Lecture 32 – Chapter 19 – 7
Fuel Cells and Electrolysis

• Fuel Cells
• Electrolytic Cells
• Splitting Water
Fuel Cell

- Essentially the combustion of hydrogen
- But reduction of $O_2$ and oxidation of $H_2$ carried out in separate places.
- Makes lots of electricity and only waste is $H_2O$!
- But, $H_2$ is hard to make and dicey to transport

Fuel Cell:

\[
2 \text{H}_2 (g) + 4 \text{H}_2\text{O} (l) \rightarrow 4 \text{H}_3\text{O}^+ (aq) + 4 \text{e}^- \\
\text{O}_2 (g) + 2 \text{H}_2\text{O} (l) + 4 \text{e}^- \rightarrow 4 \text{OH}^- (aq)
\]

\[
2 \text{H}_2 (g) + \text{O}_2 (g) \rightarrow 2 \text{H}_2\text{O} (l)
\]
Fuel Cell

- Fuel cell vehicles with H₂ may be tough
- One alternative is to ‘burn’ hydrocarbons
- Still get CO₂ (greenhouse gas) as product
- But, do not get any nasty CO, NO, NO₂, etc.
- Also get more energy per unit fuel than standard combustion engine

Hydrocarbon Fuel Cell:

\[ 2 \text{C}_4\text{H}_{10} + 26 \text{O}^{2-} \rightarrow 8 \text{CO}_2 + 10 \text{H}_2\text{O} + 52 \text{e}^- \]

\[ 13 (\text{O}_2 + 4 \text{e}^-) \rightarrow 2 \text{O}^{2-} \]

\[ 2 \text{C}_4\text{H}_{10} + 13 \text{O}_2 \rightarrow 8 \text{CO}_2 + 10 \text{H}_2\text{O} \]
Fuel Cells Revisited

- I just said one big problem is producing the $\text{H}_2$ fuel
- Paper from last year in Nature…
  - Very efficient (2.5%) splitting of water by visible light
Electrolysis

• Recall Galvanic Cell was a spontaneous electrochemical cell – a chemical reaction generates voltage
• An Electrolytic Cell is the same thing in reverse – a non-spontaneous chemical reaction is driven by external voltage

• Examples
  – Recharging a battery
  – Splitting water
  – Electroplating
Splitting Water

- Similar to the fuel cell reaction, but in reverse – works best with acidic water

\[
4 \text{H}_3\text{O}^+ (aq) + 4 \text{e}^- \rightarrow 2 \text{H}_2 (g) + 4 \text{H}_2\text{O} (l)
\]

\[
6 \text{H}_2\text{O} (l) \rightarrow \text{O}_2 (g) + 4 \text{H}_3\text{O}^+ (aq) + 4 \text{e}^-
\]

\[
2 \text{H}_2\text{O} (l) \rightarrow 2 \text{H}_2 (g) + \text{O}_2 (g)
\]
Water and iodine

- One beaker contains KI (I\(^{-}\)\(_{(aq)}\)) and the other water
  \[ 2 \text{I}^-_{(aq)} \rightarrow \text{I}_2(s) + 2 \text{e}^- \quad -0.5355 \text{ V} \]
  \[ 2 \text{H}_2\text{O} \_{(l)} + 2 \text{e}^- \rightarrow \text{H}_2\text{(g)} + 2 \text{OH}^-_{(aq)} \quad -0.828 \text{ V} \]

- The potential on this cell is the sum of the half-rxns
  \[ E = -0.5355 + (-0.828) = -1.363 \text{ V} \]

- So, this is not spontaneous, but if we apply more than 1.4 volts, we can force the reaction to proceed.
  - At one electrode create I\(_2(s)\) (turns starch black)
  - At other electrode create H\(_2(g)\)
What reacts first?

- If we have a solution of sodium chloride in water, and we pass electricity through it, what gets reduced and what gets oxidized?
- Species present: $\text{Na}^+_{\text{aq}}$, $\text{Cl}^-_{\text{aq}}$, $\text{H}_2\text{O}_{(l)}$
  - What will get reduced? Try to add electrons

\[
\begin{align*}
\text{Na}^+_{\text{aq}} + e^- & \rightarrow \text{Na}_{(s)} & -2.71 \text{ V} \\
\text{Cl}^-_{\text{aq}} + e^- & \rightarrow \text{Cl}^2^-_{\text{aq}} & \text{Not Possible} \\
2 \text{H}_2\text{O}_{(l)} + 2 e^- & \rightarrow \text{H}_2(g) + 2 \text{OH}^-_{\text{aq}} & -0.828 \text{ V}
\end{align*}
\]

The easiest to drive is the one that is most nearly spontaneous – the one that is the least negative.

We will generate $\text{H}_2$ gas, not Na metal.
What will get oxidized?
$\text{Na}^+_{(aq)} \quad \text{Cl}^-_{(aq)} \quad \text{H}_2\text{O}_{(l)}$

25%  1. $\text{Na}^+_{(aq)}$

25%  2. $\text{Cl}^-_{(aq)}$

25%  3. $\text{H}_2\text{O}_{(l)}$

25%  4. None of them will be oxidized
What gets oxidized?

- Species present: $\text{Na}^+_{(aq)}$, $\text{Cl}^-_{(aq)}$, $\text{H}_2\text{O}_{(l)}$

  - What will get oxidized? Try to remove electrons

    
    $\text{Na}^+_{(aq)} \rightarrow \text{Na}^{2+}_{(aq)} + e^- \quad \text{Not Possible}$
    $2\text{Cl}^-_{(aq)} \rightarrow \text{Cl}_2_{(g)} + 2e^- \quad -1.35827 \text{ V}$
    $2\text{H}_2\text{O}_{(l)} \rightarrow \text{H}_2\text{O}_2_{(aq)} + 2\text{H}_3\text{O}^+_{(aq)} + 2e^- \quad -1.776 \text{ V}$

The easiest to drive is the one that is most nearly spontaneous – the one that is the least negative.

In this case we will generate Cl$_2$ gas, not peroxide.
Today

- Finish CAPA #18 – due tonight
- Review Review Review

Friday

- Go to Neckers Lecture!
- Read Chapt 22
- Finish CAPA #19