IME 601 - FUNDAMENTALS OF MFG. ENG.

CHEMICAL PROPERTIES MODULE **BASIC CLASS NOTES**

Outline
- Review of Electrochemistry
- Corrosion
  - Definition
  - Modeled as Galvanic Cell
  - Prevention

Review of Electrochemistry
- Electrons Drive Chemical Reactions
  - Movement of Charged Particles Creates Voltage
- Determining
  - Cell Potentials (Standard, Nernst Equation)
  - Thermodynamic Quantities
- Applications
  - Cladding
  - Plating
  - Electrolysis

Chemical Reaction

- Drop Zn Metal in Copper Sulfate
  - Copper Precipitates
  - Zinc Disappears

- Chemical Reaction

$$Zn(s) + CuSO_4(aq) \dashrightarrow Cu(s) + ZnSO_4(aq)$$

https://www.youtube.com/watch?v=2gPRK0HmYu4

<u>Further Analysis</u>

- Chemical Reactions Occur as a Result of Electron Exchange Between Atoms

$$Zn(s) + CuSO_4(aq) \text{-->} Cu(s) + ZnSO_4(aq)$$

$$Zn^0 \qquad Cu^{2+},\ SO_4^{2-} \qquad Cu^0 \qquad Zn^{2+},\ SO_4^{2-}$$

<u>Electron Transfer</u>

- Electrons Transfered From Zn to Cu

$$Zn^0 + Cu^{2+}$$

$$Zn^{2+} + Cu^0$$

- Zinc
  - Loses Two Electrons
  - Oxidation
- Copper
  - Gains Two Electrons
  - Reduction

$$Zn^0 \text{-->} Zn^{2+} + 2e^-$$

$$Cu^{2+} + 2e^- \text{-->} Cu^0$$

Half Reactions

- 2 Reactions Required
- Anode
  - Oxidation
  - Produces Electrons
  - Negative E^0

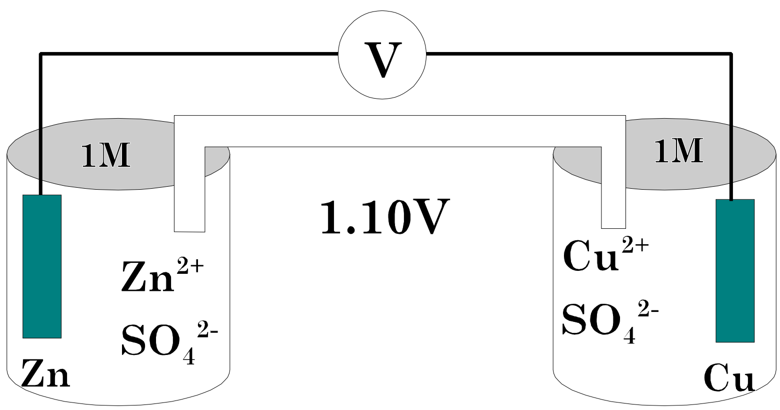
$$Zn^0 \text{ --> } Zn^{2+} + 2e^-$$

- Cathode
  - Reduction
  - Consumes Electrons
  - Positive E^0

$$Cu^{2+} + 2e^- \text{ --> } Cu^0$$

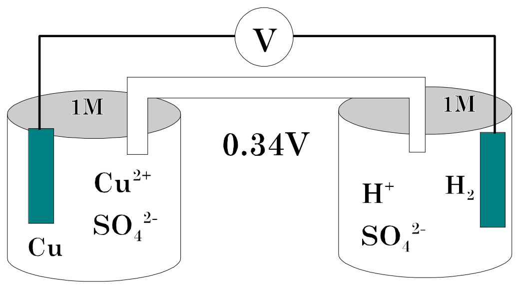
Calculation of Voltage

- Use Standard Reduction Potentials
- E^0 Must Be Positive
  - $Zn^{2+} + 2e^- \rightarrow Zn^0 \quad E^0 = -0.76V$
  - $Cu^{2+} + 2e^- \rightarrow Cu^0 \quad E^0 = 0.34V$



E^0 For Half Reactions

- No Half Reaction Occurs Alone
- Standard Reduction Potential Table
  - $2H^+ + 2e^- \rightarrow H_2(g)$ $E^0 = 0.00V$
- Defined



Facts About Batteries

- Voltage Independent of Size
  - AAA, AA, A, B, C, D
- Energy Output Depends on Size
- Batteries Die
  - Approach Equilibrium
  - Voltage Drops
- Both Reactions Must Occur
- Use Experience as a Guide

Thermodynamics

- Definition of Volt
    - Joule/Coulomb
    - Energy/Charge
- Electrons Carry Energy

$$\Delta G^0 = -nFE^0$$

Determine Energy Output

- Design a Cu/Zn Battery Which Can Power a 10W Bulb for 1 Day
- Multistep Problem
    - Determine Required Energy
    - Determine Energy Output From Voltage
    - Determine Size
- Energy Required

$$E = (10\,W)\left(3600\frac{\sec}{hr}\right)\left(24\frac{hrs}{day}\right) = 864\ kJ$$

Determine Available Energy

- Energy Required

$$E = (10\,W)\left(3600\frac{\sec}{hr}\right)\left(24\frac{hrs}{day}\right) = 864\ kJ$$

- Use ΔG^0, E^0 Relation

$$\Delta G^0 = -nFE^0$$

$$\Delta G^0 = -2\left(96{,}500\frac{C}{mole}\right)1.1V$$

$$\Delta G^0 = -212.3\frac{kJ}{mole}$$

Specify Amounts

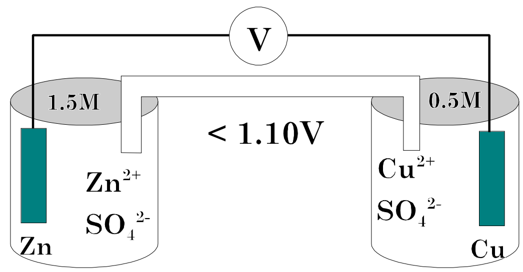
- Energy Required
  - 864kJ

- Energy Available
  - 213.3kJ/mole

- Supply Required
  - 4.1 moles
  - 269 g Zn Metal
  - 638 g Copper Sulfate to Be Dissolved in 4 liters of Water (1M Solution)
  - This is a 1kg or 2.2 lb Battery

Battery Death

- Determine Voltage of Cu/Zn Battery When Half Reactants are Consumed



Effect of Concentration Change

- Reactants Change
  - $CuSO_4$ From 1.0M to 0.5 M
- Products Change
  - $ZnSO_4$ From 1.0M to 1.5 M
- Chemical Reaction
  - $Zn(s) + CuSO_4(aq) \rightarrow Cu(s) + ZnSO_4(aq)$

$$E = E^0 - \frac{RT}{nF}\ln Q$$

$$E = 1.10V - \frac{\left(8.314\frac{J}{molK}\right)(298K)}{(2)\left(96{,}500\frac{C}{mole}\right)}\ln\frac{1.5M}{0.5M} = 1.086V$$

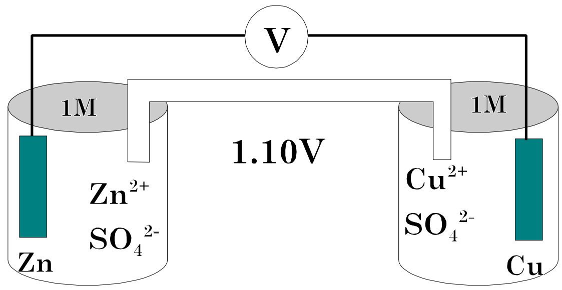
Voltage Over Time

- Constant Decay
- Note How Slowly Voltage Drops

E/Ezero	Delta E	Q	Extent	Remaining
1	0	1	0	1
0.9	0.11	5265.193	0.99962	0.00038
0.8	0.22	2.8E+07	1	7.2E-08
0.7	0.33	1.5E+11	1	1.4E-11
0.6	0.44	7.7E+14	1	2.6E-15
0.5	0.55	4E+18	1	0
0.4	0.66	2.1E+22	1	0
0.3	0.77	1.1E+26	1	0
0.2	0.88	5.9E+29	1	0
0.1	0.99	3.1E+33	1	0
0.05	1.045	2.3E+35	1	0
0.02	1.078	3E+36	1	0
0.01	1.089	7E+36	1	0
0.001	1.0989	1.5E+37	1	0
0.0001	1.09989	1.6E+37	1	0

Examples of Batteries

- Copper - Zinc



Corrosion

- The Environmental Degradation of Materials
- All Materials are Vulnerable
  - Metals Especially
- Primary Cause of Failure-- Big Bucks
- Electrochemical Reactions

Metal Oxidation

- Most Metals Oxidize

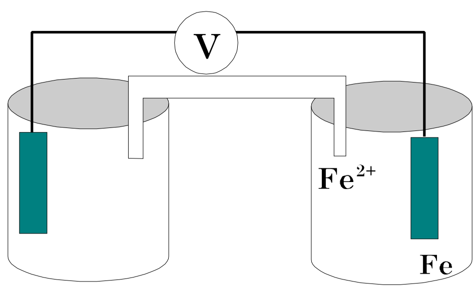
- Destructive Oxides
  - Rust

- Protective Oxides
  - Aluminum
  - Copper

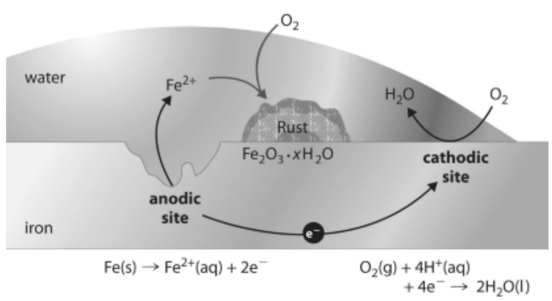
Corrosion of Steel

- Familiar Formation of Rust

- Model as Cell



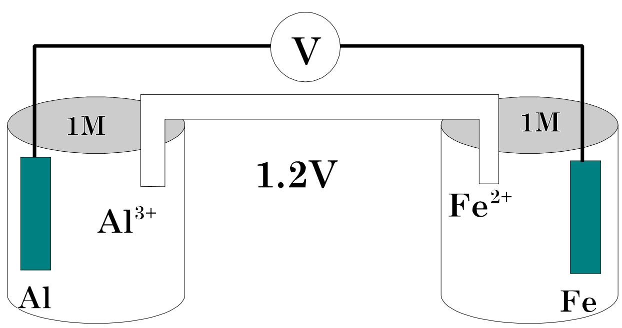
- Predict Products



http://chemwiki.ucdavis.edu/Analytical_Chemistry/Electrochemistry/Case_Studies/Corrosion/Corrosion

Bi-Metallic Corrosion

- Place Steel (Fe) and Al in Contact
  - With Water and Dirt
  - Aluminum Corrodes



Corrosion Prevention
- Prevent One of the Half Reactions
  - Paint - Prevents Oxygen From Reaching Fe
  - Use Protective Oxide

Sacrificial Metals
- Galvanize Steel
  - Place Zinc Coating on Fe
  - Zn Corrodes at Expense of Steel
- Sacrifical Anodes
  - Make a Circuit With a More Reactive Metal
- Team Problem Determine Cell Potentials for Bi-Metal Reactions

Summary and Wrap Up
- Review of Electrochemistry
- Corrosion
  - Definition
  - Modeled as Galvanic Cell
  - Prevention