For the redox process
\[ \text{Cu}^{2+}(aq) + \text{Zn}(s) \rightarrow \text{Cu}(s) + \text{Zn}^{2+}(aq) \]
when the ions each are 1 M, Zn(s) is consumed. This means ...

1. \( K > 1 \)
2. \( K < 1 \)
3. \( Q > 1 \)
4. \( Q < 1 \)
5. More information needed

What determines cell voltage, \( E_{\text{cell}} \)?

We know spontaneity is determined by \( Q \) relative to \( K \).

For now we can simplify things by arranging for \( Q = 1 \), typically by making reactants and products be in their standard state.

This arrangement defines what we call the standard free energy change,

\[ \Delta G^\circ_{\text{cell}} = -n F E^\circ_{\text{cell}} \]

Calculating standard cell voltage, \( E^\circ_{\text{cell}} \)

Since \( E^\circ_{\text{cell}} \) is proportional to the \( \Delta G^\circ_{\text{cell}} \)

\[ \Delta G^\circ_{\text{cell}} = -n F E^\circ_{\text{cell}} \]

and because we know how to express a redox process as the sum of its half reactions, we can use Hess’s law to express \( \Delta G^\circ_{\text{cell}} \) as

\[ \Delta G^\circ_{\text{cell}} = \Delta G^\circ_{\text{cathode}} + \Delta G^\circ_{\text{anode}} \]
Calculating standard cell voltage, $E_{\text{cell}}^0$

By convention, reduction half reactions have a standard reduction potential $E^\circ$, whose value is the cell potential relative to the standard hydrogen electrode, SHE,

$$2 \text{H}^+(1 \text{ M}) + 2 e^- \rightarrow \text{H}_2(1 \text{ atm}), \; E^\circ = 0 \text{ V}$$

All other reductions defined relative to SHE

$$\text{Zn}^{2+}(1 \text{ M}) + 2 e^- \rightarrow \text{Zn}(s), \; E^\circ = -0.763 \text{ V}$$

$$\text{Cu}^{2+}(1 \text{ M}) + 2 e^- \rightarrow \text{Cu}(s), \; E^\circ = +0.340 \text{ V}$$

etc.

Calculating standard cell voltage, $E_{\text{cell}}^0$

This means we can write

$$\Delta G^\circ_{\text{cathode}} = -n_e F E^\circ_{\text{cathode}}$$

$$\Delta G^\circ_{\text{anode}} = +n_e F E^\circ_{\text{anode}}$$

$$\Delta G^\circ_{\text{cell}} = \Delta G^\circ_{\text{cathode}} + \Delta G^\circ_{\text{anode}}$$

we get the fundamental expression for $E^\circ_{\text{cell}}$ in terms of reduction potentials,

$$E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}}$$

Note that both $E^\circ_{\text{cathode}}$ and $E^\circ_{\text{anode}}$ are standard reduction potentials.

Calculating standard cell voltage, $E_{\text{cell}}^0$

Here is an example: Does Cu$^{2+}$ oxidize Zn?

$$\text{Cu}^{2+}(1 \text{ M}) + \text{Zn}(s) \rightarrow \text{Cu}(s) + \text{Zn}^{2+}(1 \text{ M}), \; E^\circ > 0?$$

The standard reduction potentials are

$$\text{Zn}^{2+}(1 \text{ M}) + 2 e^- \rightarrow \text{Zn}(s), \; E^\circ = -0.763 \text{ V}$$

$$\text{Cu}^{2+}(1 \text{ M}) + 2 e^- \rightarrow \text{Cu}(s), \; E^\circ = +0.340 \text{ V}$$

The standard cell potential is

$$E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}} = +0.340 \text{ V} - (-0.763 \text{ V}) = +1.103 \text{ V} > 0$$

So, Zn is oxidized by Cu$^{2+}$
Cell voltage versus spontaneity
Spontaneity is proportional to voltage
Spontaneity is proportional to how far away from equilibrium
Voltage versus \( Q/K \)?

[Quiz] For the redox process
\[ \text{Cu}^{2+}(aq) + \text{Zn}(s) \rightarrow \text{Cu}(s) + \text{Zn}^{2+}(aq) \]
when \( Q = x \), Zn(s) is consumed. This means ...

\begin{itemize}
  \item 20% 1. \( K > 1 \)
  \item 20% 2. \( K < 1 \)
  \item 20% 3. \( Q > K \)
  \item 20% 4. \( Q < K \)
  \item 20% 5. More information needed
\end{itemize}

[TP] For the redox process
\[ \text{Cu}^{2+}(aq) + \text{Zn}(s) \rightarrow \text{Cu}(s) + \text{Zn}^{2+}(aq) \]
when \( Q = 10 \), Zn(s) is consumed. This means ...

This means over time the cell voltage will ...

\begin{itemize}
  \item 25% 1. become smaller
  \item 25% 2. stay the same
  \item 25% 3. become larger
  \item 25% 4. More information needed
\end{itemize}
For the redox process
\[ \text{Cu}^{2+}(aq) + \text{Zn}(s) \rightarrow \text{Cu}(s) + \text{Zn}^{2+}(aq) \]
when \( Q = 10 \), \( \text{Zn}(s) \) is consumed.
Compared to the voltage when \( Q = 1 \), the voltage when \( Q = 10 \) is ...

1. smaller
2. the same
3. larger
4. More information needed

A redox reaction has \( K = 10 \). If there are only products present, \(-\log(Q/K)\)

1. \(-\infty\)
2. 2
3. 1
4. 0
5. \(-1\)
6. \(-\infty\)