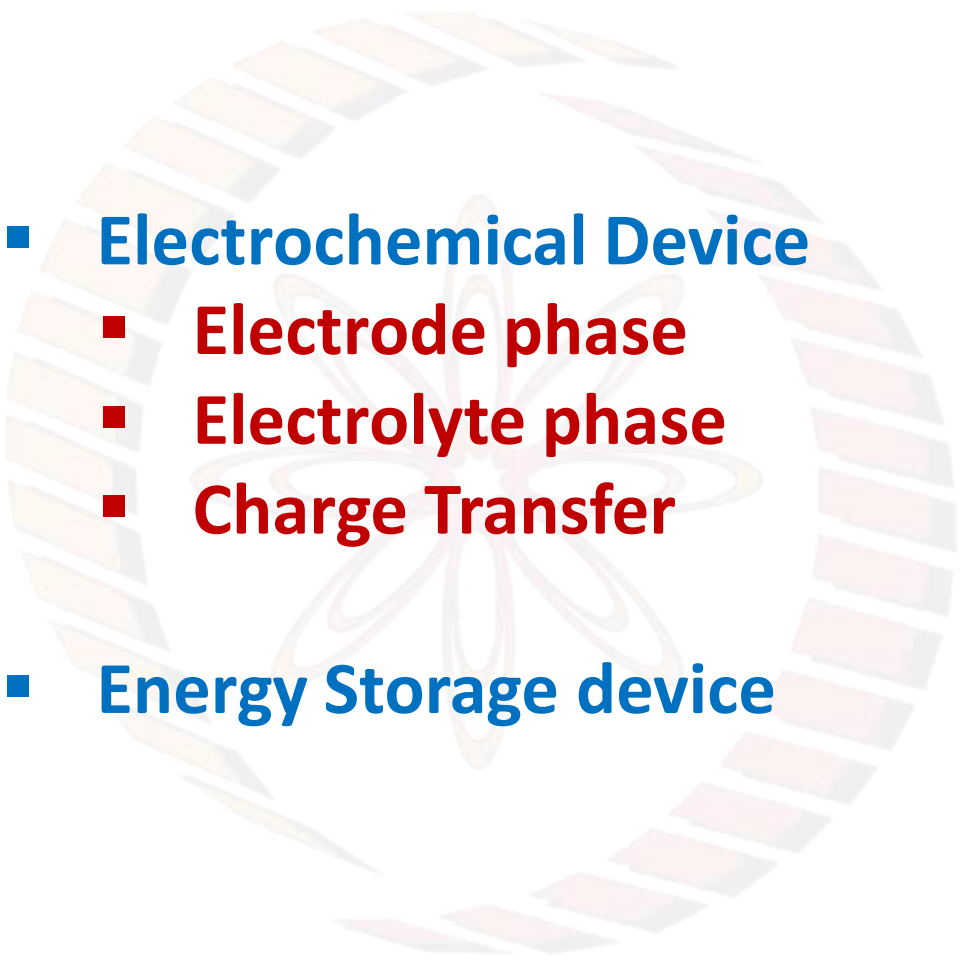




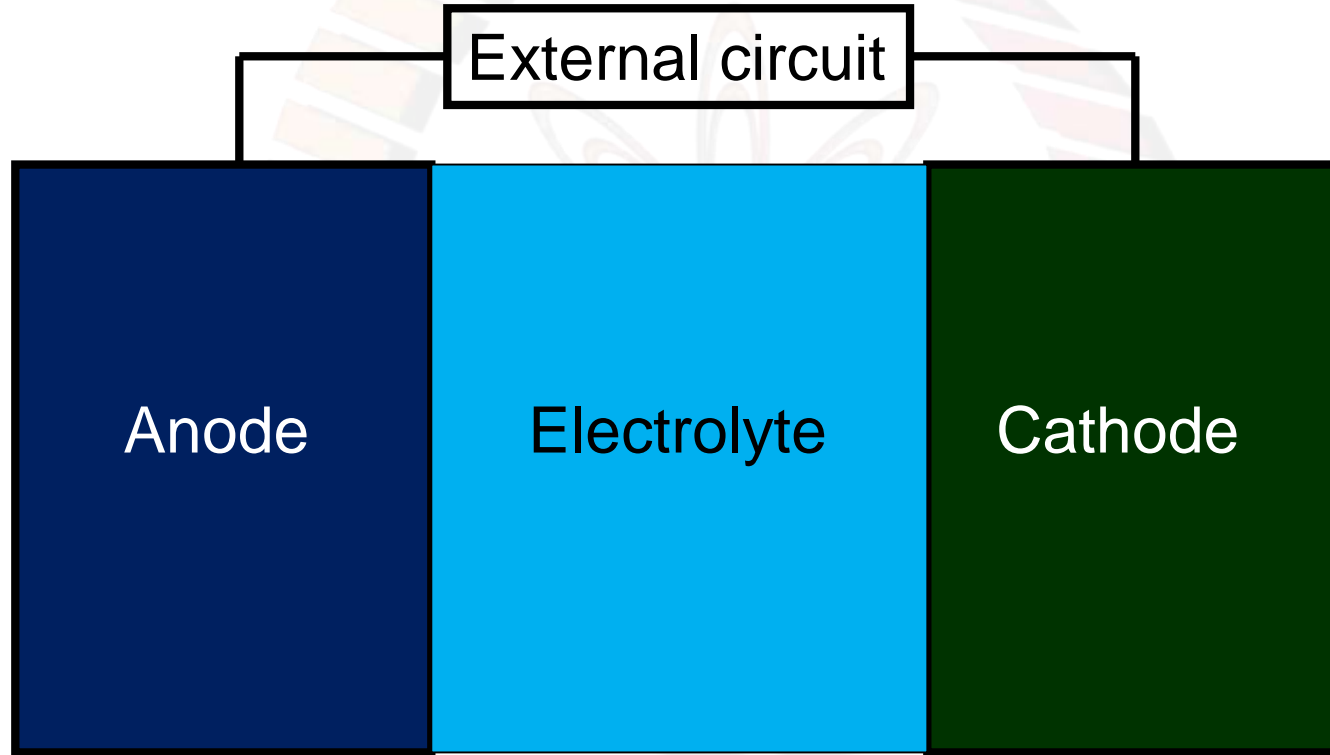
Battery Basics

Learning Objectives

- 1) To state the various parts of the battery and their functions
- 2) To indicate the use of the electrochemical series
- 3) To distinguish between primary and secondary batteries
- 4) To indicate the meaning of terms used in the context of battery technology

- 
- **Electrochemical Device**
 - **Electrode phase**
 - **Electrolyte phase**
 - **Charge Transfer**
 - **Energy Storage device**

Electrochemical Device



Anode

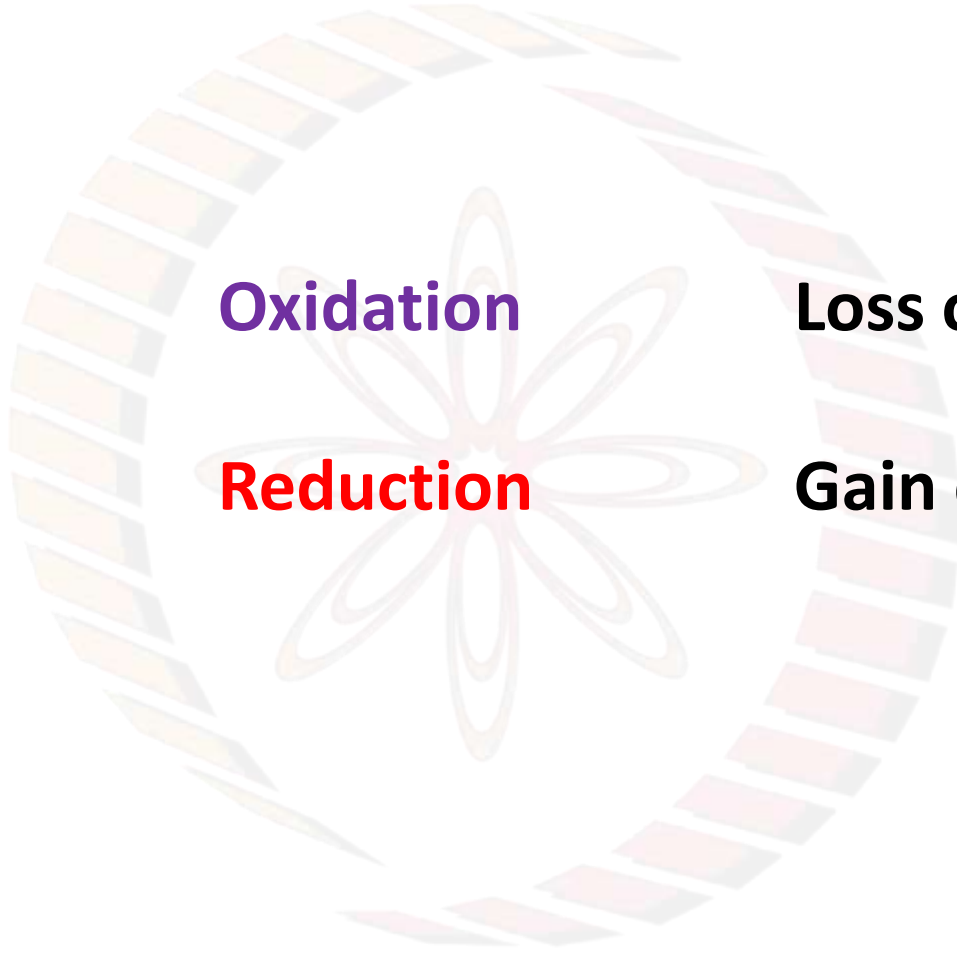
Oxidation

Loss of electrons

Cathode

Reduction

Gain of electrons



The Electrochemical Cell

Standard Half Cell and SHE



Standard Electrode Potential

Standard Electrochemical Series





Energy Storage Device:

Fuel and oxidant are stored within the device.

Energy Conversion Device:

Fuel and oxidant are stored external to the device



Cell:

A single electrochemical unit; i.e. one anode, one cathode, and the electrolyte

Battery:

A collection of cells in series or parallel



Primary Cell:

Single use power source

Secondary Cell:

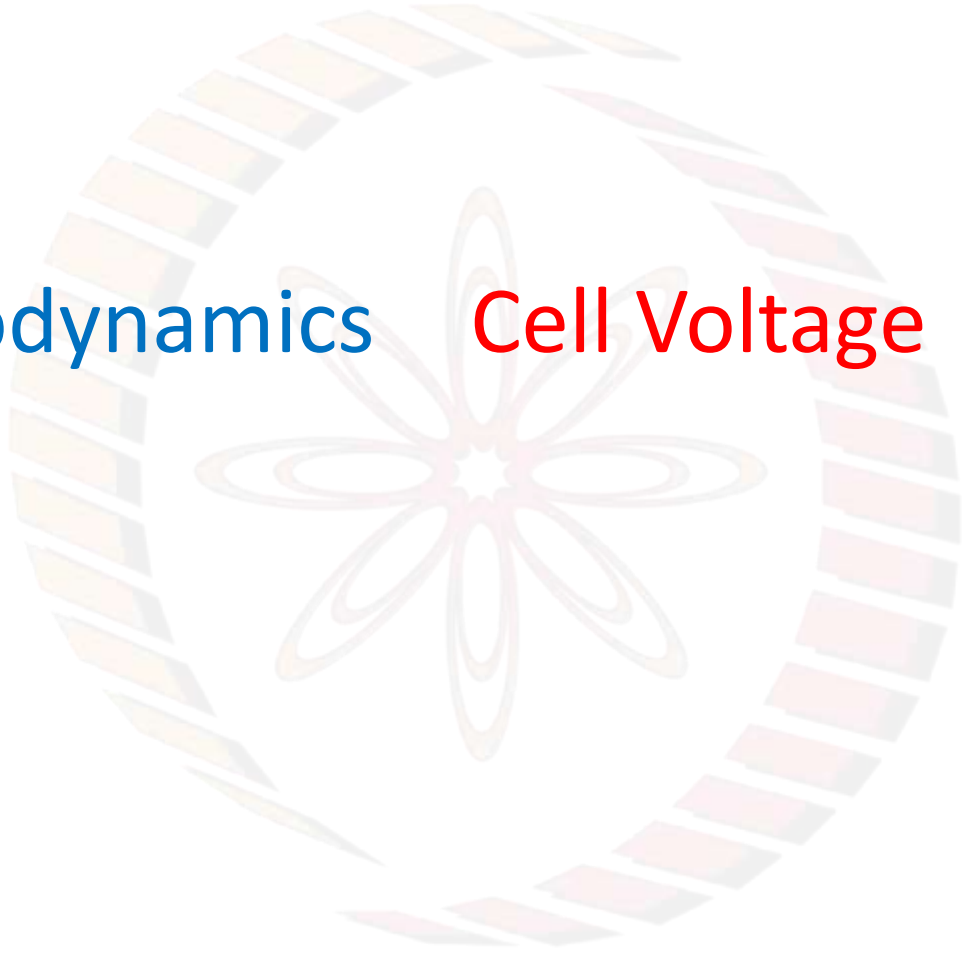
Can be recharged

Thermodynamics



Thermodynamics

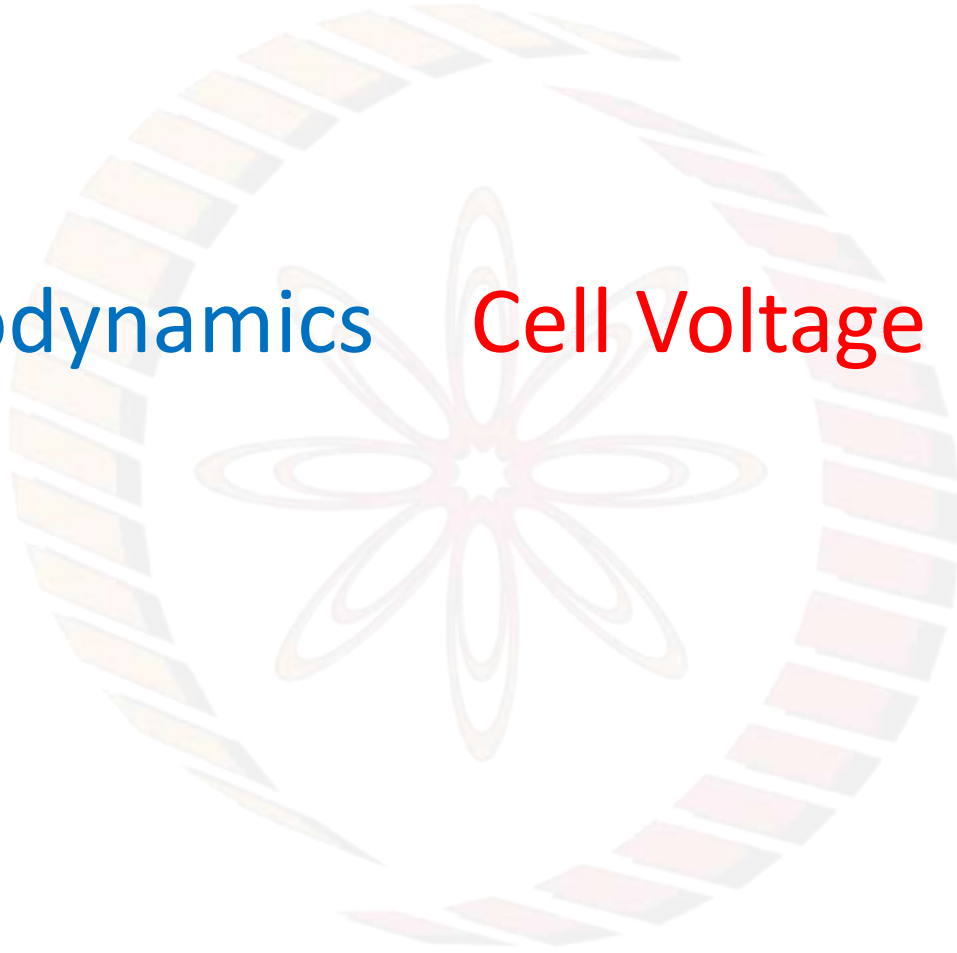
Cell Voltage



Thermodynamics

Cell Voltage

Kinetics

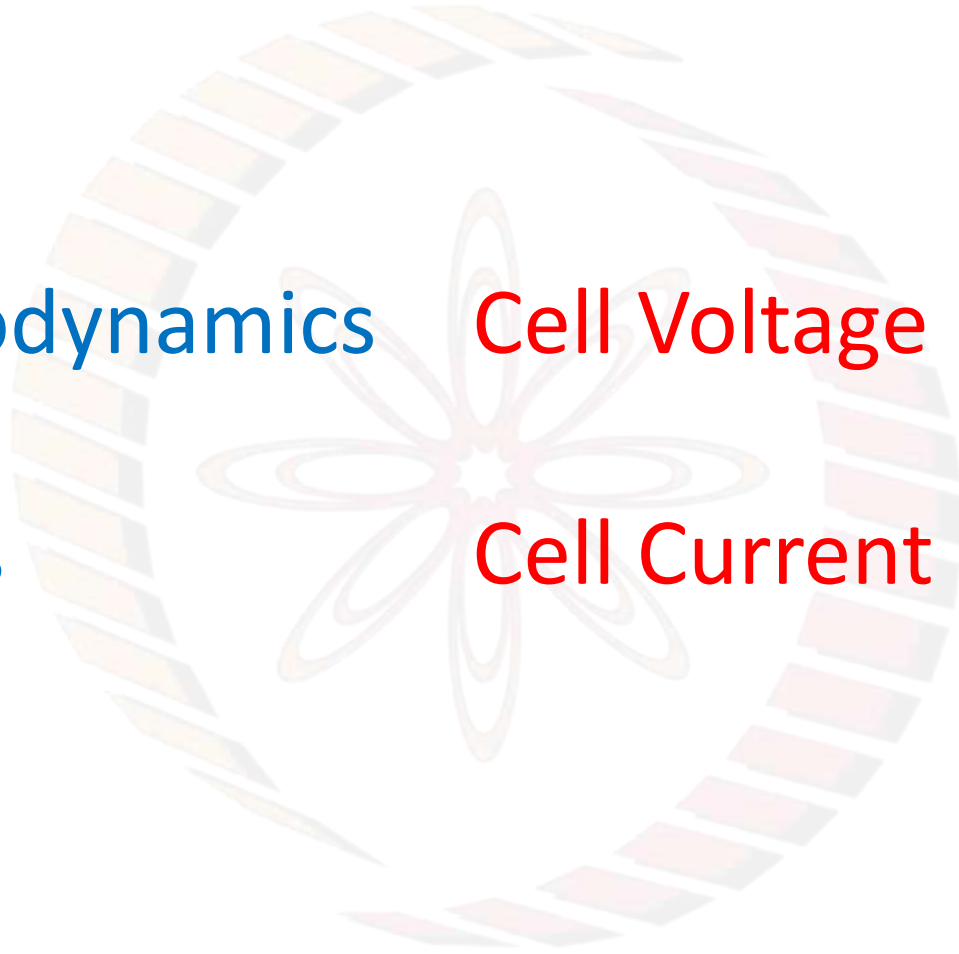


Thermodynamics

Cell Voltage

Kinetics

Cell Current



Cell characteristics:

Capacity: Total charge in cell
Coulombs or Ah

Voltage

Current

Time

Energy:

Power = $V * I$
Watts

Power * Time
Joules or Wh

Conclusions

- 1) Batteries have specific parts that can have dramatically opposite functions
- 2) The electrochemical series is the starting point to understand Battery voltages
- 3) Primary and secondary batteries are both commonly used

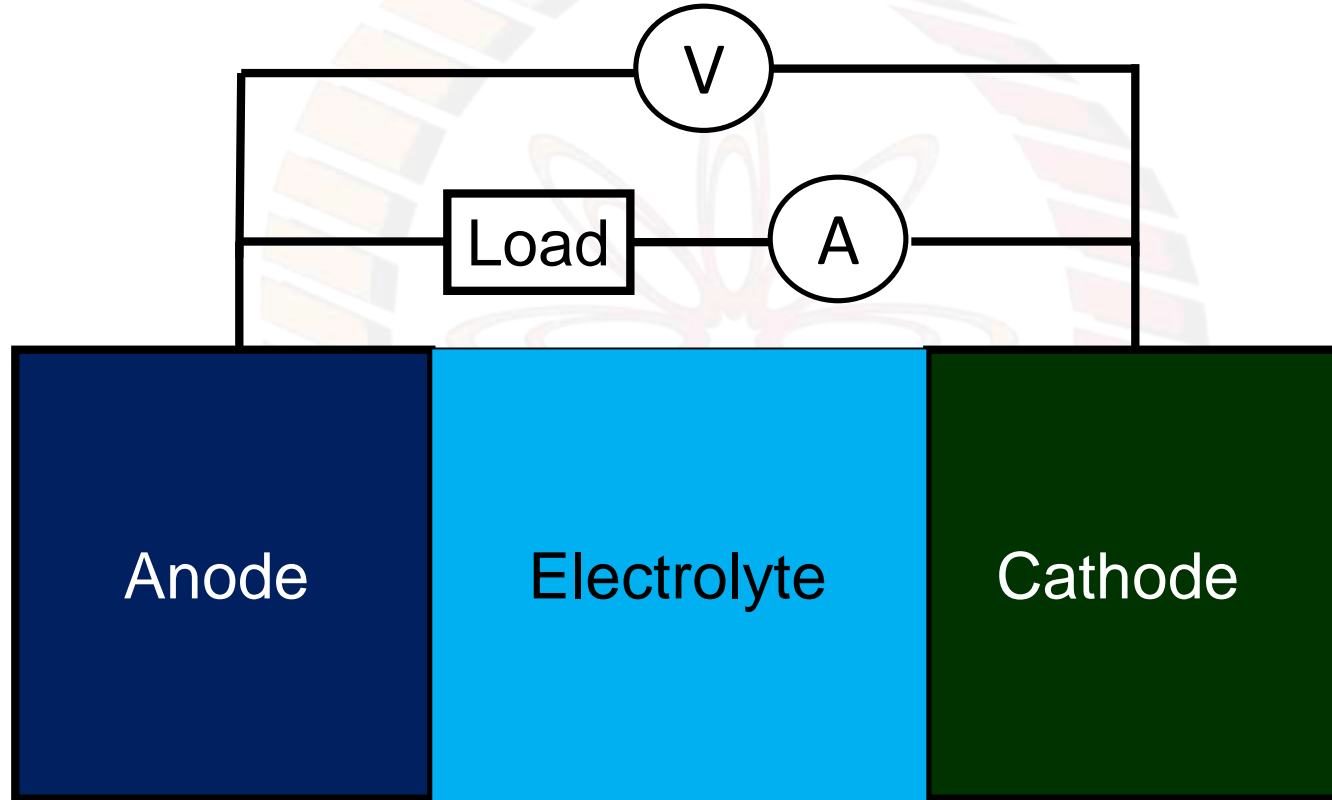


Battery Testing and Performance

Learning Objectives

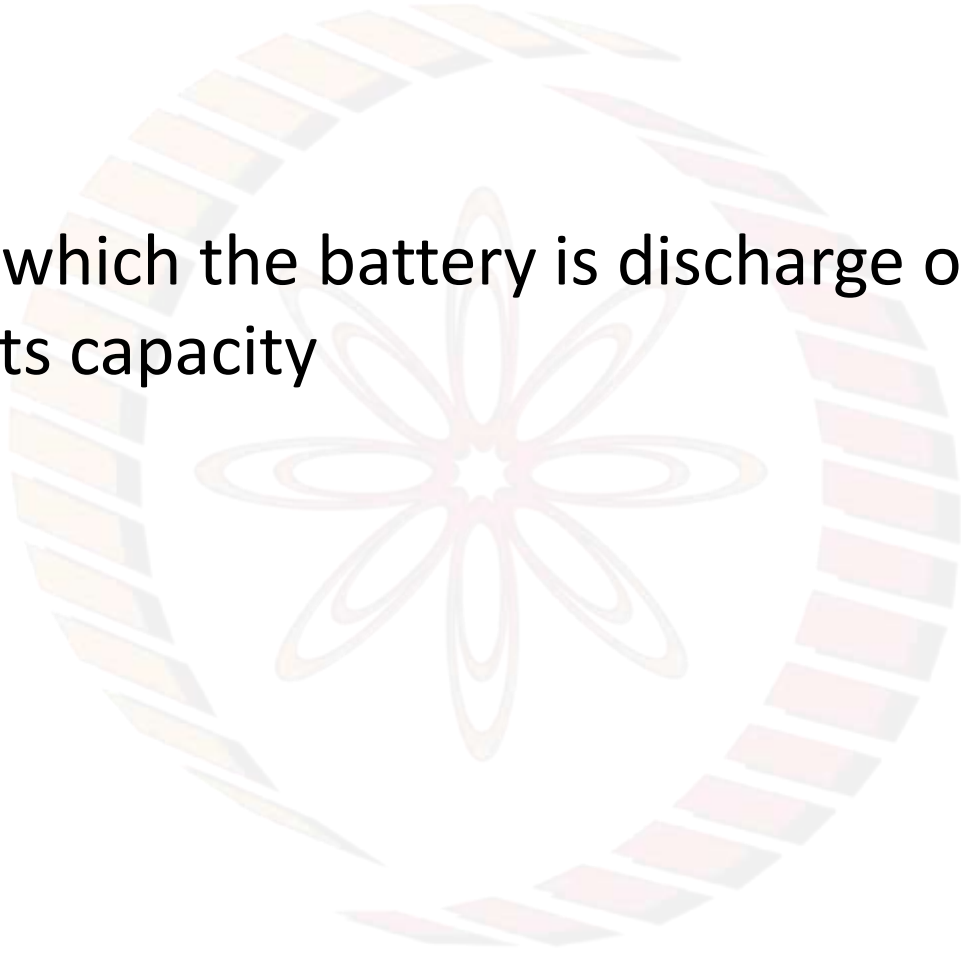
- 1) To draw a schematic of the typical battery test process
- 2) To indicate the significance of C-Rate
- 3) To be familiar with the typical discharge and charge curves
- 4) To indicate the effect of the C-Rate on the charge-discharge curve
- 5) To indicate the significance of the polarization curve

Battery Testing



The C-Rate

The rate at which the battery is discharge or charged, relative to its capacity



The C-Rate

The rate at which the battery is discharge or charged, relative to its capacity

1 C Rate => Discharge or Charge in 1 hour

2 C Rate => Discharge or Charge in $\frac{1}{2}$ hour

5 C Rate => Discharge or Charge in 12 minutes

0.1 C Rate => Discharge or Charge in 10 hours

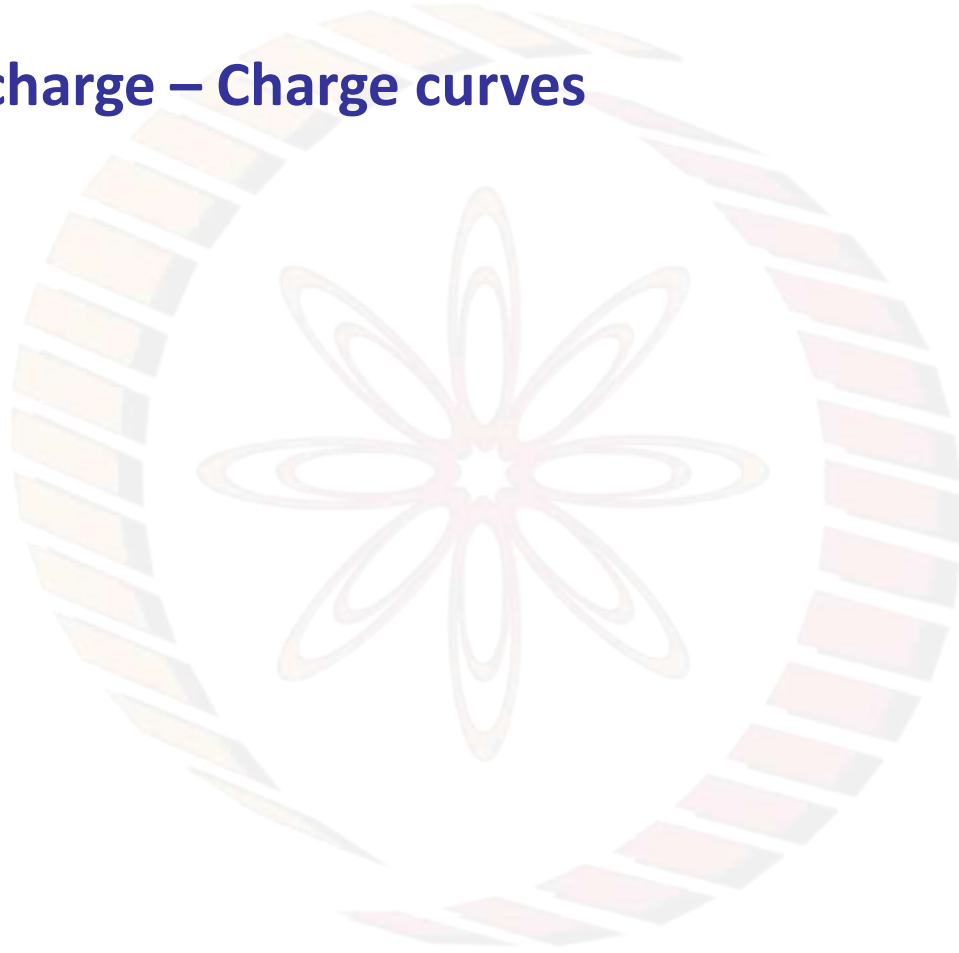
Terminology associated with use

State of charge: % of maximum capacity that is remaining unused

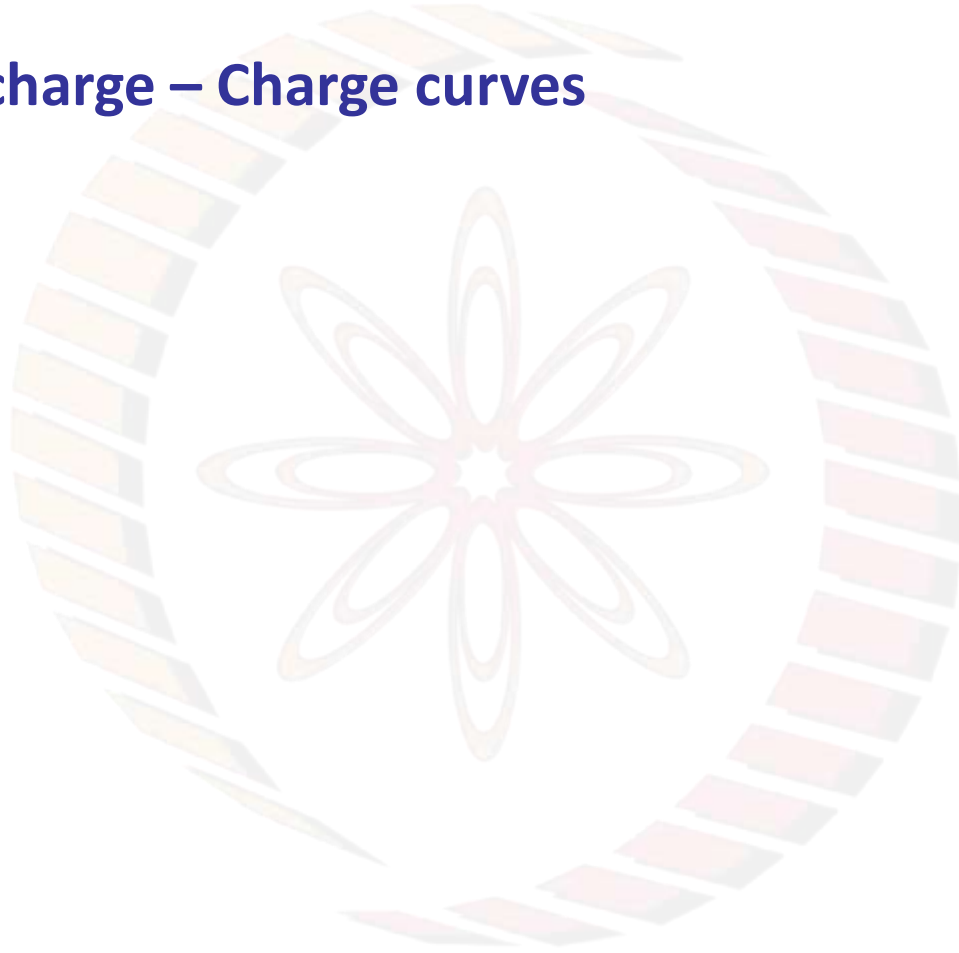
Depth of Discharge: % of maximum capacity that has been discharged

Cycle life: Number of cycles before the battery fails to meet performance specifications. Affected by Depth of Discharge

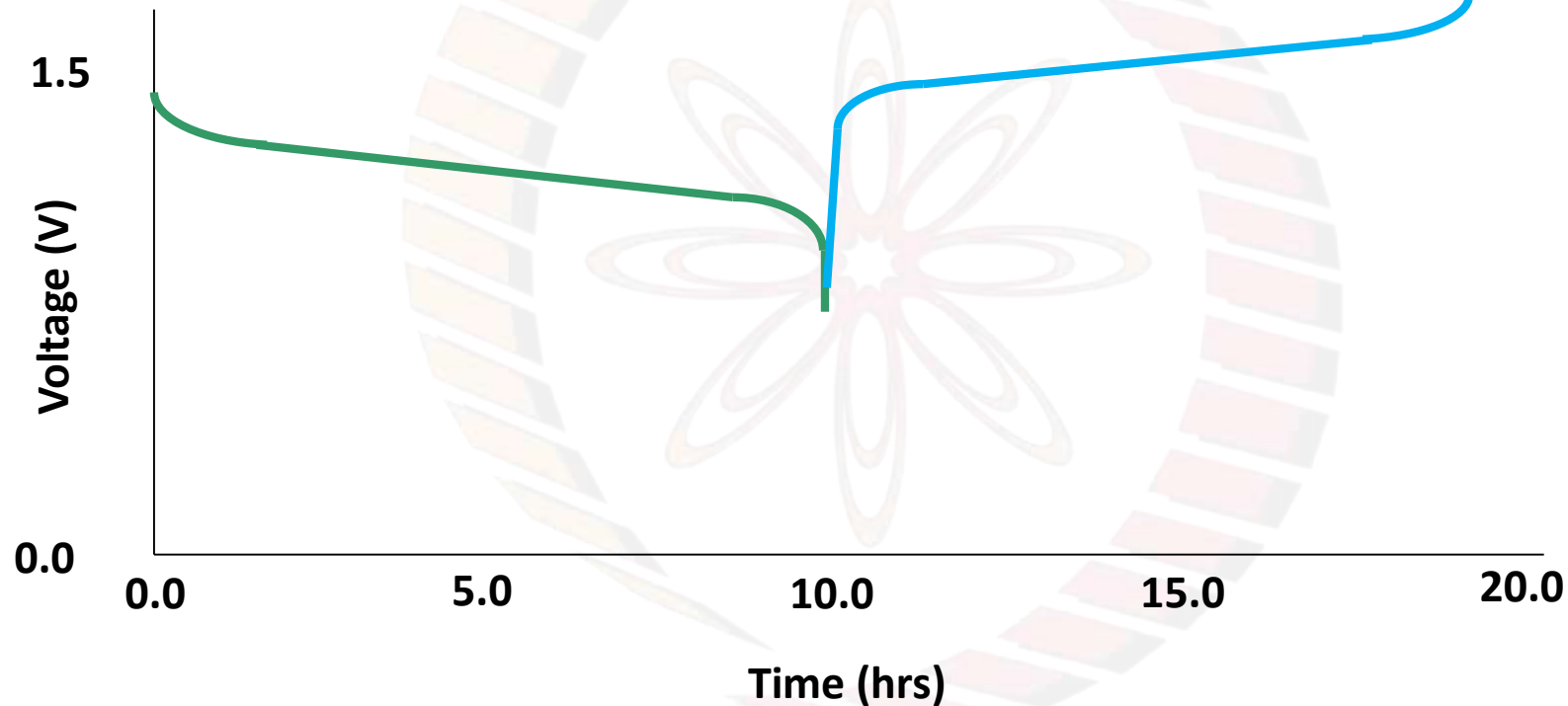
Discharge – Charge curves



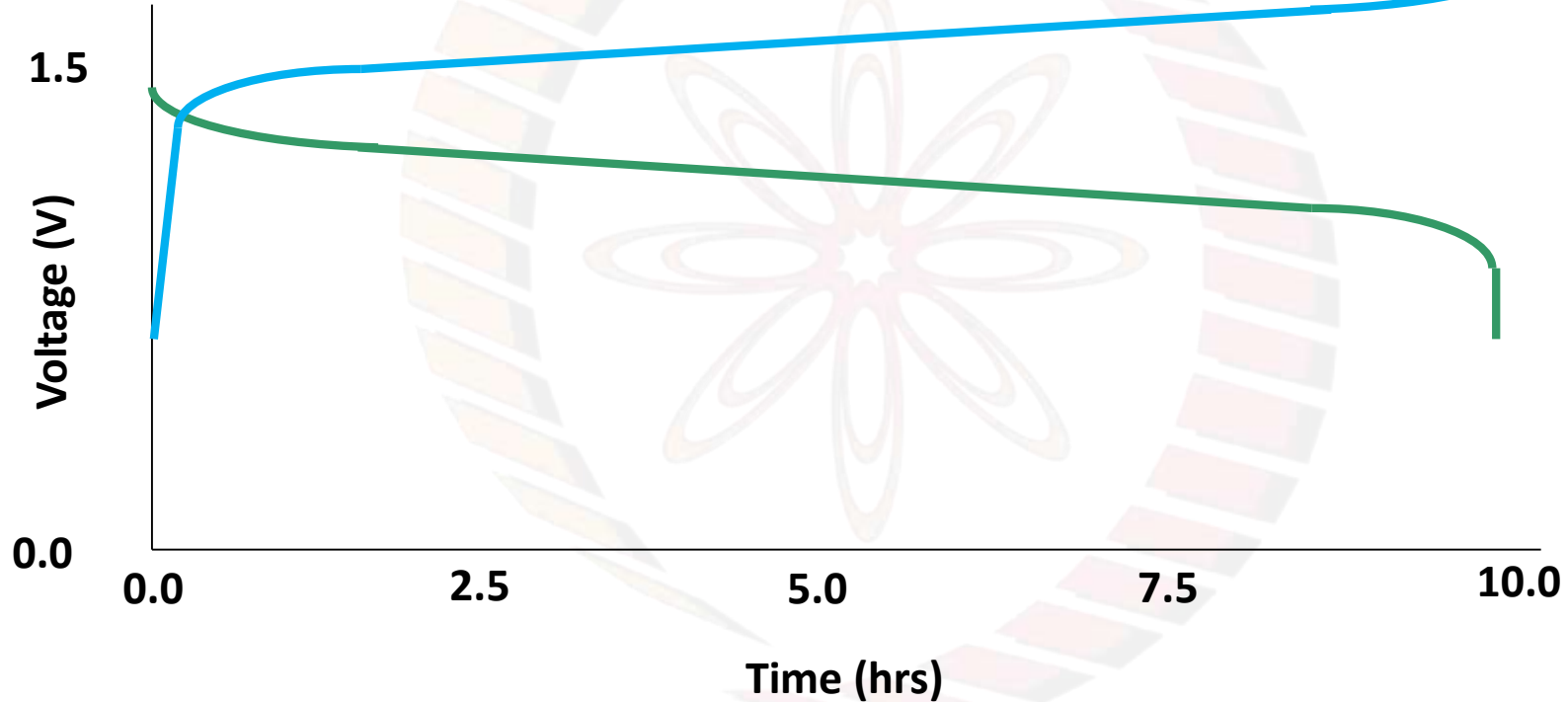
Discharge – Charge curves



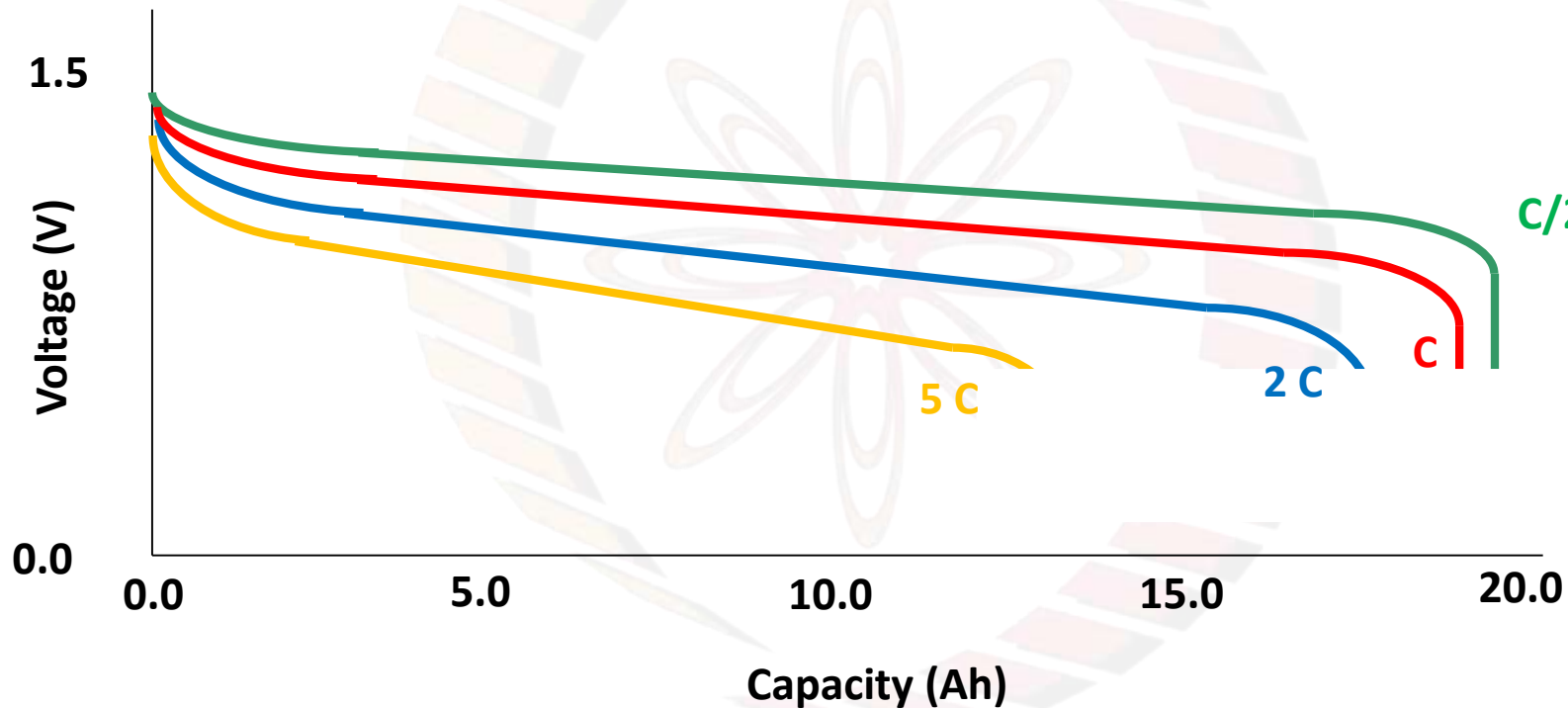
Discharge – Charge curves



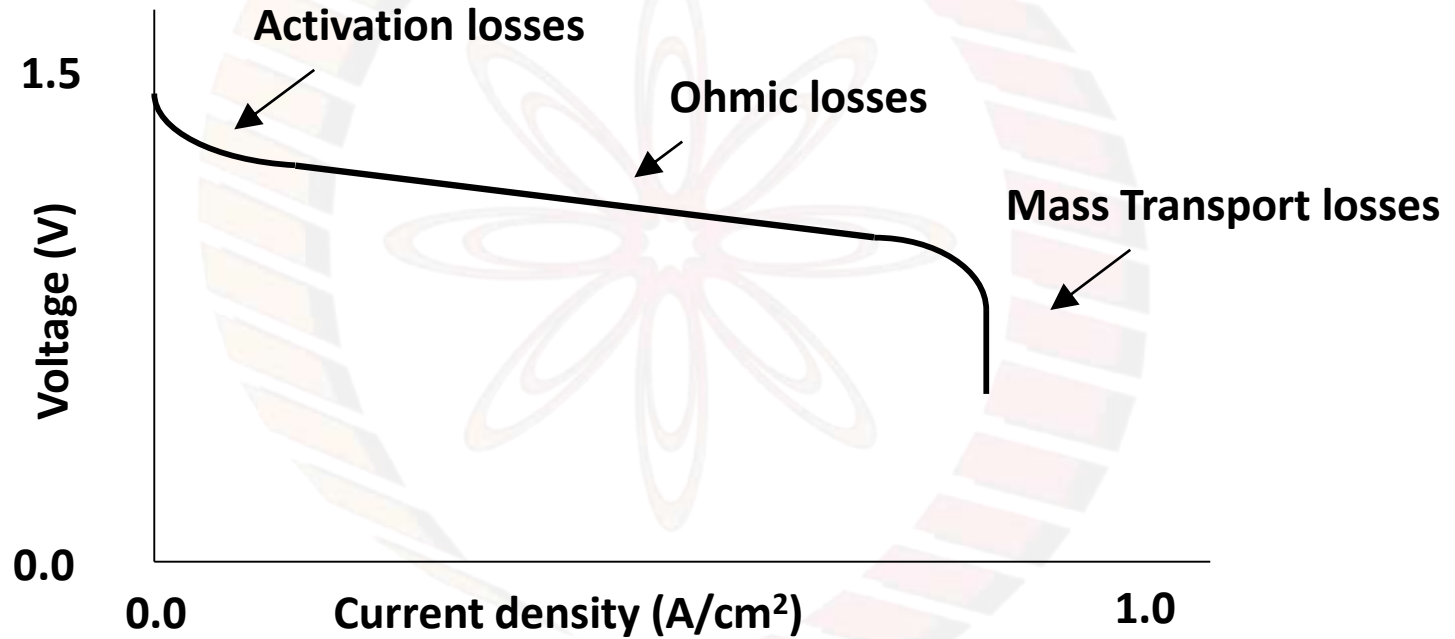
Discharge – Charge curves

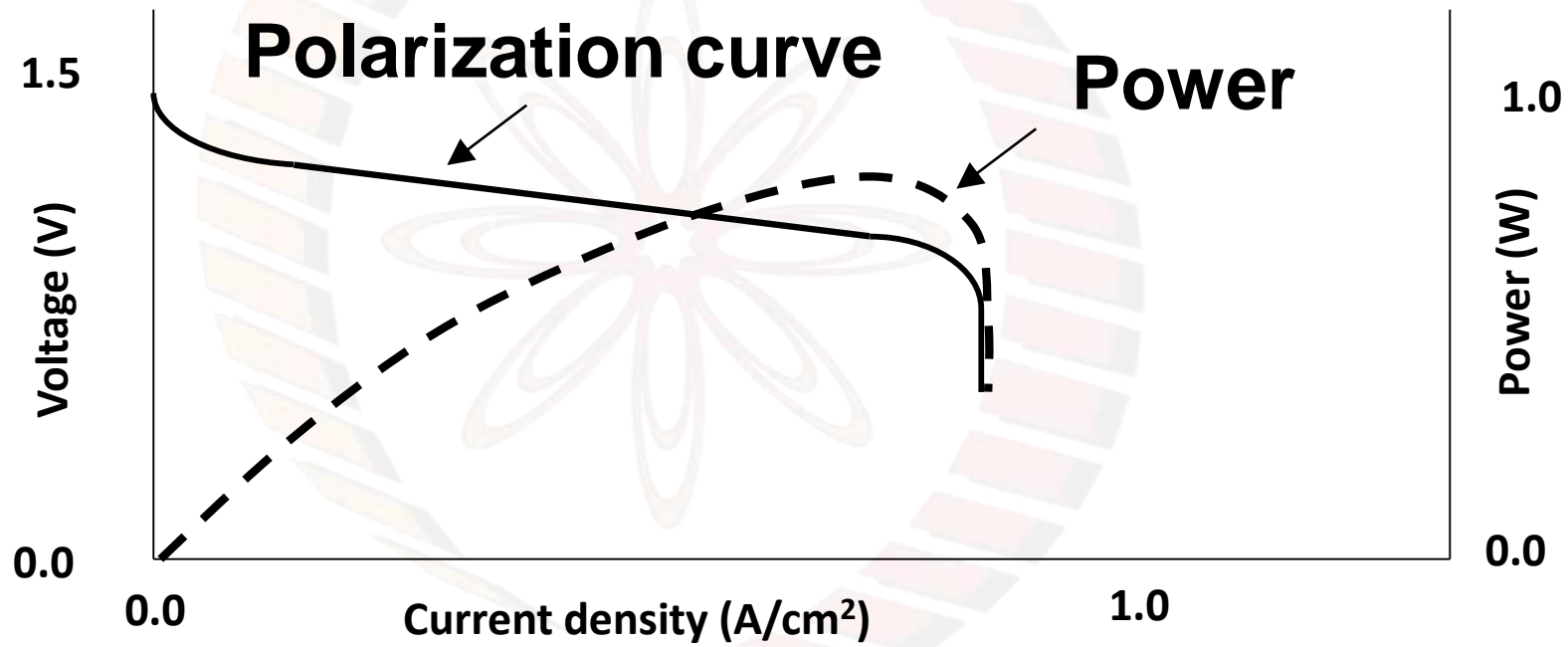


Effect of C-Rate on Discharge

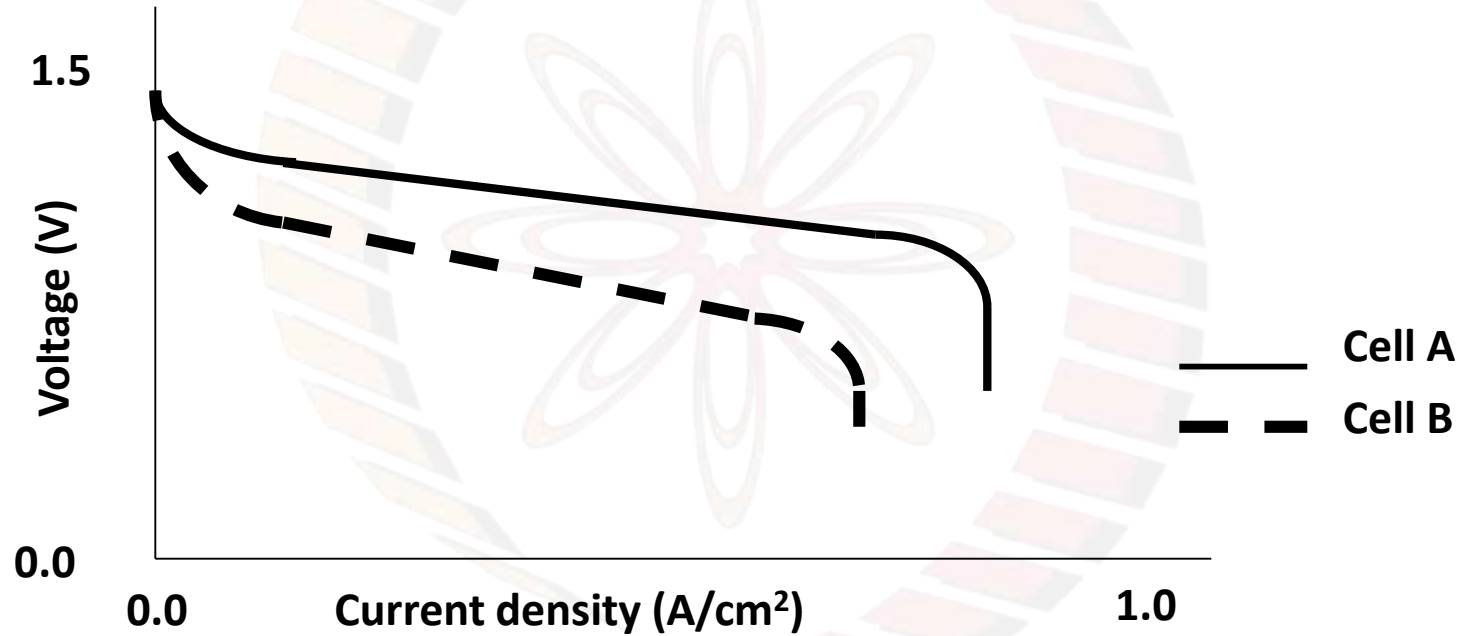


Polarization curve





A comparison between two cells



Conclusions

- 1) C-Rate indicates the rate at which the battery is being charged or discharged relative to its capacity
- 2) Charge – discharge curves typically show steady performance of the batteries excepting close to the fully charged and fully discharged conditions
- 3) The polarization curve enables comparison between batteries from the perspective of power delivery



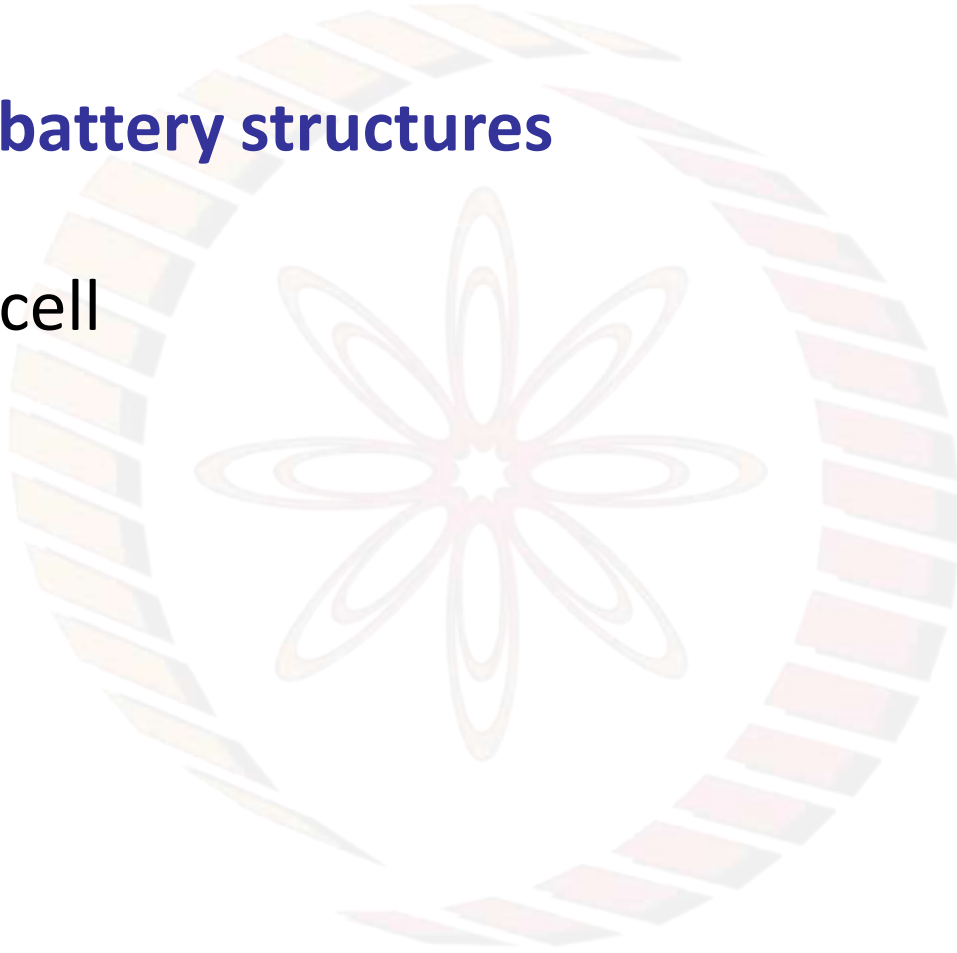
Common Battery Types

Learning Objectives

- 1) To become familiar with common battery types
- 2) To indicate advantages and disadvantages of these different battery types

Different battery structures

Prismatic cell

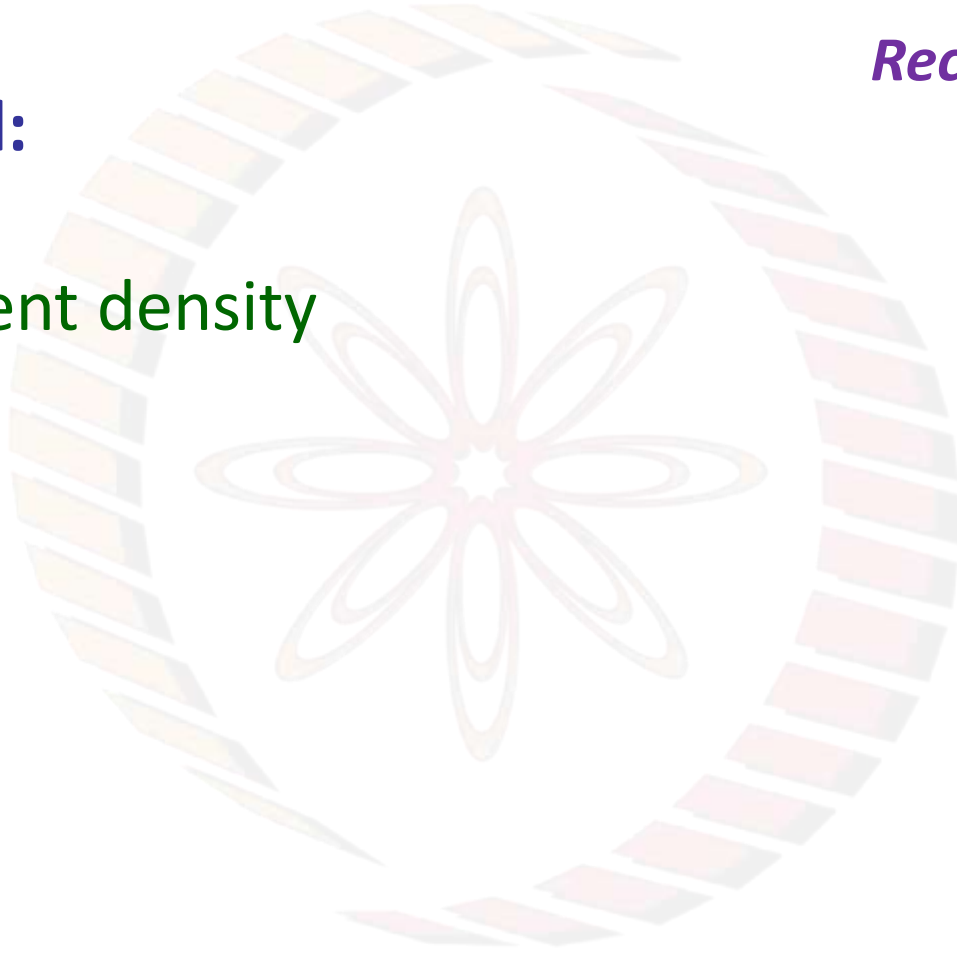


Lead-Acid:

High current density

Toxic

Rechargeable

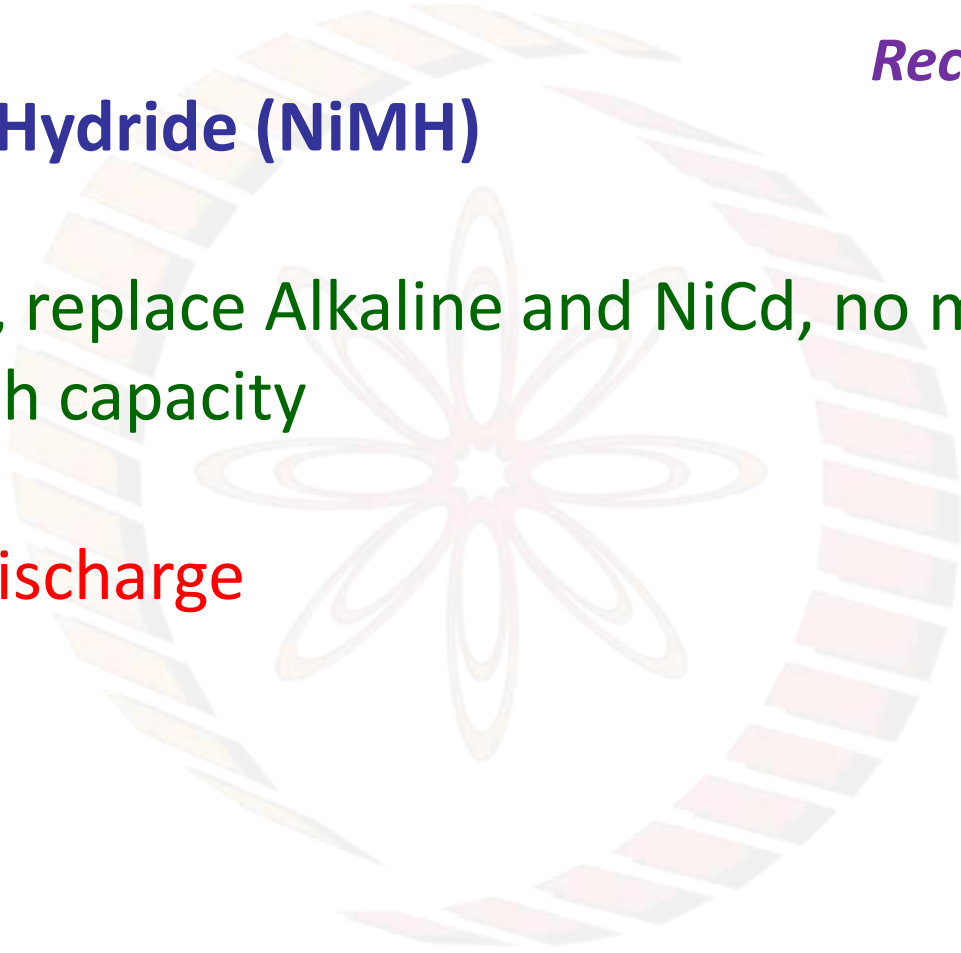


Rechargeable

Ni-Metal Hydride (NiMH)

Non toxic, replace Alkaline and NiCd, no memory effect, high capacity

Can self discharge



Rechargeable

Ni-Cd (NiCad)

High cycle life (much more than NiMH), reliable

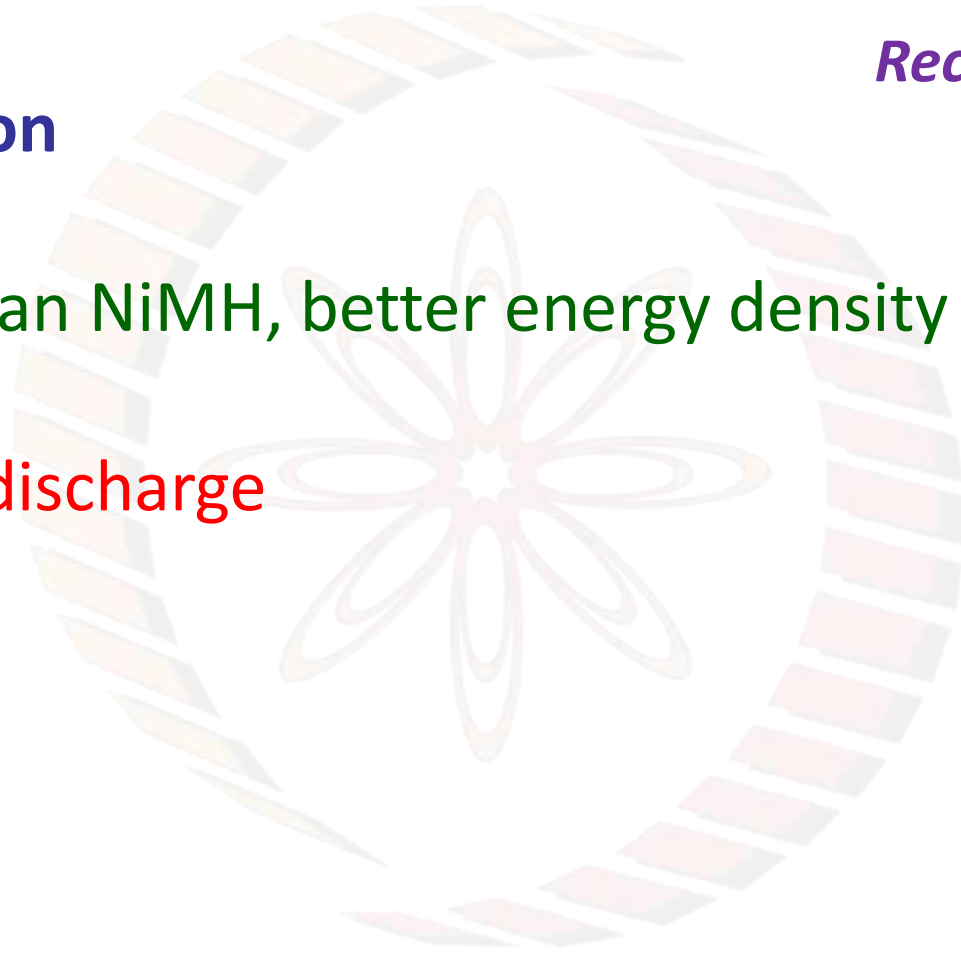
Lower capacity than NiMH, toxic, memory effect

Rechargeable

Lithium Ion

Lighter than NiMH, better energy density

May self discharge

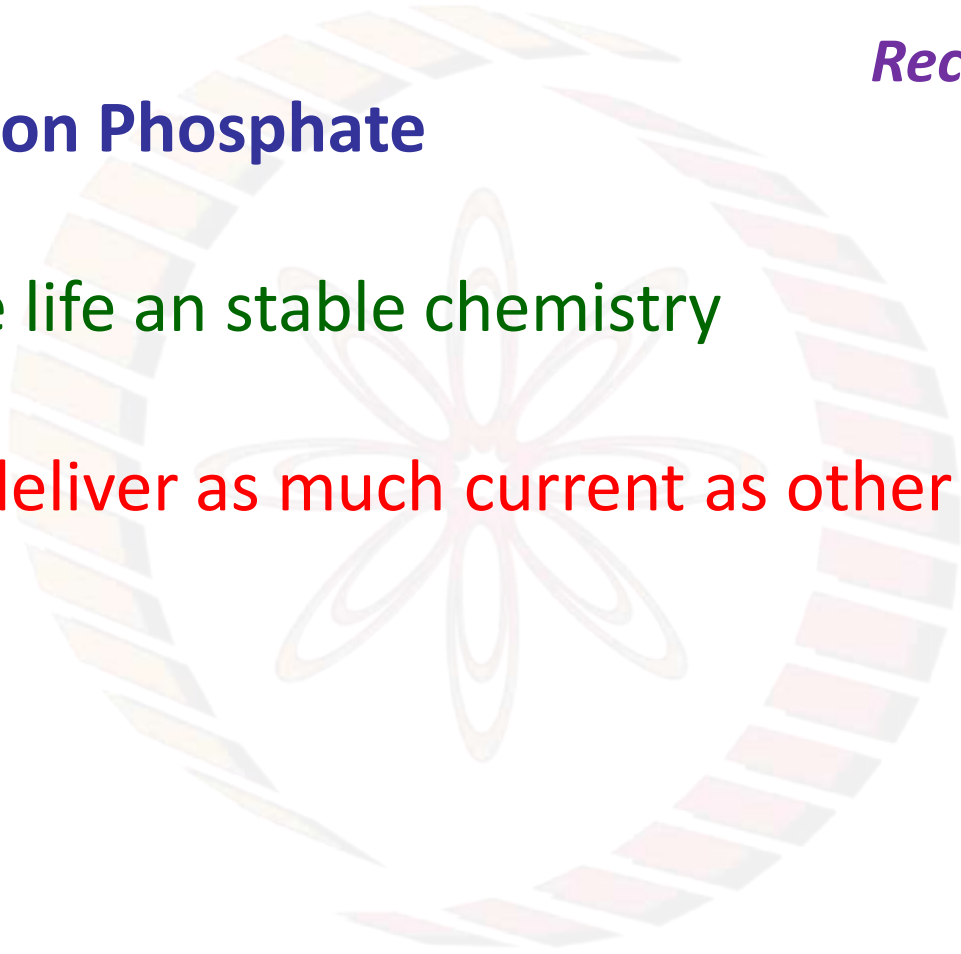


Rechargeable

Lithium Iron Phosphate

High cycle life and stable chemistry

May not deliver as much current as other chemistries



Alkaline

Non-Rechargeable

Inexpensive

May not deliver as much current

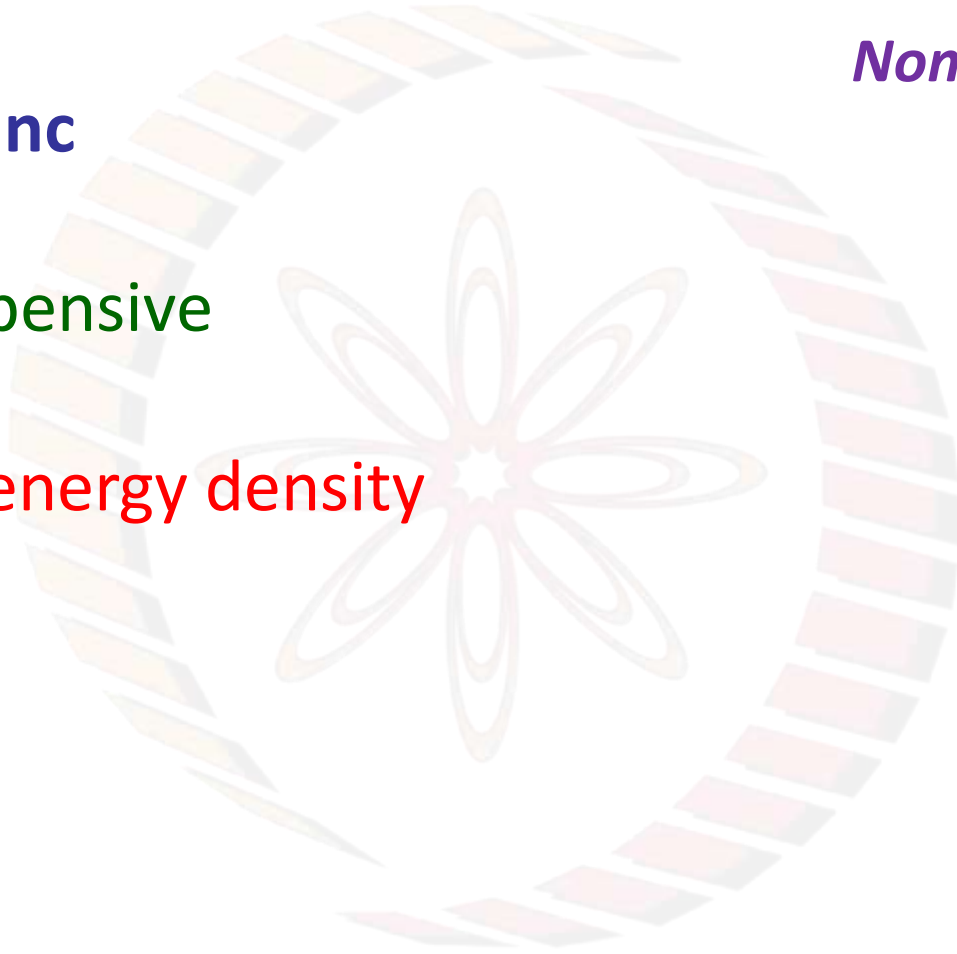


Carbon-Zinc

Non-Rechargeable

Very Inexpensive

Very low energy density



Lithium

Non-Rechargeable

High energy density, light weight

Expensive



Conclusions

- 1) There are a wide range of battery types
- 2) These batteries differ from each other in terms of capacity, environmental friendliness, current densities supported, and cycle life
- 3) Careful analysis is needed to match a battery with a specific end use

A large, faint, stylized graphic of a battery cell is centered in the background. The cell is represented by a circular outline composed of many small, colored rectangular segments in shades of yellow, orange, and red. Inside the circle, there is a stylized flower or star-like pattern with multiple pointed petals or segments radiating from the center.

Lithium ion Batteries

Learning Objectives

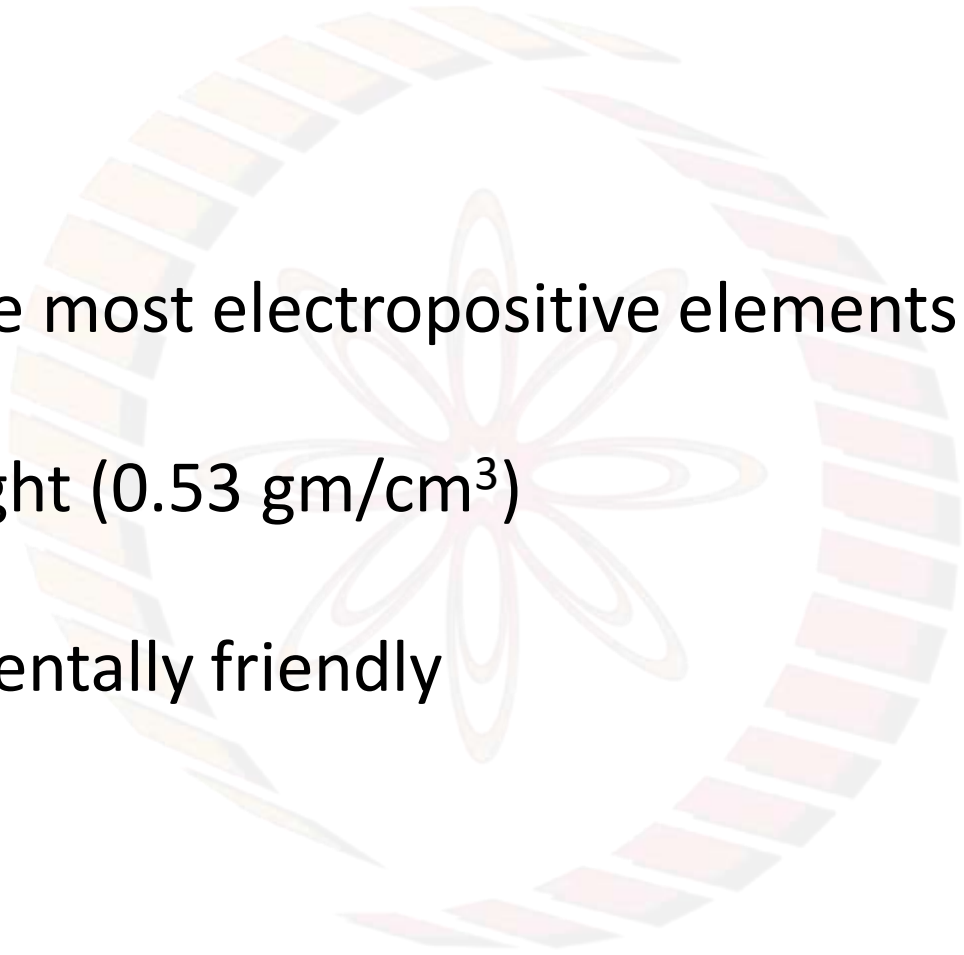
- 1) State the advantages of Lithium based battery chemistry
- 2) Indicate the hazard with Lithium metal based batteries
- 3) Indicate how lithium ion batteries overcome the hazard
- 4) Describe the process of Intercalation
- 5) Indicate the relative position of the energy levels required for stability of the electrolyte

Lithium

One of the most electropositive elements

Light weight (0.53 gm/cm^3)

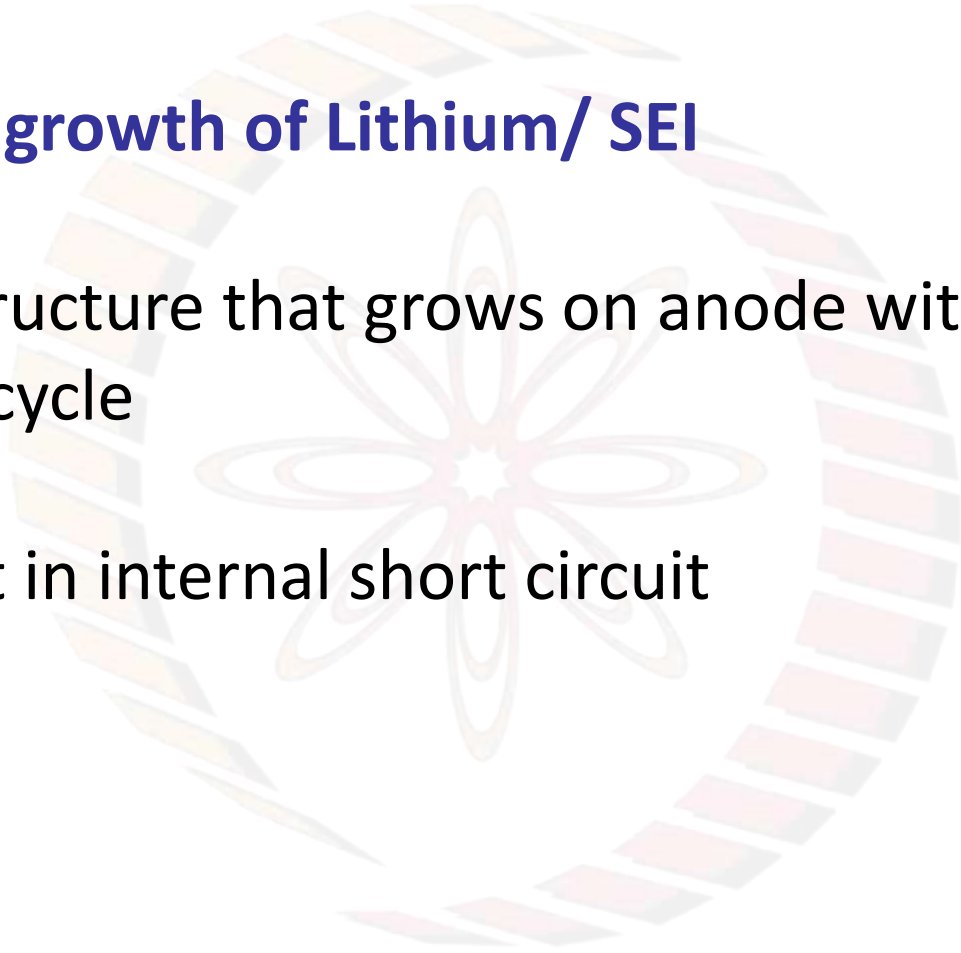
Environmentally friendly



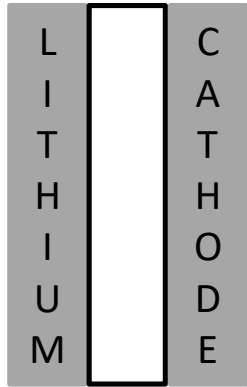
Dendritic growth of Lithium/ SEI

Porous structure that grows on anode with each recharge cycle

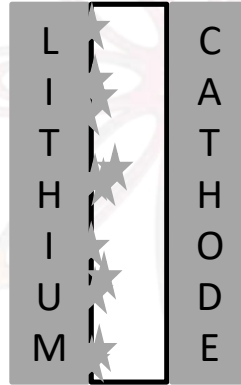
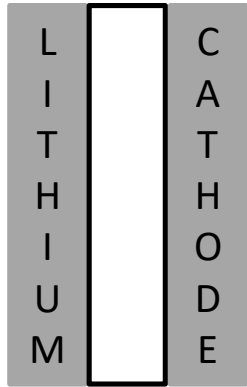
Can result in internal short circuit



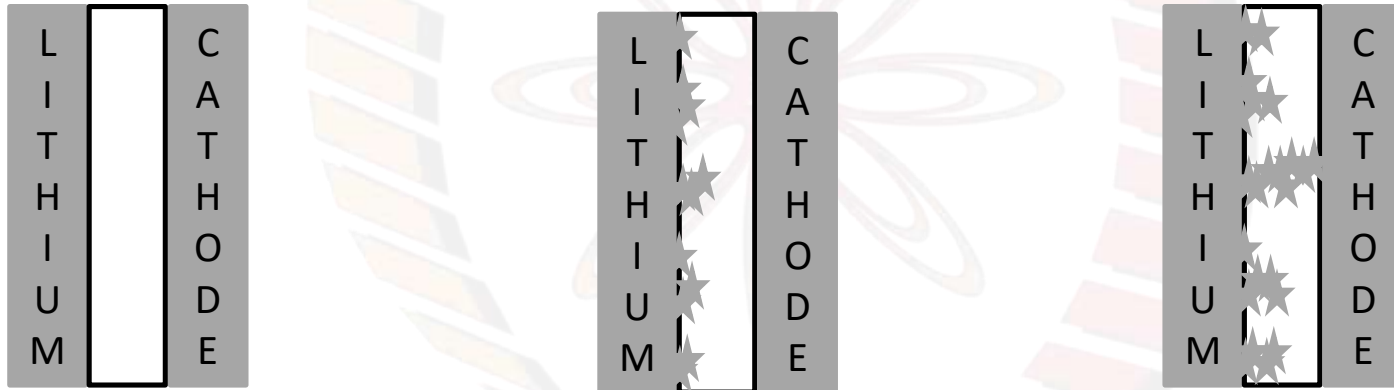
Dendritic growth of Lithium



Dendritic growth of Lithium



Dendritic growth of Lithium

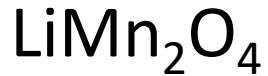


Intercalation

Carbon based host materials



Anode

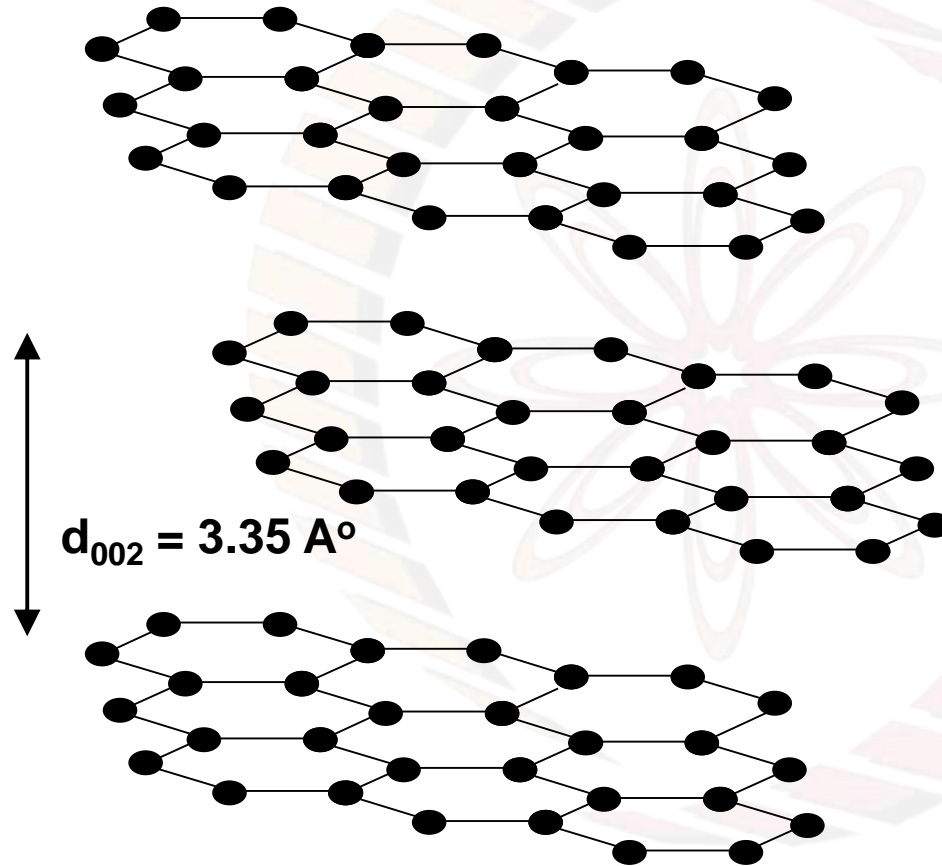


Cathode



Electrolyte (Lithium Hexafluorophosphate in Ethylene Carbonate and Diethyl Carbonate)

Graphite

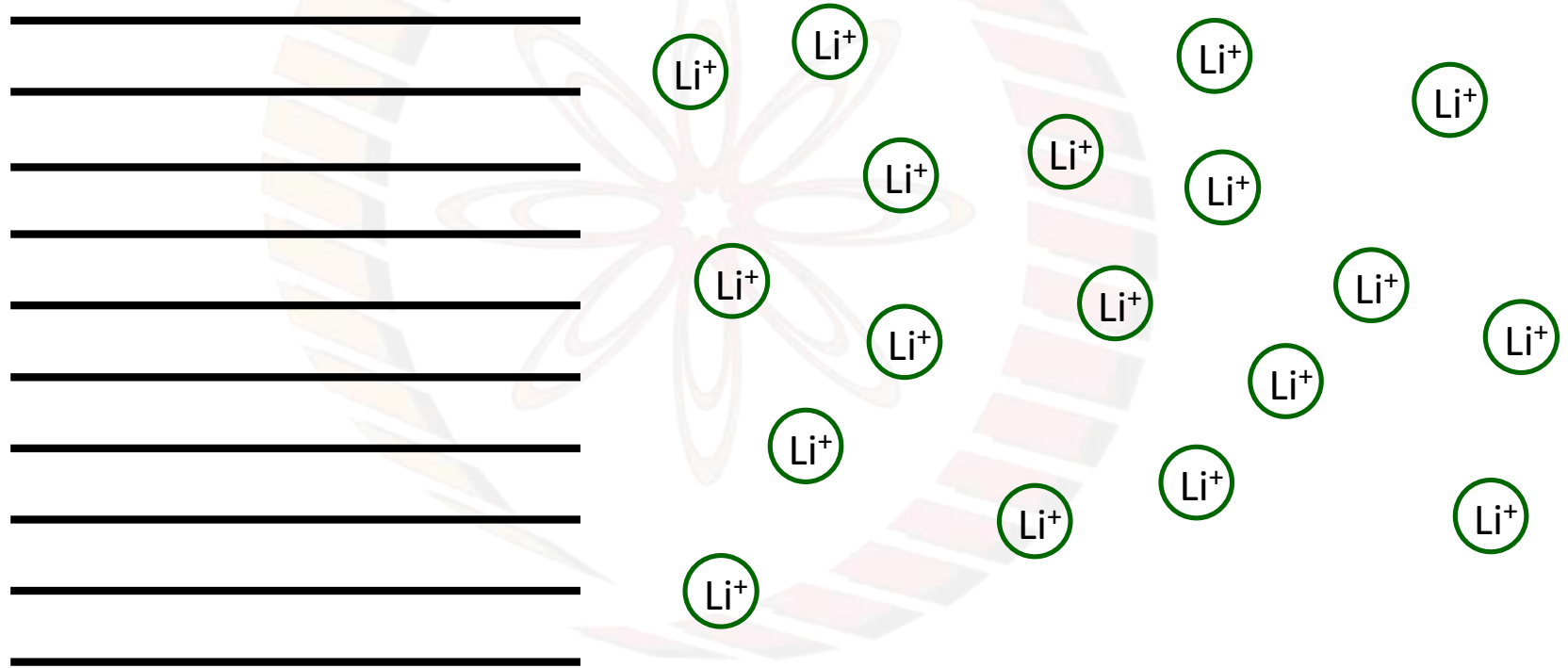


Unit Cell

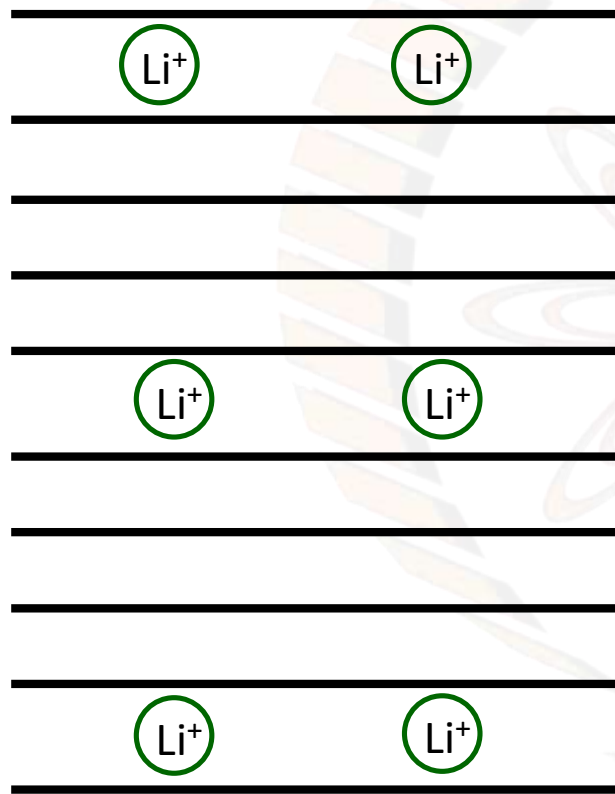
$$a = b = 2.46 \text{ Å}$$

$$a_{cc} = 1.42 \text{ Å}$$

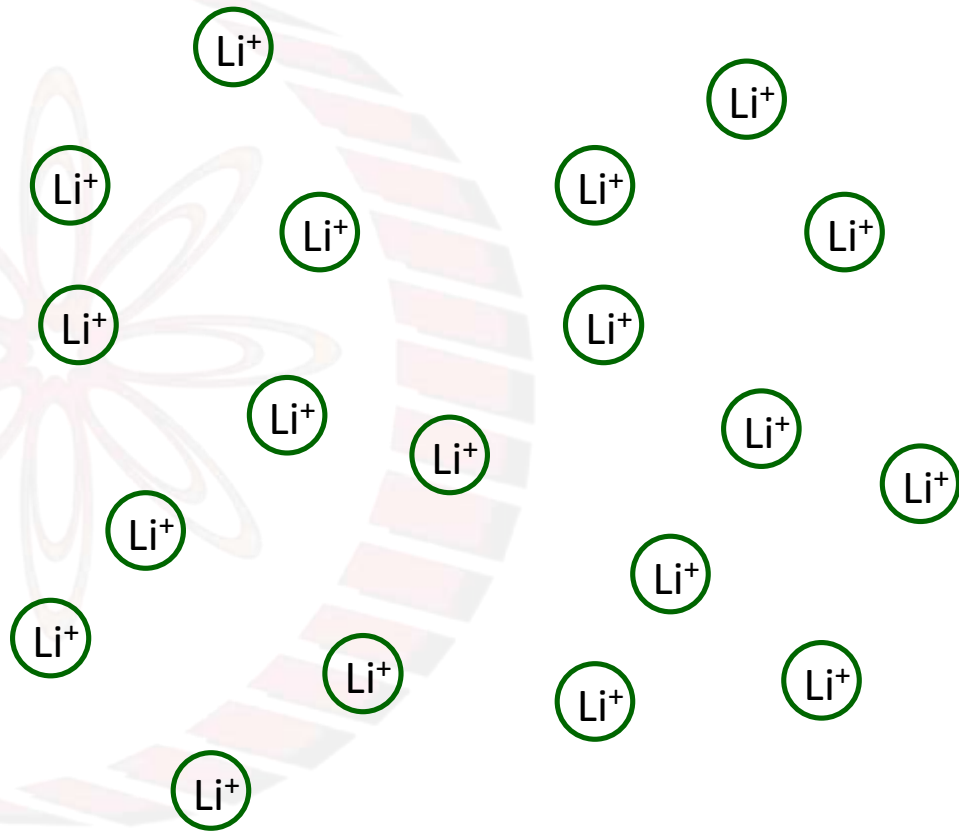
Intercalation



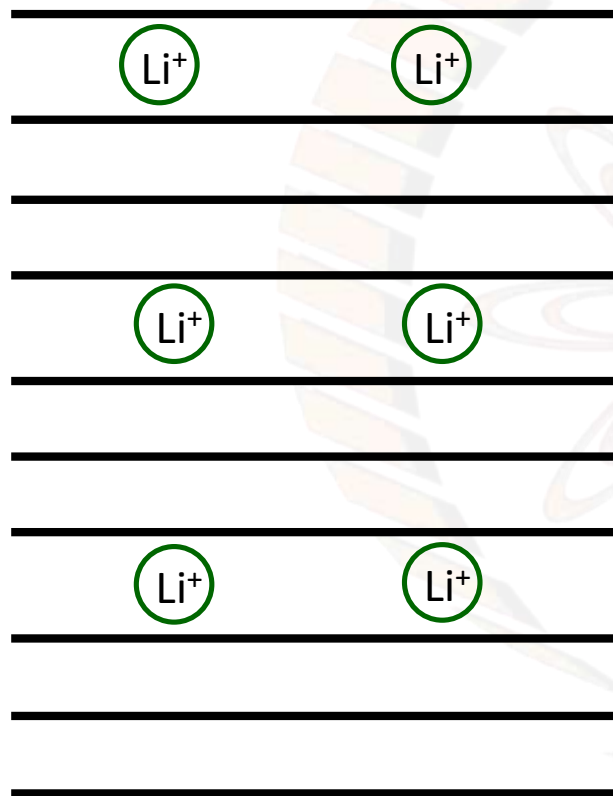
Stage 4



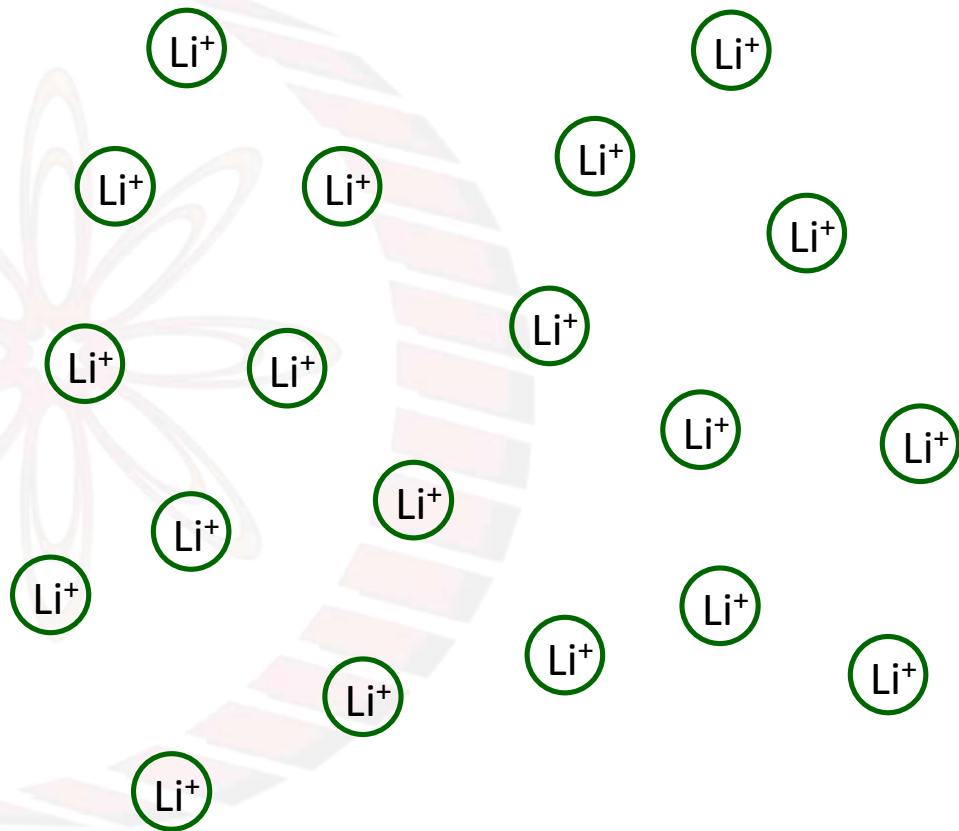
Intercalation



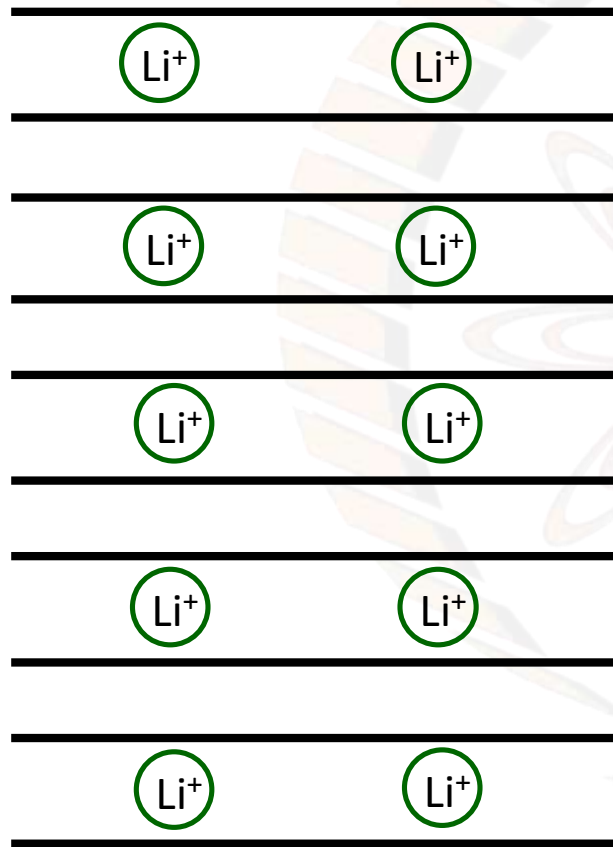
Stage 3



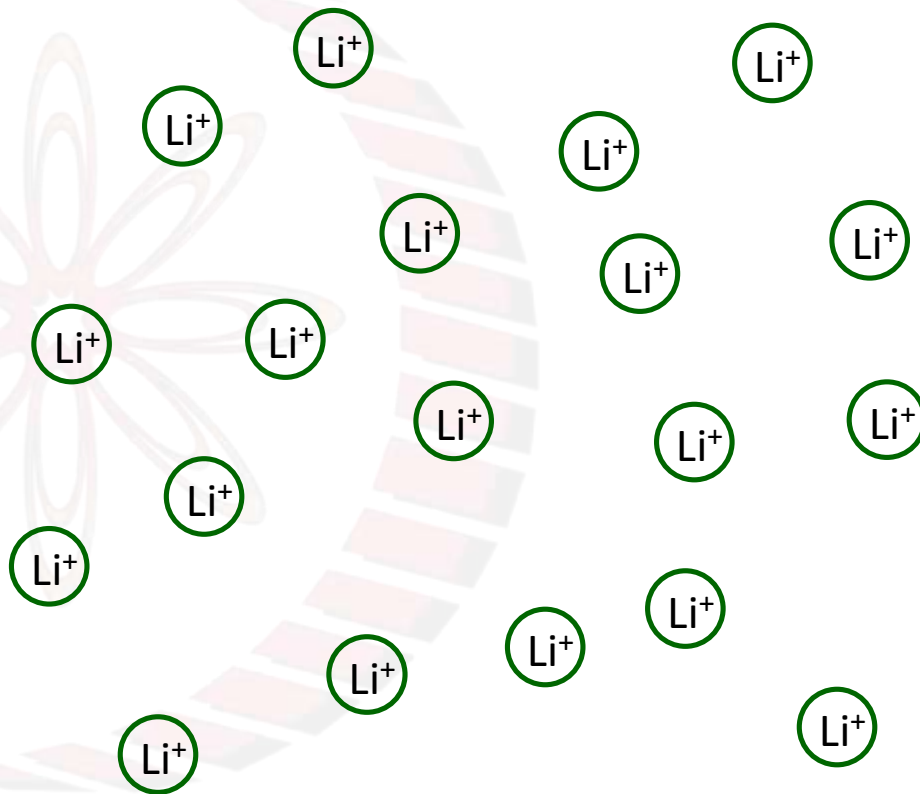
Intercalation



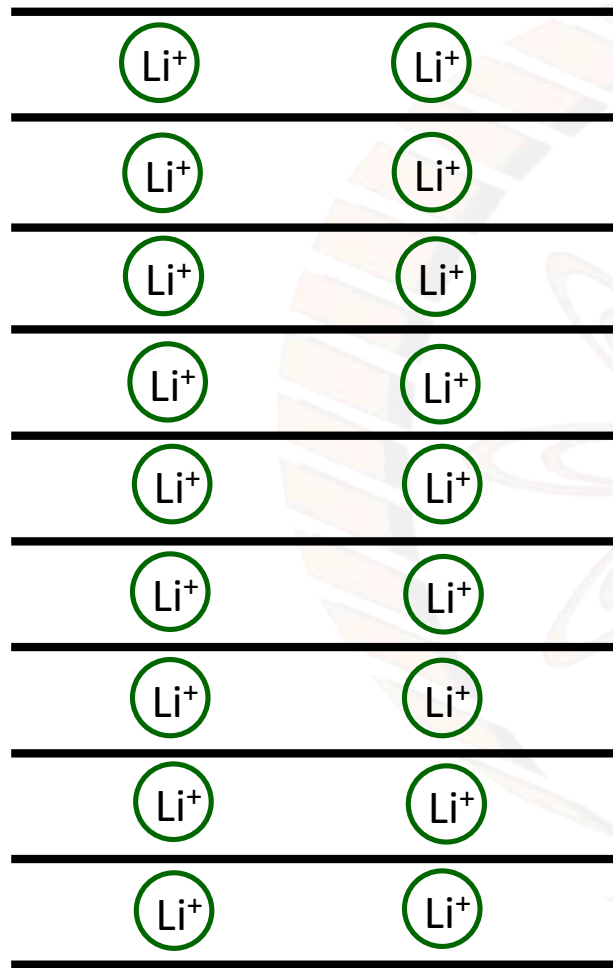
Stage 2



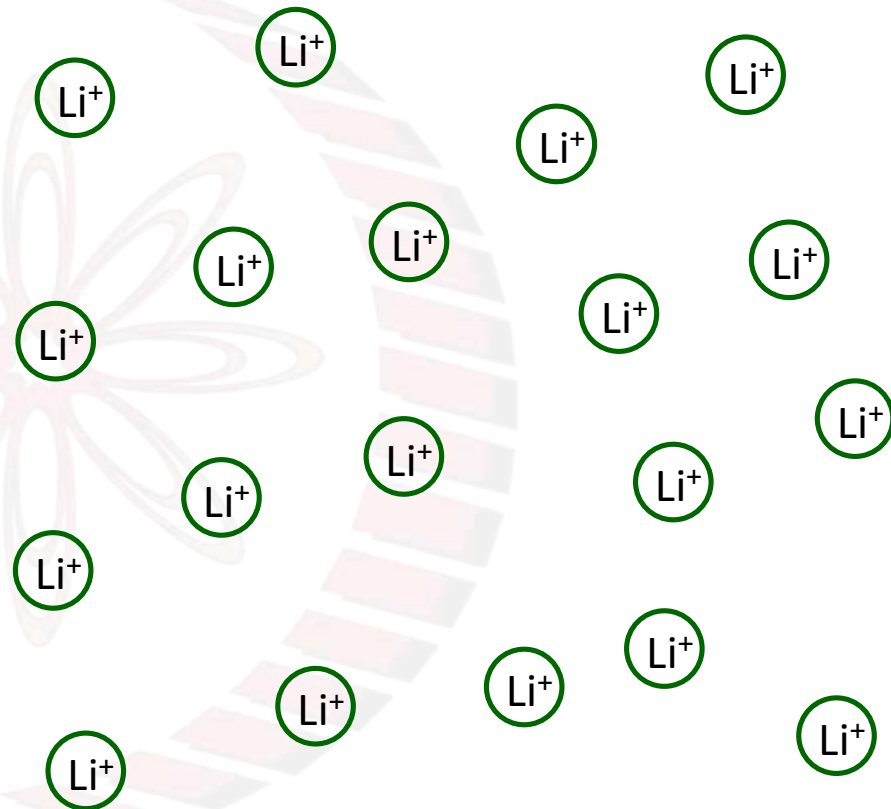
Intercalation



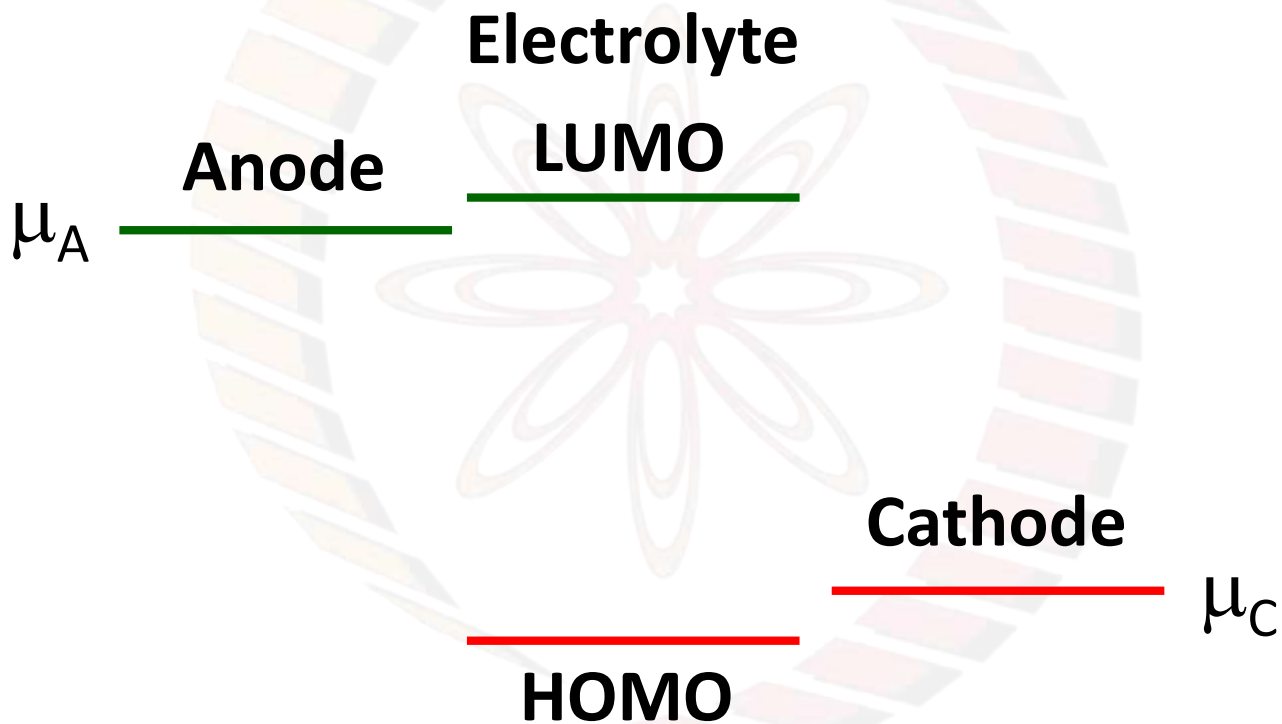
Stage 1



Intercalation



Electrolyte Stability Window



Conclusions

- 1) Lithium metal based rechargeable batteries can develop internal short circuit with repeated cycling.
- 2) Lithium ion batteries overcome this issue
- 3) Intercalation and host compounds make Li-ion batteries safe
- 4) HOMO and LUMO of electrolyte important in determining electrolyte stability window