarrow \text{Mn}^{2+}$	+1.51
$\text{Be}^{2+} + 2 \text{e}^- \rightarrow \text{Be}$	-1.85	$\text{MnO}_2 + 4 \text{H}^+ + 2 \text{e}^- \rightarrow \text{Mn}^{2+} + 2 \text{H}_2\text{O}$	+1.23
$\text{Bi}^{3+} + 3 \text{e}^- \rightarrow \text{Bi}$	+0.20	$\text{MnO}_4^- + \text{e}^- \rightarrow \text{MnO}_4^{2-}$	+0.56
$\text{Br}_2 + 2 \text{e}^- \rightarrow 2 \text{Br}^-$	+1.09	$\text{MnO}_4^- + 8 \text{H}^+ + 5 \text{e}^- \rightarrow \text{Mn}^{2+} + 4 \text{H}_2\text{O}$	+1.51
$\text{BrO}^- + \text{H}_2\text{O} + 2 \text{e}^- \rightarrow \text{Br}^- + 2 \text{OH}^-$	+0.76	$\text{MnO}_4^{2-} + 2 \text{H}_2\text{O} + 2 \text{e}^- \rightarrow \text{MnO}_2 + 4 \text{OH}^-$	+0.60
$\text{Ca}^{2+} + 2 \text{e}^- \rightarrow \text{Ca}$	-2.87	$\text{NO}_3^- + 2 \text{H}^+ + \text{e}^- \rightarrow \text{NO}_2 + \text{H}_2\text{O}$	+0.80
$\text{Cd}^{2+} + 2 \text{e}^- \rightarrow \text{Cd}$	-0.40	$\text{NO}_3^- + 4 \text{H}^+ + 3 \text{e}^- \rightarrow \text{NO} + 2 \text{H}_2\text{O}$	+0.96
$\text{Cd}(\text{OH})_2 + 2 \text{e}^- \rightarrow \text{Cd} + 2 \text{OH}^-$	-0.81	$\text{NO}_3^- + \text{H}_2\text{O} + 2 \text{e}^- \rightarrow \text{NO}_2^- + 2 \text{OH}^-$	+0.01
$\text{Ce}^{3+} + 3 \text{e}^- \rightarrow \text{Ce}$	-2.48	$\text{Na}^+ + \text{e}^- \rightarrow \text{Na}$	-2.71
$\text{Ce}^{4+} + \text{e}^- \rightarrow \text{Ce}^{3+}$	+1.61	$\text{Ni}^{2+} + 2 \text{e}^- \rightarrow \text{Ni}$	-0.23
$\text{Cl}_2 + 2 \text{e}^- \rightarrow 2 \text{Cl}^-$	+1.36	$\text{Ni}(\text{OH})_3 + \text{e}^- \rightarrow \text{Ni}(\text{OH})_2 + \text{OH}^-$	+0.49
$\text{ClO}^- + \text{H}_2\text{O} + 2 \text{e}^- \rightarrow \text{Cl}^- + 2 \text{OH}^-$	+0.89	$\text{O}_2 + \text{e}^- \rightarrow \text{O}_2^-$	-0.56
$\text{ClO}_4^- + 2 \text{H}^+ + 2 \text{e}^- \rightarrow \text{ClO}_3^- + \text{H}_2\text{O}$	+1.23	$\text{O}_2 + 4 \text{H}^+ + 4 \text{e}^- \rightarrow 2 \text{H}_2\text{O}$	+1.23
$\text{ClO}_4^- + \text{H}_2\text{O} + 2 \text{e}^- \rightarrow \text{ClO}_3^- + 2 \text{OH}^-$	+0.36	$\text{O}_2 + \text{H}_2\text{O} + 2 \text{e}^- \rightarrow \text{HO}_2^- + \text{OH}^-$	-0.08
$\text{Co}^{2+} + 2 \text{e}^- \rightarrow \text{Co}$	-0.28	$\text{O}_2 + 2 \text{H}_2\text{O} + 4 \text{e}^- \rightarrow 4 \text{OH}^-$	+0.40
$\text{Co}^{3+} + \text{e}^- \rightarrow \text{Co}^{2+}$	+1.81	$\text{O}_3 + 2 \text{H}^+ + 2 \text{e}^- \rightarrow \text{O}_2 + \text{H}_2\text{O}$	+2.07
$\text{Cr}^{2+} + 2 \text{e}^- \rightarrow \text{Cr}$	-0.91	$\text{O}_3 + \text{H}_2\text{O} + 2 \text{e}^- \rightarrow \text{O}_2 + 2 \text{OH}^-$	+1.24
$\text{Cr}_2\text{O}_7^{2-} + 14 \text{H}^+ + 6 \text{e}^- \rightarrow 2 \text{Cr}^{3+} + 7 \text{H}_2\text{O}$	+1.33	$\text{Pb}^{2+} + 2 \text{e}^- \rightarrow \text{Pb}$	-0.13
$\text{Cr}^{3+} + 3 \text{e}^- \rightarrow \text{Cr}$	-0.74	$\text{Pb}^{4+} + 2 \text{e}^- \rightarrow \text{Pb}^{2+}$	+1.67
$\text{Cr}^{3+} + \text{e}^- \rightarrow \text{Cr}^{2+}$	-0.41	$\text{PbSO}_4 + 2 \text{e}^- \rightarrow \text{Pb} + \text{SO}_4^{2-}$	-0.36
$\text{Cs}^+ + \text{e}^- \rightarrow \text{Cs}$	-2.92	$\text{Pt}^{2+} + 2 \text{e}^- \rightarrow \text{Pt}$	+1.20
$\text{Cu}^+ + \text{e}^- \rightarrow \text{Cu}$	+0.52	$\text{Pu}^{4+} + \text{e}^- \rightarrow \text{Pu}^{3+}$	+0.97
$\text{Cu}^{2+} + 2 \text{e}^- \rightarrow \text{Cu}$	+0.34	$\text{Ra}^{2+} + 2 \text{e}^- \rightarrow \text{Ra}$	-2.92
$\text{Cu}^{2+} + \text{e}^- \rightarrow \text{Cu}^+$	+0.15	$\text{Rb}^+ + \text{e}^- \rightarrow \text{Rb}$	-2.93
$\text{F}_2 + 2 \text{e}^- \rightarrow 2 \text{F}^-$	+2.87	$\text{S} + 2 \text{e}^- \rightarrow \text{S}^{2-}$	-0.48
$\text{Fe}^{2+} + 2 \text{e}^- \rightarrow \text{Fe}$	-0.44	$\text{SO}_4^{2-} + 4 \text{H}^+ + 2 \text{e}^- \rightarrow \text{H}_2\text{SO}_3 + \text{H}_2\text{O}$	+0.17
$\text{Fe}^{3+} + 3 \text{e}^- \rightarrow \text{Fe}$	-0.04	$\text{S}_2\text{O}_8^{2-} + 2 \text{e}^- \rightarrow 2 \text{SO}_4^{2-}$	+2.05
$\text{Fe}^{3+} + \text{e}^- \rightarrow \text{Fe}^{2+}$	+0.77	$\text{Se} + 2 \text{e}^- \rightarrow \text{Se}^{2-}$	-0.67
$\text{Ga}^+ + \text{e}^- \rightarrow \text{Ga}$	-0.53	$\text{Sn}^{2+} + 2 \text{e}^- \rightarrow \text{Sn}$	-0.14
$2 \text{H}^+ + 2 \text{e}^- \rightarrow \text{H}_2$	0, by definition	$\text{Sn}^{4+} + 2 \text{e}^- \rightarrow \text{Sn}^{2+}$	+0.15
$2 \text{HBrO} + 2 \text{H}^+ + 2 \text{e}^- \rightarrow \text{Br}_2 + 2 \text{H}_2\text{O}$	+1.60	$\text{Sr}^{2+} + 2 \text{e}^- \rightarrow \text{Sr}$	-2.89
$2 \text{HClO} + 2 \text{H}^+ + 2 \text{e}^- \rightarrow \text{Cl}_2 + 2 \text{H}_2\text{O}$	+1.63	$\text{Te} + 2 \text{e}^- \rightarrow \text{Te}^{2-}$	-0.84
$2 \text{H}_2\text{O} + 2 \text{e}^- \rightarrow \text{H}_2 + 2 \text{OH}^-$	-0.83	$\text{Ti}^{2+} + 2 \text{e}^- \rightarrow \text{Ti}$	-1.63
$\text{H}_2\text{O}_2 + 2 \text{H}^+ + 2 \text{e}^- \rightarrow 2 \text{H}_2\text{O}$	+1.78	$\text{Ti}^{3+} + \text{e}^- \rightarrow \text{Ti}^{2+}$	-0.37
$\text{H}_4\text{XeO}_6 + 2 \text{H}^+ + 2 \text{e}^- \rightarrow \text{XeO}_3 + 3 \text{H}_2\text{O}$	+3.0	$\text{Ti}^{4+} + \text{e}^- \rightarrow \text{Ti}^{3+}$	0.00
$\text{Hg}_2^{2+} + 2 \text{e}^- \rightarrow 2 \text{Hg}$	+0.79	$\text{Tl}^+ + \text{e}^- \rightarrow \text{Tl}$	-0.34
$\text{Hg}_2^{2+} + 2 \text{e}^- \rightarrow \text{Hg}$	+0.85	$\text{U}^{3+} + 3 \text{e}^- \rightarrow \text{U}$	-1.79
$2 \text{Hg}^{2+} + 2 \text{e}^- \rightarrow \text{Hg}_2^{2+}$	+0.92	$\text{U}^{4+} + \text{e}^- \rightarrow \text{U}^{3+}$	-0.61
$\text{Hg}_2\text{Cl}_2 + 2 \text{e}^- \rightarrow 2 \text{Hg} + 2 \text{Cl}^-$	+0.27	$\text{V}^{2+} + 2 \text{e}^- \rightarrow \text{V}$	-1.19
$\text{I}_2 + 2 \text{e}^- \rightarrow 2 \text{I}^-$	+0.54	$\text{V}^{3+} + \text{e}^- \rightarrow \text{V}^{2+}$	-0.26
$\text{I}_3^- + 2 \text{e}^- \rightarrow 3 \text{I}^-$	+0.53	$\text{Zn}^{2+} + 2 \text{e}^- \rightarrow \text{Zn}$	-0.76
$\text{In}^+ + \text{e}^- \rightarrow \text{In}$	-0.14		

Standard Hydrogen Electrode Coupled with a Standard Copper Electrode



Standard Hydrogen Electrode Coupled with a Standard Zinc Electrode

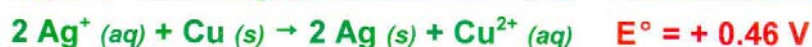




Half-cell reactions with the most positive reduction potentials involve reactants that are strong oxidizing agents (e.g., F_2 , MnO_4^- , H_2O_2)

Half-cell reactions with the most negative reduction potentials involve products that are strong reducing agents (e.g., Groups I and II metals, Li, Na, Mg, Ca, etc.)

Electrochemical Series



Thus, Cu spontaneously reduces Ag^+ to Ag, while itself becoming oxidized to Cu^{2+} .



Thus, Zn spontaneously reduces Cu^{2+} to Cu, while itself becoming oxidized to Zn^{2+} .

Since $E^\circ = 0$ for



then H_2 can reduce Cu^{2+} to Cu, but cannot reduce Zn^{2+} to Zn. In fact, Zn reduces H_3O^+ to $H_2 + H_2O$.

This comparative oxidizing and reducing capabilities of redox couples (half-reactions) is termed the **“Electrochemical Series.”**

"Derived" Half-Reactions

Because E° is an intensive property, when two half-reactions are combined to form a galvanic cell, their E° 's are not multiplied by the coefficients in the overall balanced reaction, as is done for extensive properties, such as ΔG_r° (*i.e.*, cell voltage is independent of the size of the cell).

When adding or subtracting two different half-cell reactions to obtain another half-cell reaction, one cannot simply add or subtract E° 's, but must first determine ΔG_r° for the new half-cell from the ΔG_r° 's of the two original half-cells, and use it to calculate E° of the new cell:

$$\Delta G_3^\circ = \Delta G_1^\circ - \Delta G_2^\circ = -n_1 F E_1^\circ + n_2 F E_2^\circ = -n_3 F E_3^\circ$$

Thus,
$$E_3^\circ = \frac{n_1 E_1^\circ - n_2 E_2^\circ}{n_3}$$



$$E_3^\circ = \frac{(2)(+0.34) - (1)(+0.52)}{1} = +0.16\text{ V}$$

Another example:



$$E_3^\circ = \frac{(3)(-0.04) - (2)(-0.44)}{1} = +0.76\text{ V}$$