Lecture 1:

I) Introduction to Battery and Fuel Cells:

A) What is an electrochemical cell?
B) Batteries (Energy and Power density, efficiency)
C) Fuel Cells (Phosphoric acid Fuel Cell, Alkaline Fuel Cell)
I) A) Electrochemical cell:

Components: Two electrodes (Cathode and Anode) (WE and CE - y people want to study the kinetic at one electrode)

Electrolyte (glow g ions)

External conductor (glow g electrons) \( \rightarrow \) external circuits

Representation:

Electrode (mobile species: electrons): conductivity \( 10^2 \) to \( 10^8 \) S/cm

  e.g.: Metal, semiconductor

Electrolyte (mobile species: ions, NO electrons): conductivity \( 10^{-9} \) to \( 10^{-1} \) S/cm

  e.g.: dissociated salt, molten salt, polymer (Naylon, FAA)
Difference between electrochemical reaction and chemical reaction

Electrochemical rxn

![Diagram showing an electrochemical reaction with anode and cathode, electrons, water, and oxygen](image)

- Generate electricity
- Electron pass through potential difference between 2 electrodes
- Anode
- Cathode

Chemical rxn

\[
H_2 + \frac{1}{2} O_2 \rightarrow H_2O
\]

- Generate heat
- Electron pass through potential difference between two nuclei
B) Batteries:

A "self-contained" electrochemical device which stores electrical energy.

Discharged reaction: \( \text{LiC}_6 + 2\text{Li}_{0.5}\text{CoO}_2 \rightarrow \text{C}_6 + 2\text{LiCoO}_2 \)

Cathode

\( 2\text{LiCoO}_2 \)

\( \text{Li}_{0.5}\text{CoO}_2 \)

Anode

\( \text{LiC}_6 \)

\( \text{C}_6 \)

Li-ion battery

Anode is made of graphite

electrolyte can be some sort of ethylene carbonate.

Primary \( \rightarrow \) Non-rechargeable

Secondary \( \rightarrow \) Rechargeable

<table>
<thead>
<tr>
<th>Metric</th>
<th>Gravimetric</th>
<th>Volumetric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>( Q_g = \frac{Q}{m} = \frac{nF}{MW} )</td>
<td>( Q_v = \frac{Q}{V} )</td>
</tr>
<tr>
<td>Energy Density</td>
<td>( Q_g \cdot V )</td>
<td>( Q_v \cdot V )</td>
</tr>
<tr>
<td>Power Density</td>
<td>( i_g \cdot V )</td>
<td>( i_v \cdot V )</td>
</tr>
</tbody>
</table>
where \( Q = n \cdot F \cdot N_m \)
\( \downarrow \) moles of reactant being consumed

\( \# \) electrons
for each reactant

C-rate = \( \frac{i}{Q} \times \frac{1}{c} \)

[\( \approx \) time]

e.g.: \( 3 \frac{1}{\text{hour}} \) means the cell is fully discharged in \( \frac{1}{3} \) hour

**Efficiency:**

On a charge basis: \( q_c = \frac{Q_d}{Q_c} \)

Columbic

Efficiency

On an energy basis: \( q_e = \frac{Q_d \cdot V_d}{Q_c \cdot V_c} \)

Examples of battery:

**Primary:**

<table>
<thead>
<tr>
<th>Battery</th>
<th>Anode</th>
<th>Cathode</th>
<th>reaction</th>
<th>U</th>
<th>Capacity (A.h/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leuanche</td>
<td>Zn</td>
<td>MnO₂</td>
<td>( \text{Zn} + \text{MnO}_2 \rightarrow \text{ZnO} + \text{MnO}_2 )</td>
<td>1.6 V</td>
<td>224</td>
</tr>
<tr>
<td>Zinc - Air</td>
<td>Zn</td>
<td>O₂</td>
<td>( \text{Zn} + \frac{1}{2} \text{O}_2 \rightarrow \text{ZnO} )</td>
<td>1.65 V</td>
<td>658</td>
</tr>
<tr>
<td>Li - MnO₂</td>
<td>Li</td>
<td>MnO₂</td>
<td>( \text{Li} + \text{MnO}_2 \rightarrow \text{LiHnO}_2 )</td>
<td>3.1 V</td>
<td>286</td>
</tr>
</tbody>
</table>
C) Fuel Cells:

An electrochemical cell which converts chemical energy of a fuel into electricity → Not "self-contained" device

Typically $O_2$ and $H_2/CH_3OH/N$-based substances → Harness energy from oxidation reaction

Example: $H_2/O_2$ fuel cell
H₂/O₂ fuel cell can operate in acid or basic conditions

Phosphoric acid fuel cell

Alkaline fuel cell

PEM fuel cell

AEM fuel cell

Less commercially available

Acid condition:

GDE is typically made up of Pt/C on carbon cloth.

Disadvantage: ORR is slow in acidic condition

Basic condition:

GDE can be non-precious metal

Disadvantage: AEM has low ionic conductivity

CO₂ accumulation if O₂ is taken from ambient air