Battery Basics

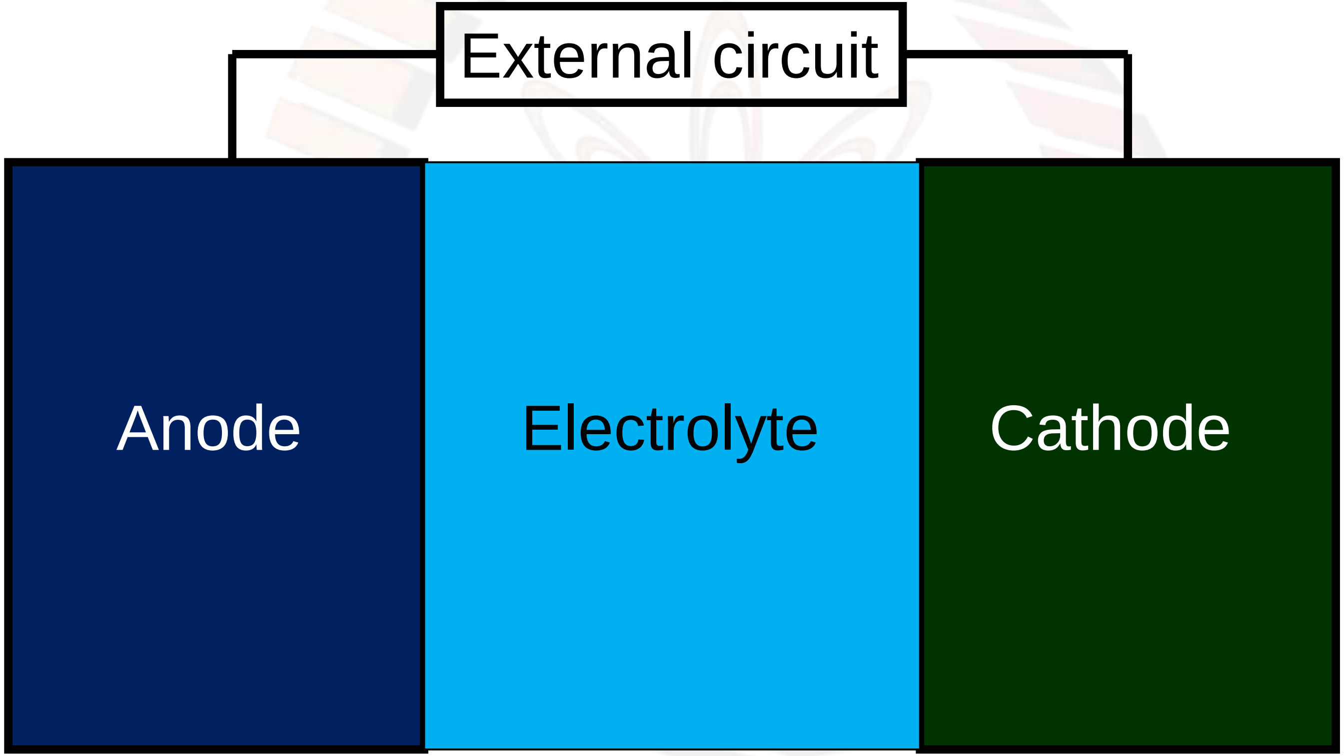
Learning Objectives

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 Electrochemical Series

Reaction	Standard Electrode Potential
$Au^{3+} + 3e^- \rightarrow Au$	$+ 1.420\ V$
$Pt^{2+} + 2e^- \rightarrow Pt$	$+ 1.200\ V$
$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$	$+ 1.229\ V$
$Ag^+ + e^- \rightarrow Ag$	$+ 0.800\ V$
$Cu^{2+} + 2e^- \rightarrow Cu$	$+ 0.340\ V$
$2H^+ + 2e^- \rightarrow H_2$	$0.000\ V$
$Pb^{2+} + 2e^- \rightarrow Pb$	$- 0.126\ V$
$Ni^{2+} + 2e^- \rightarrow Ni$	$- 0.250\ V$
$Cd^{2+} + 2e^- \rightarrow Cd$	$- 0.403\ V$
$Zn^{2+} + 2e^- \rightarrow Zn$	$- 0.763\ V$
$Li^+ + e^- \rightarrow Li$	$- 3.401\ V$

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

Power = V * I
Watts

Time

Energy: Power * Time
Joules or Wh

Conclusions

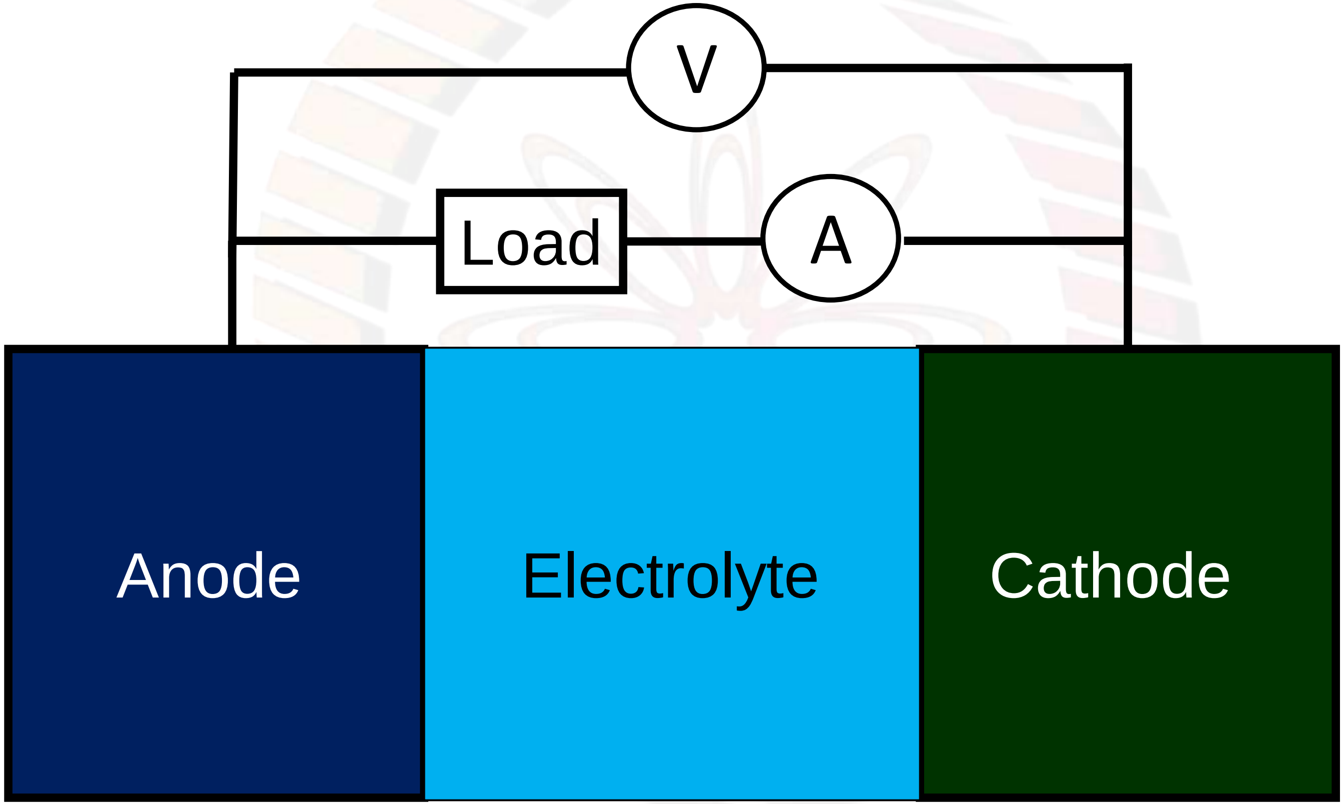
1) Batteries have specific parts that can have dramatically opposite functions
2) The electrochemical series is the starting point to understand Battery voltages
3) Primary and secondary batteries are both commonly used

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 ½ 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

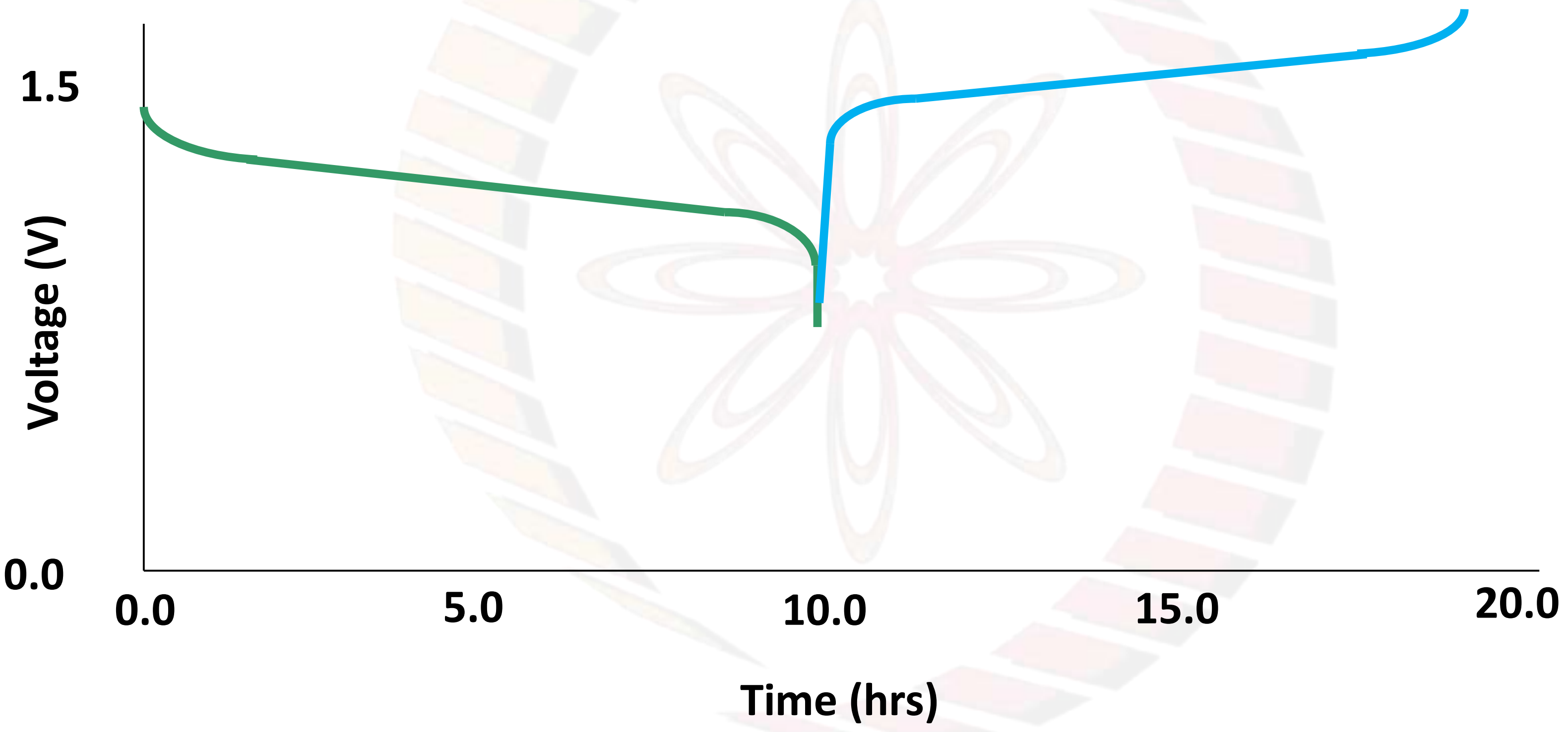
Depth of Discharge: % of maximum capacity that has been discharged

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

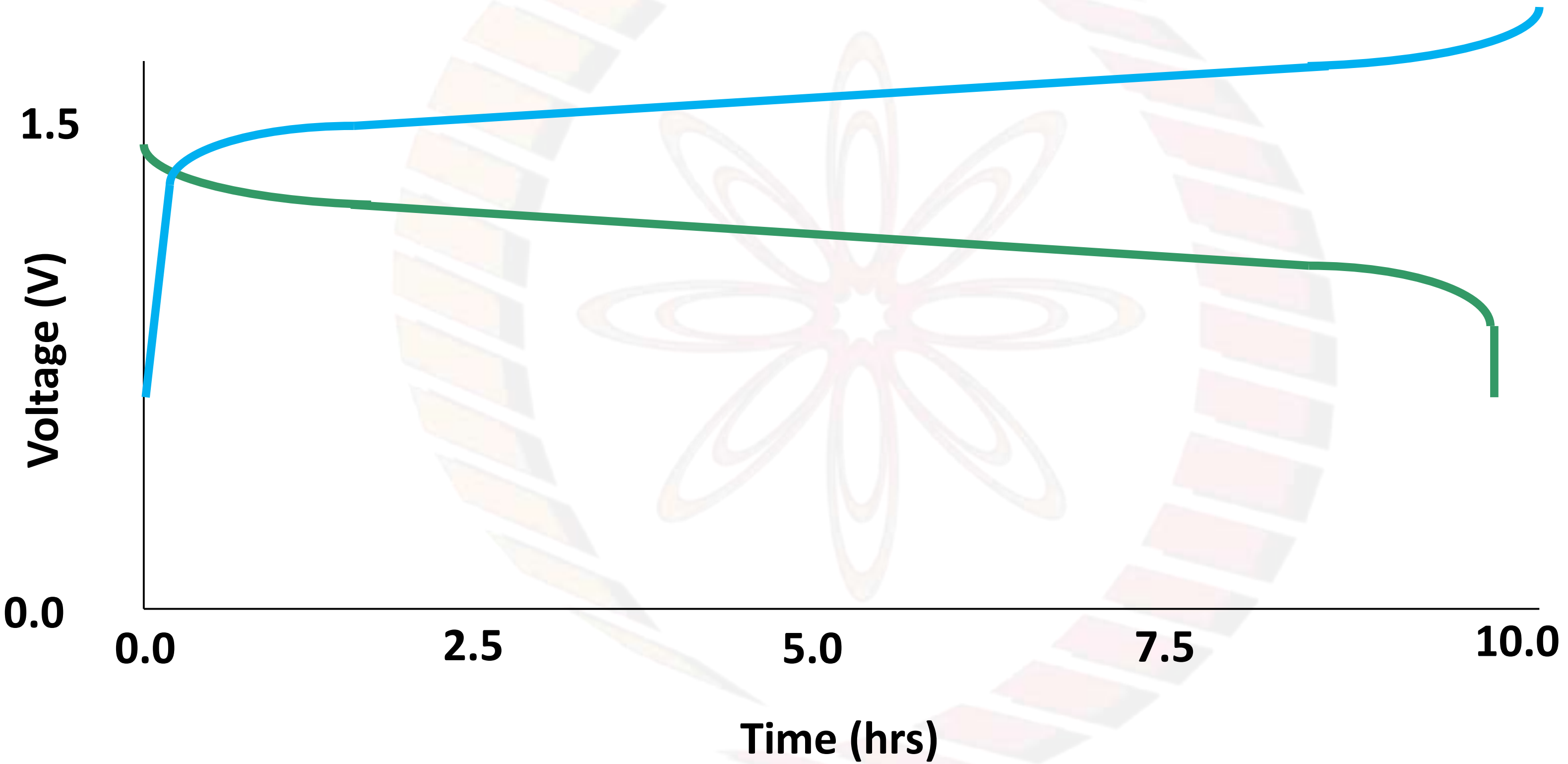
Discharge – Charge curves

Discharge – Charge curves

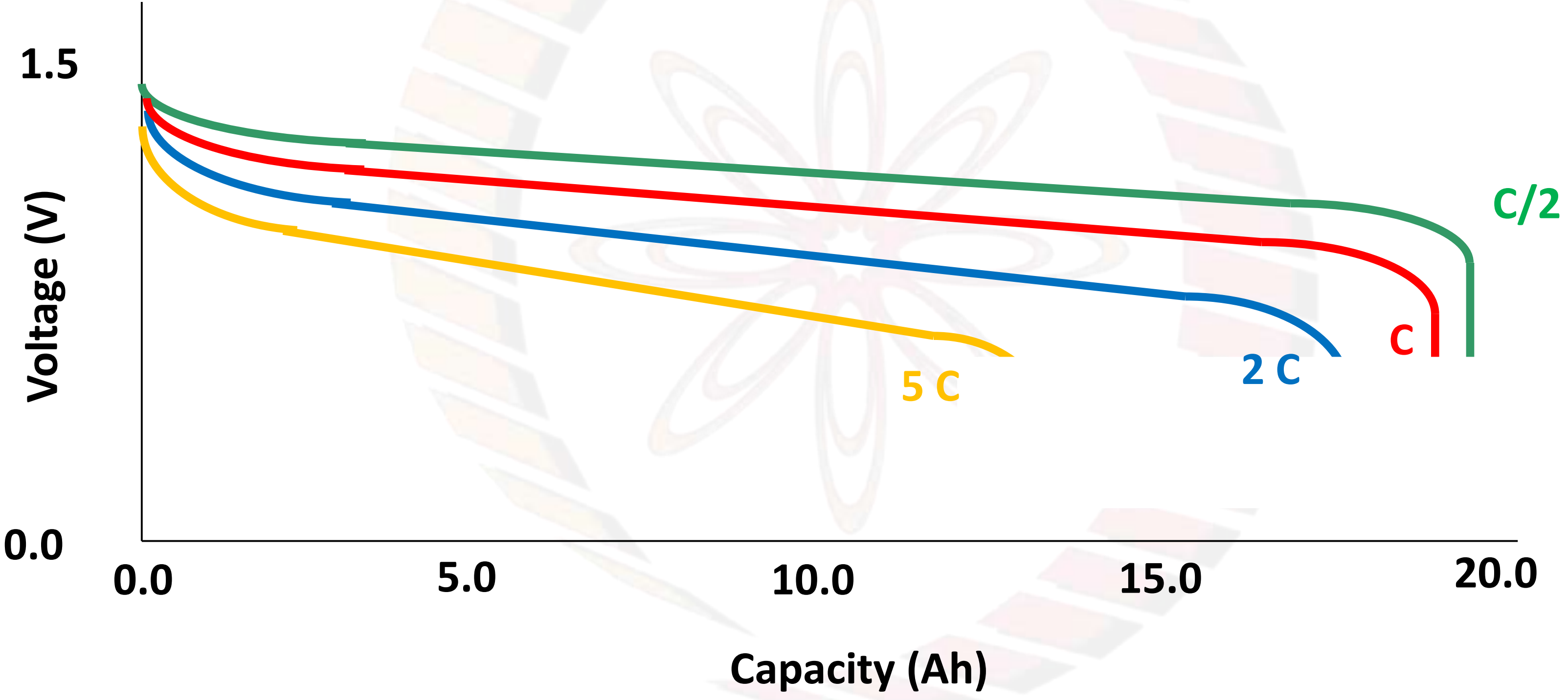
Discharge – Charge curves



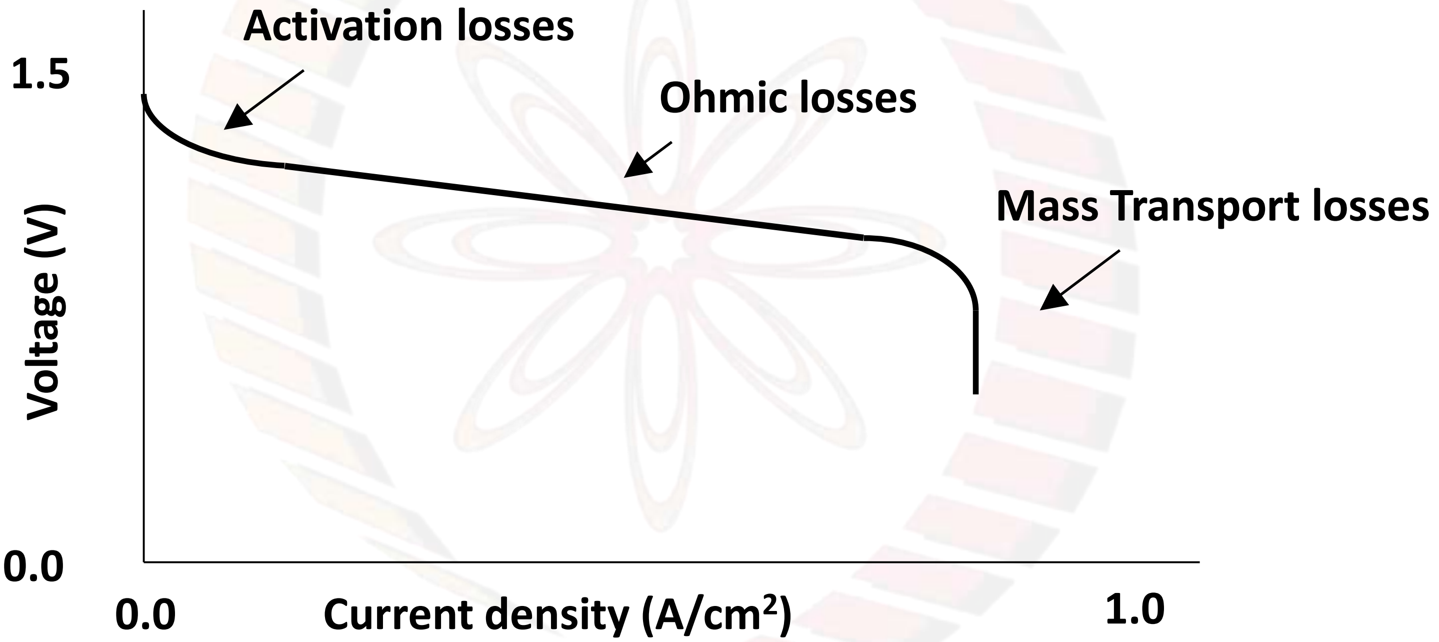
Discharge – Charge curves

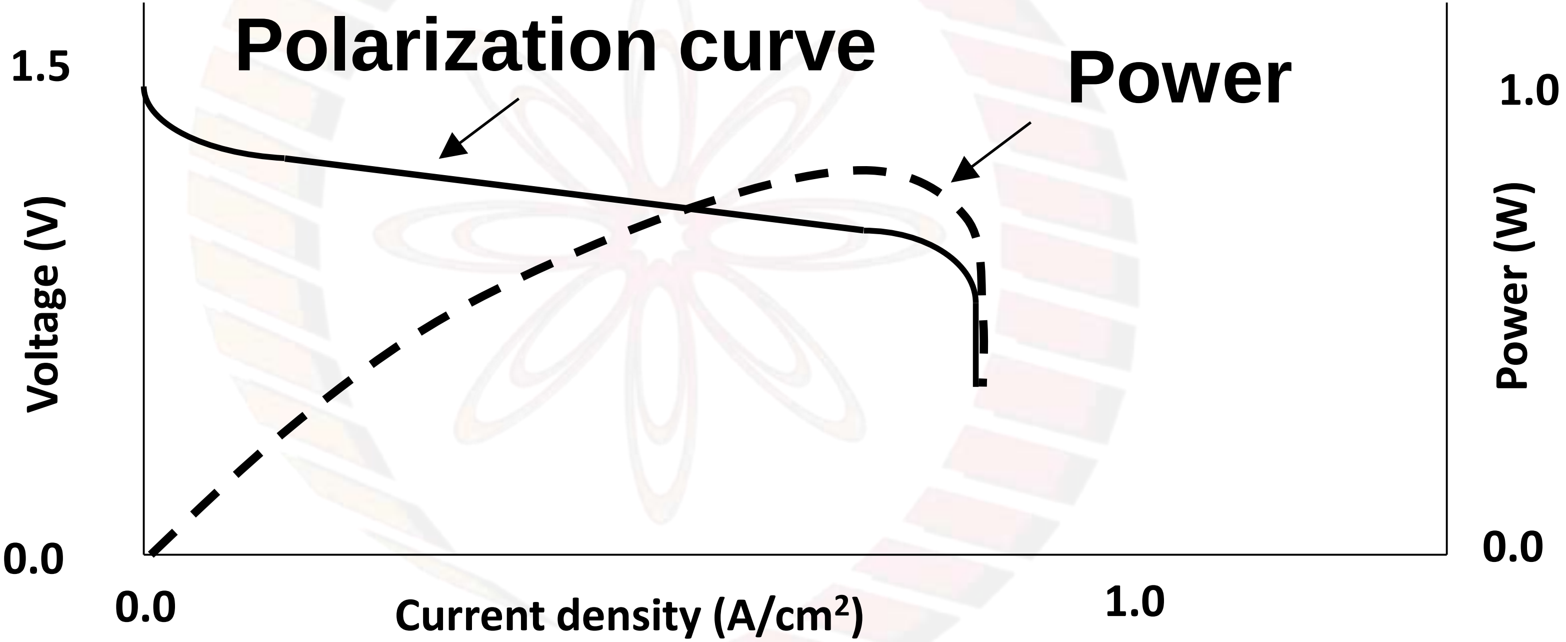


Effect of C-Rate on Discharge

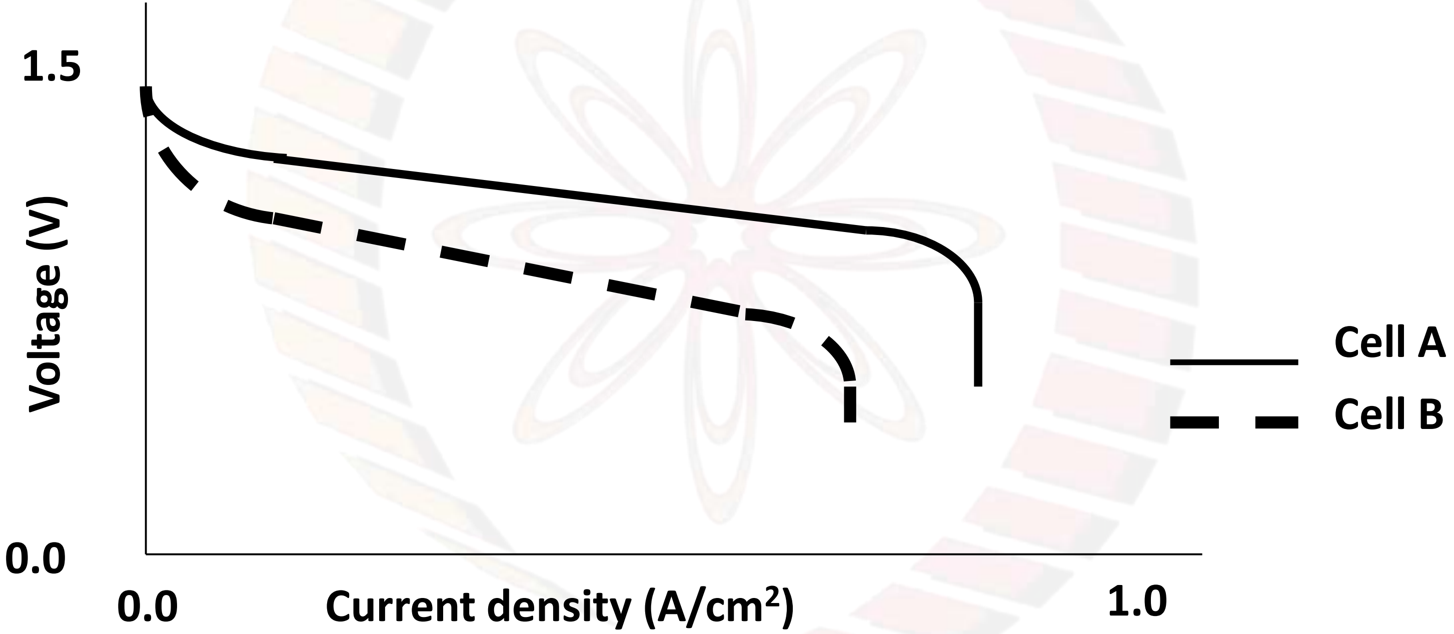


Polarization curve




Polarization curve
Power
1.5
0.0
1.0
0.0
Voltage (V)
Power (W)
0.0
1.0
Current density (A/cm²)

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 Structures and Types

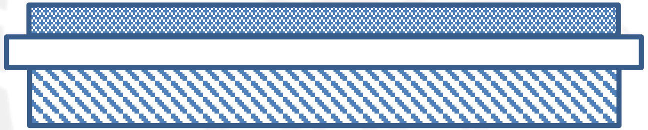
Learning Objectives

1) Become familiar with the different battery structures
2) Become familiar with common battery types
3) Indicate advantages and disadvantages of these different battery types

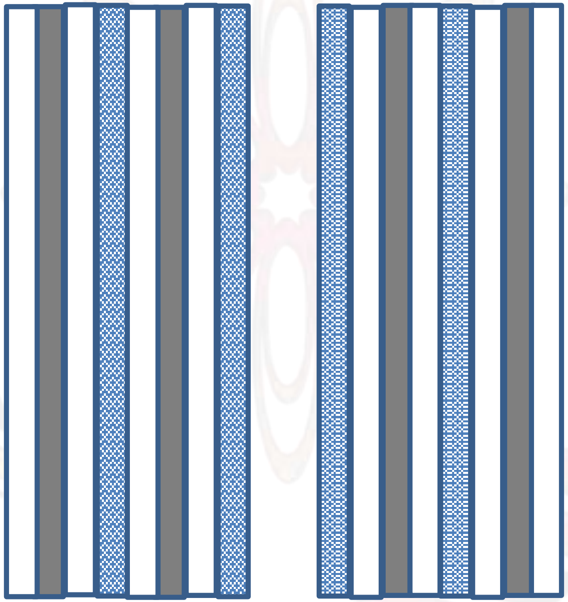
Different Battery Structures

- Cylindrical Cell
- Button cell
- Prismatic cell
- Pouch cell

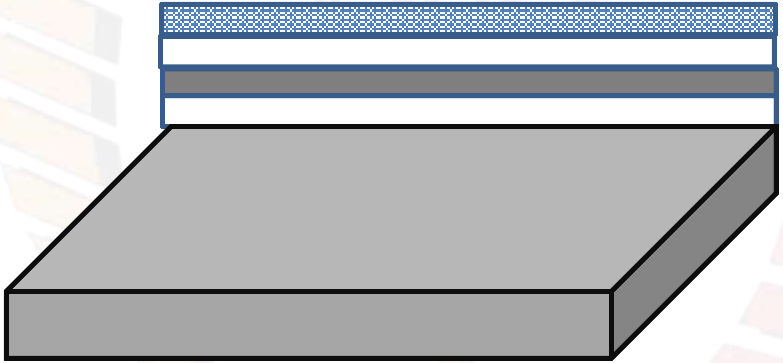
Button cell



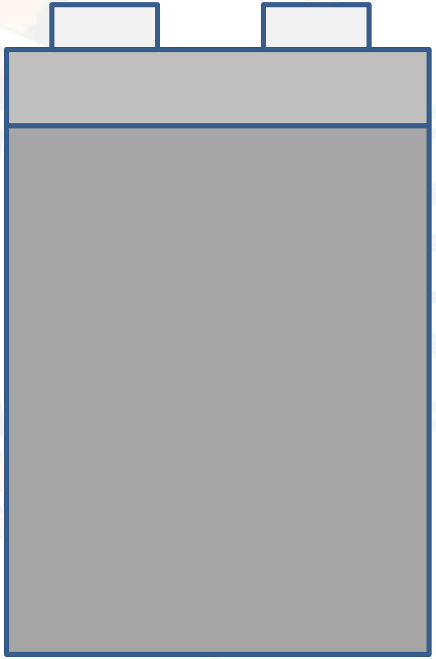
Cylindrical cell



Prismatic cell



Pouch cell

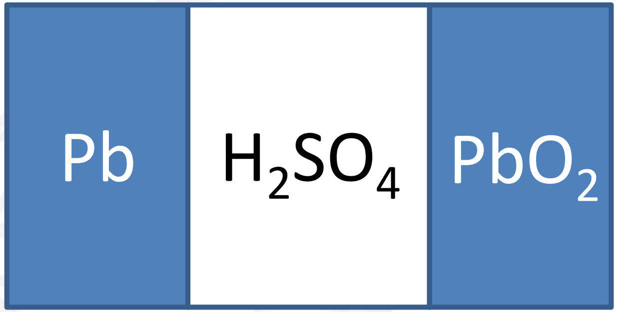


Rechargeable

Lead-Acid:

High current density

Toxic



$$Pb(s) + H_2SO_4 \rightarrow PbSO_4 + 2H^+ + 2e^-$$

$$PbO_2(s) + H_2SO_4 + 2H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O$$

Rechargeable

Ni-Cd (NiCad)

High cycle life (much more than NiMH), reliable

Lower capacity than NiMH, toxic, memory effect

$$Cd + 2OH^- \rightarrow Cd(OH)_2 + 2e^-$$

$$2NiO(OH) + 2H_2O + 2e^- \rightarrow 2Ni(OH)_2 + 2OH^-$$

Ni-Metal Hydride (NiMH)

Rechargeable

Non toxic, replace Alkaline and NiCd, no memory effect, high capacity, energy density approaches that of Li ion

Can self discharge

$$MH + OH^{-} \rightarrow M + H_2O + e^{-}$$

$$NiO(OH) + H_2O + e^{-} \rightarrow Ni(OH)_2 + OH^{-}$$

Rechargeable

Lithium Ion

Lighter than NiMH, better energy density

May self discharge

$$LiC_6 \rightarrow C_6 + Li^+ + e^-$$

$$CoO_2 + Li^+ + e^- \rightarrow LiCoO_2$$

Non-Rechargeable

Alkaline

Inexpensive

May not deliver as much current

$$Zn + 2OH^- \rightarrow ZnO + H_2O + 2e^-$$

$$2MnO_2 + H_2O + 2e^- \rightarrow Mn_2O_3 + 2OH^-$$

Non-Rechargeable

Carbon-Zinc

Very Inexpensive

Very low energy density

$$Zn \rightarrow Zn^{2+} + 2e^-$$

$$2MnO_2 + 2NH_4Cl + 2e^- \rightarrow Mn_2O_3 + 2NH_3 + H_2O + 2Cl^-$$

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

Non-Rechargeable

Lithium

High energy density, light weight

Expensive

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)

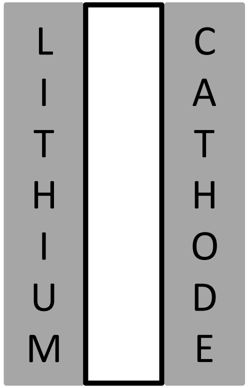
Environmentally friendly

Dendritic growth of Lithium/ SEI

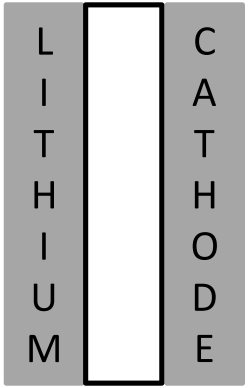
Porous structure that grows on anode with each recharge cycle

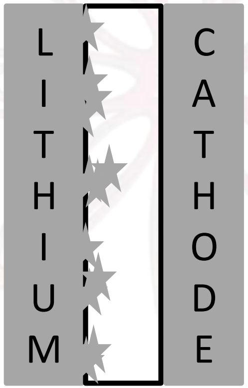
Can result in internal short circuit

Dendritic growth of Lithium

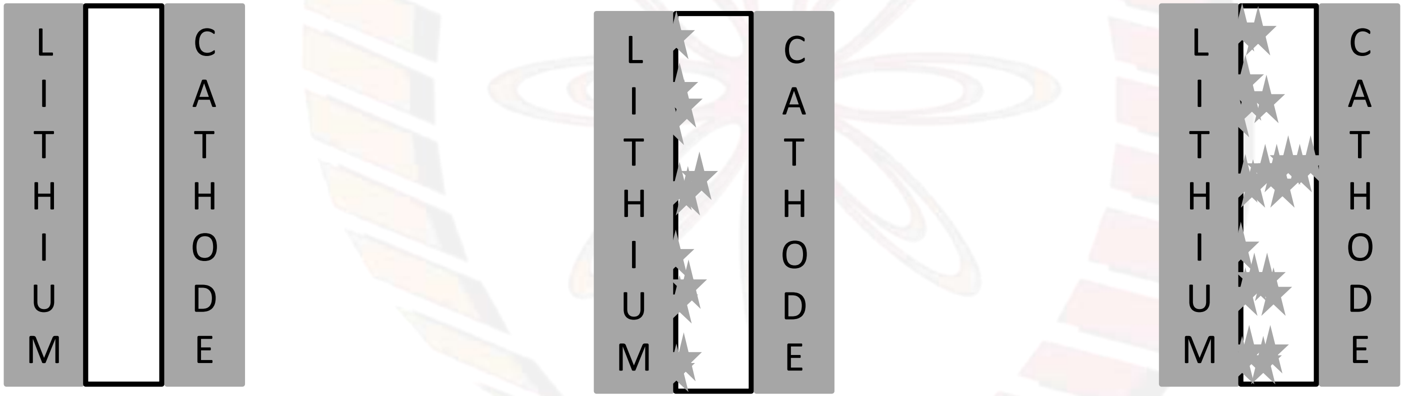


Dendritic growth of Lithium





Dendritic growth of Lithium

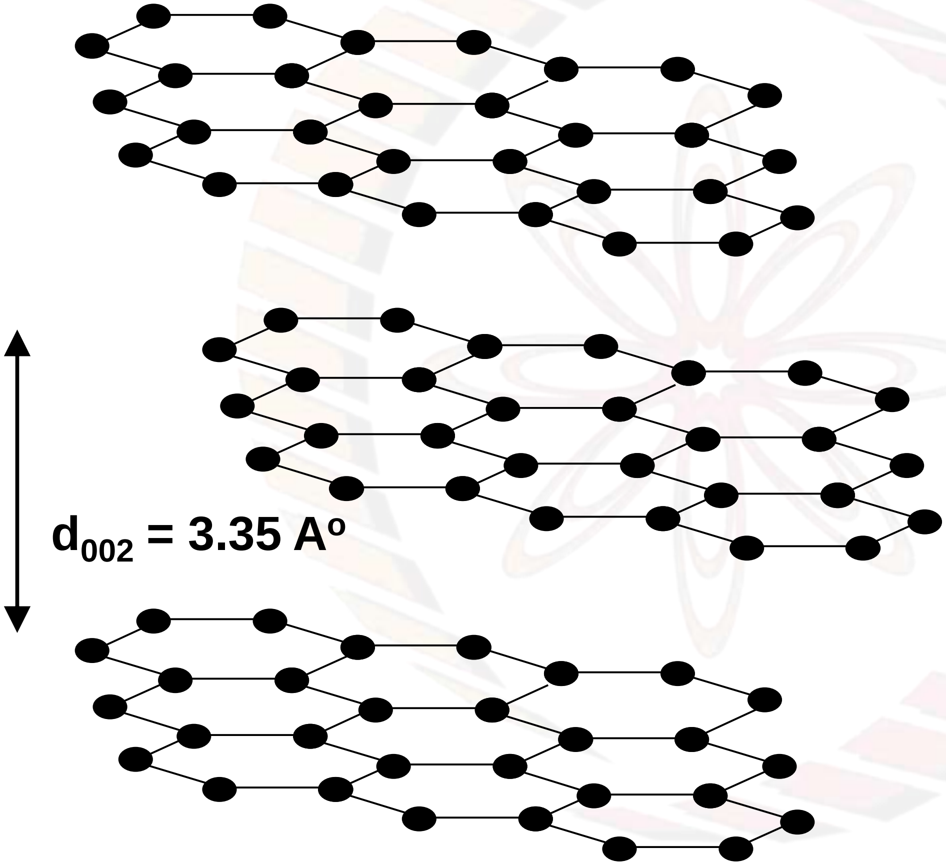


Intercalaction

Carbon based host materials

LiC_6	Anode
$LiMn_2O_4$	Cathode
$LiPF_6$ in EC/DEC	Electrolyte (Lithium Hexafluorophosphate in Ethylene Carbonate and Diethyl Carbonate)

Graphite

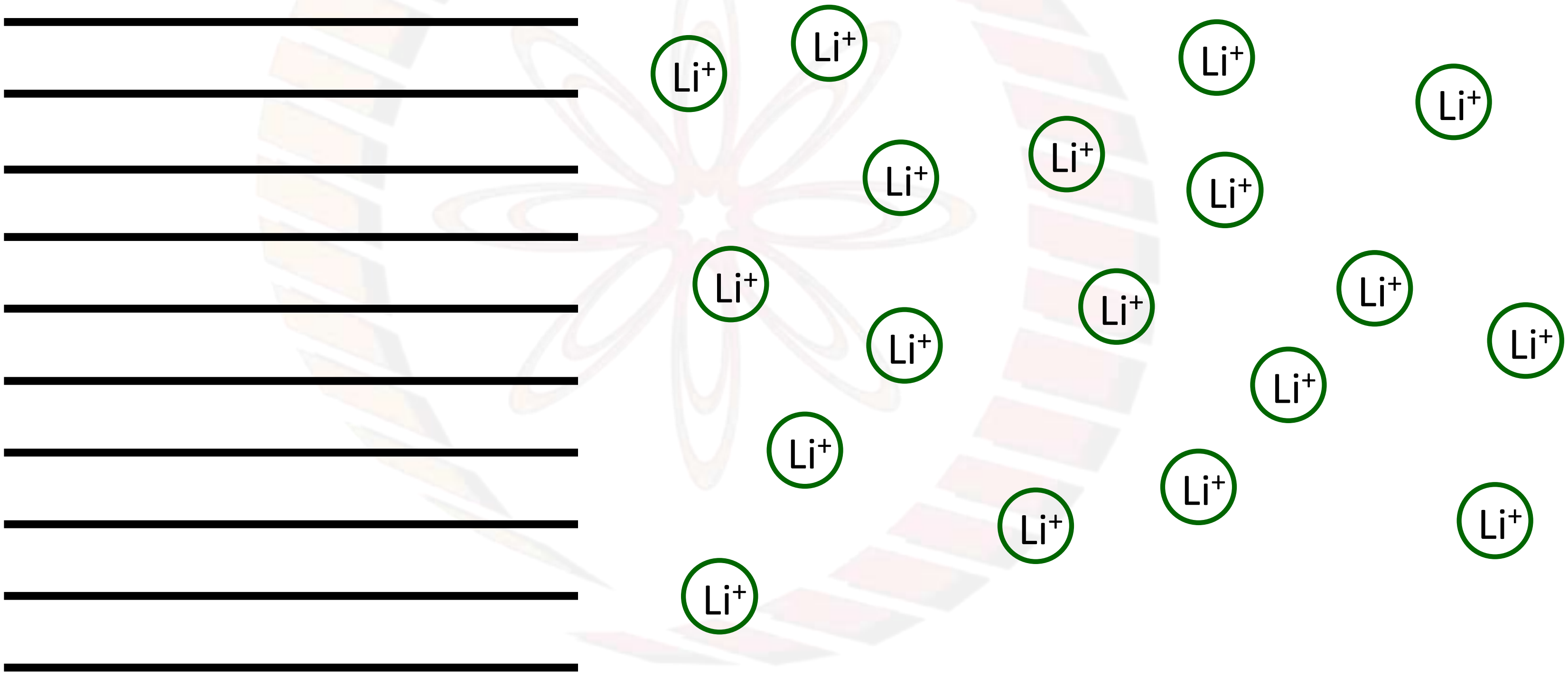


Unit Cell

a = b = 2.46 A^o

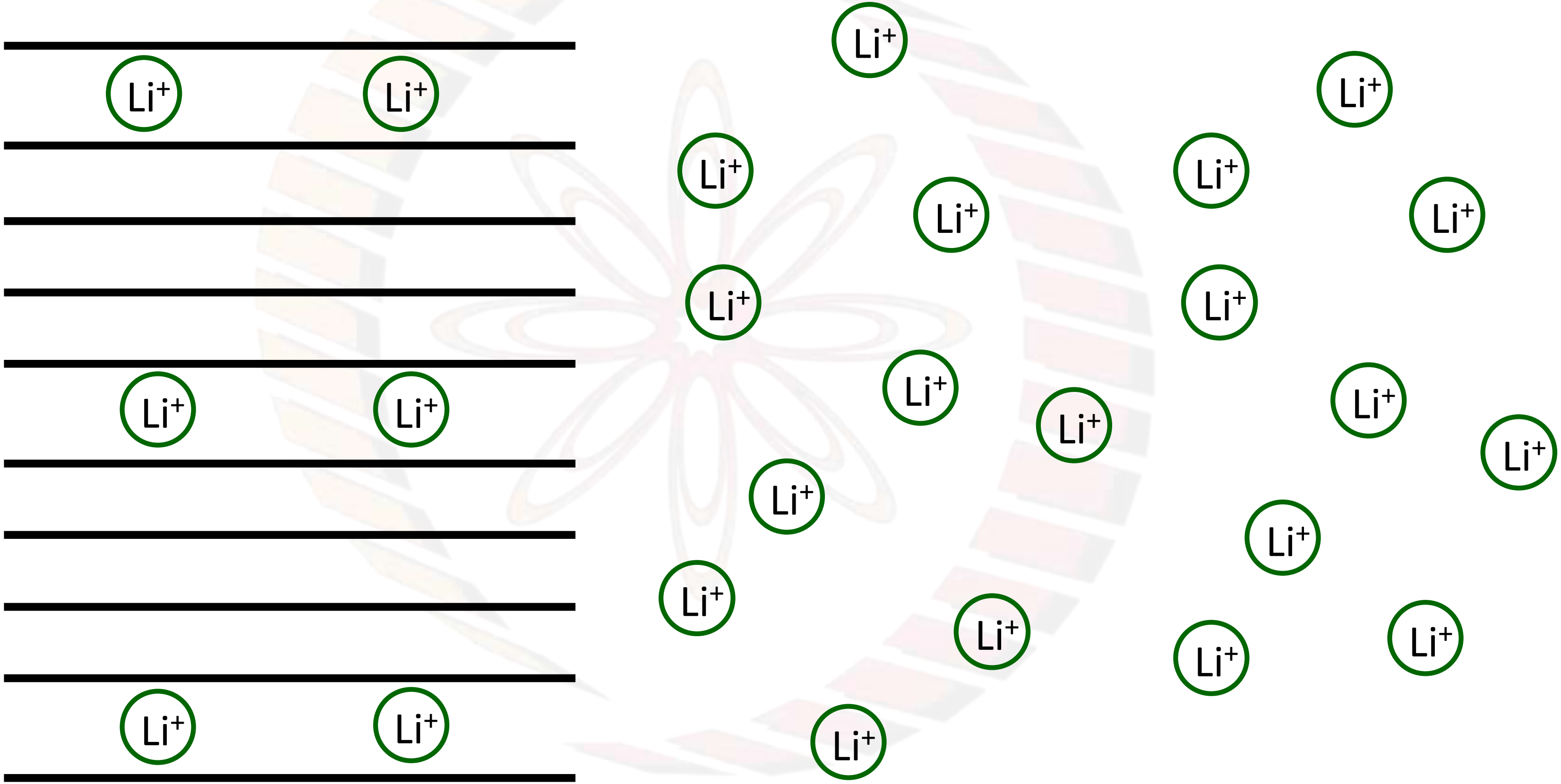
a_{cc} = 1.42 A^o

Intercalaction



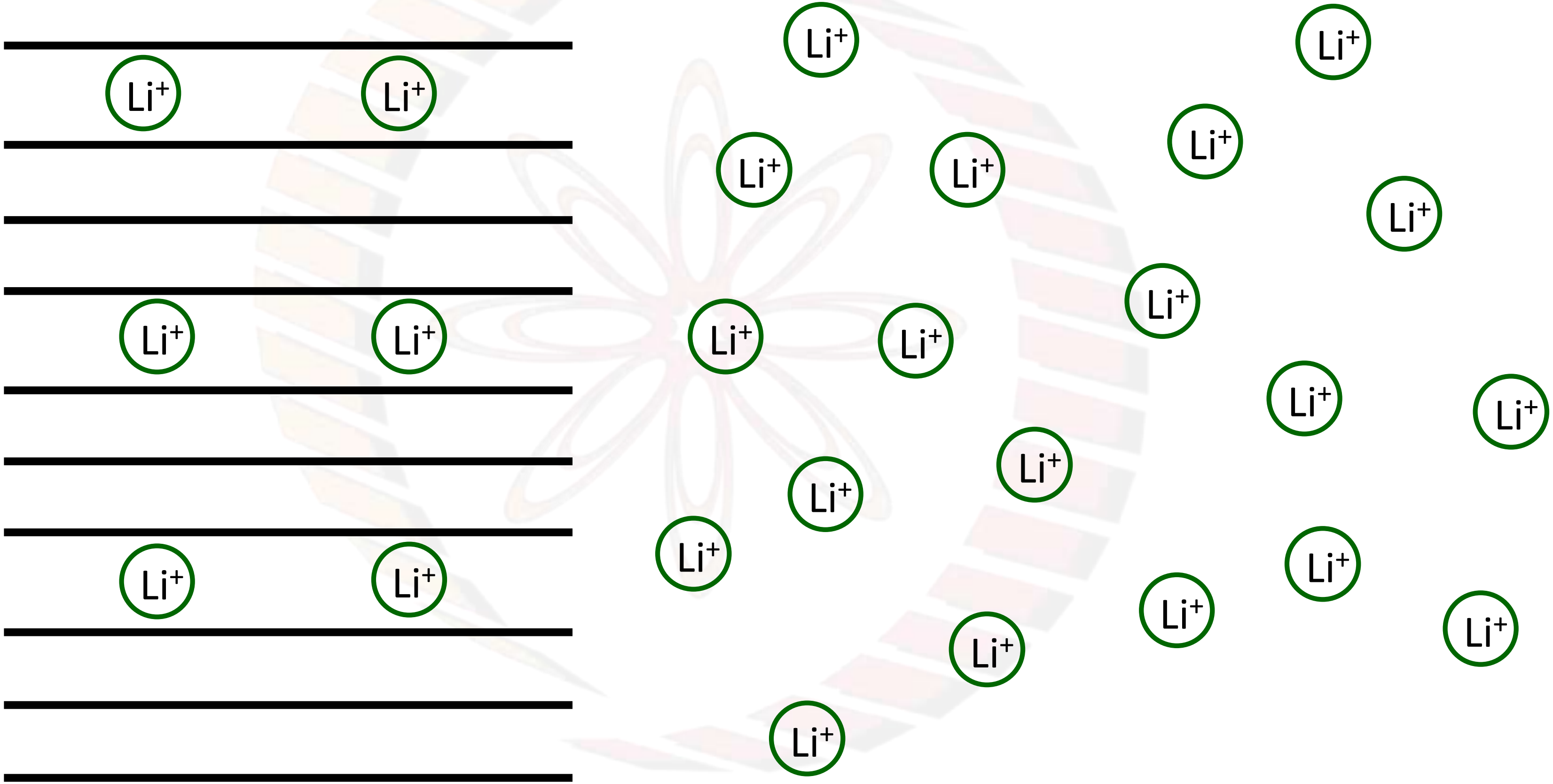
Stage 4

Intercalaction



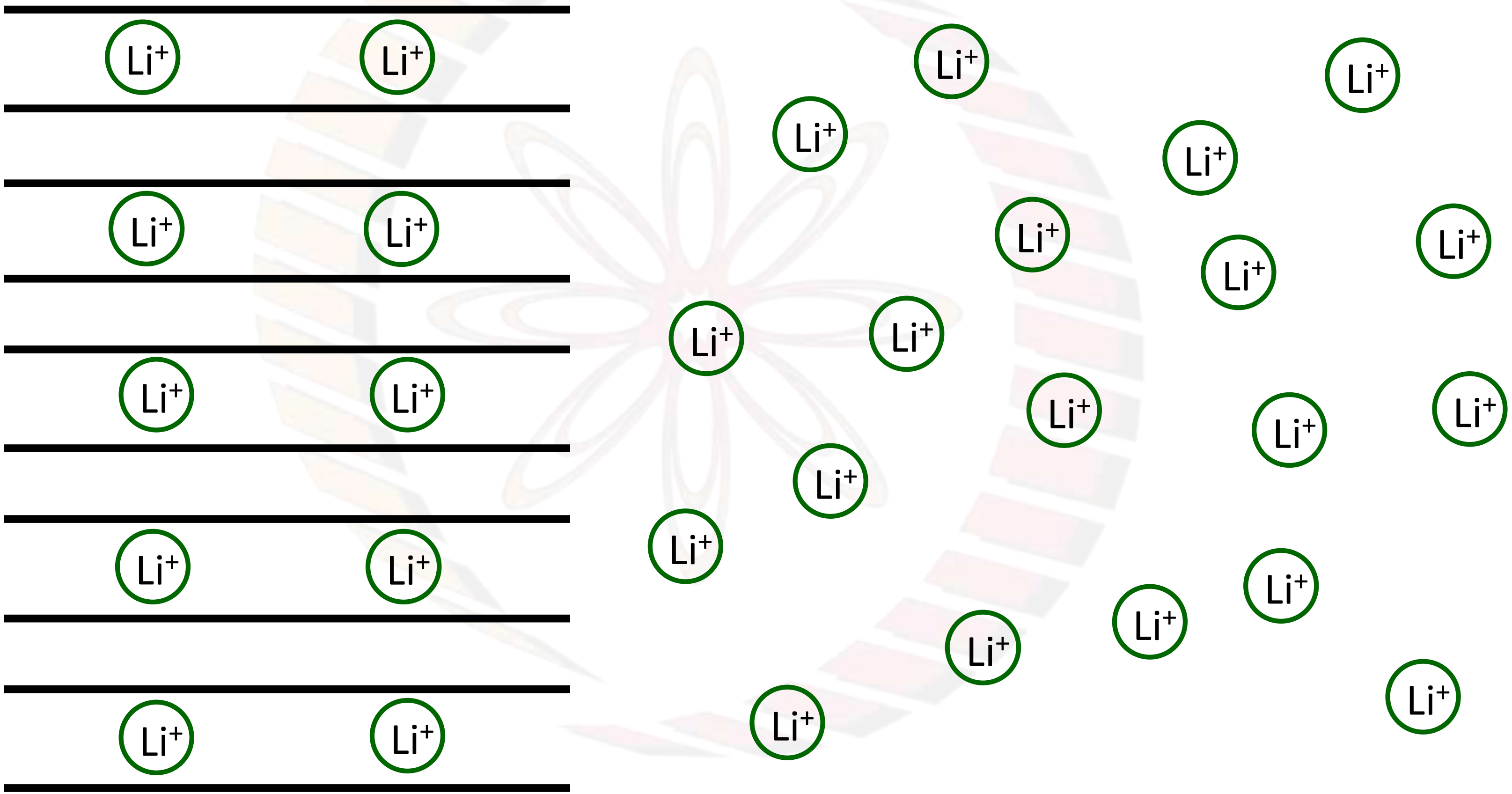
Stage 3

Intercalaction



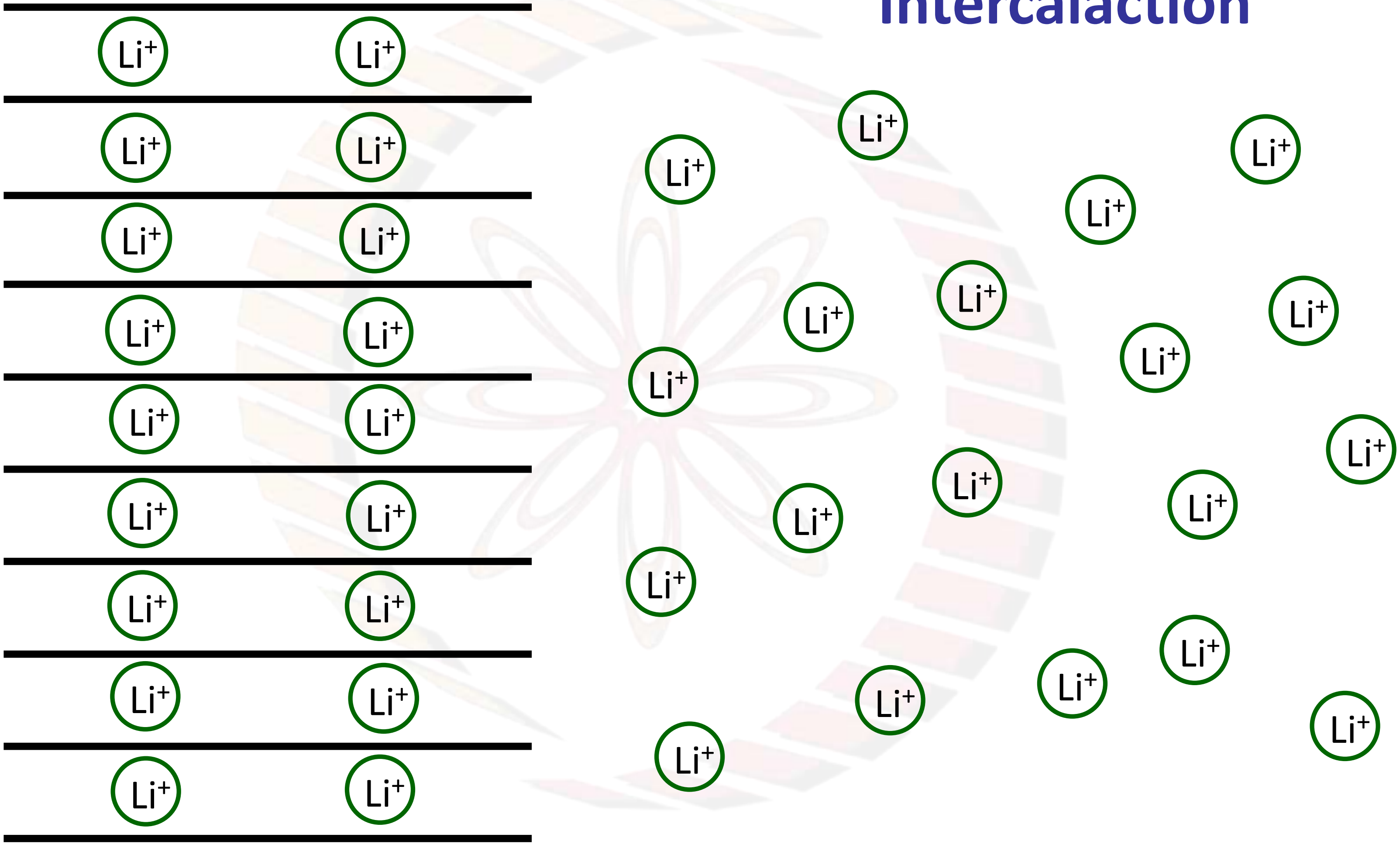
Stage 2

Intercalaction

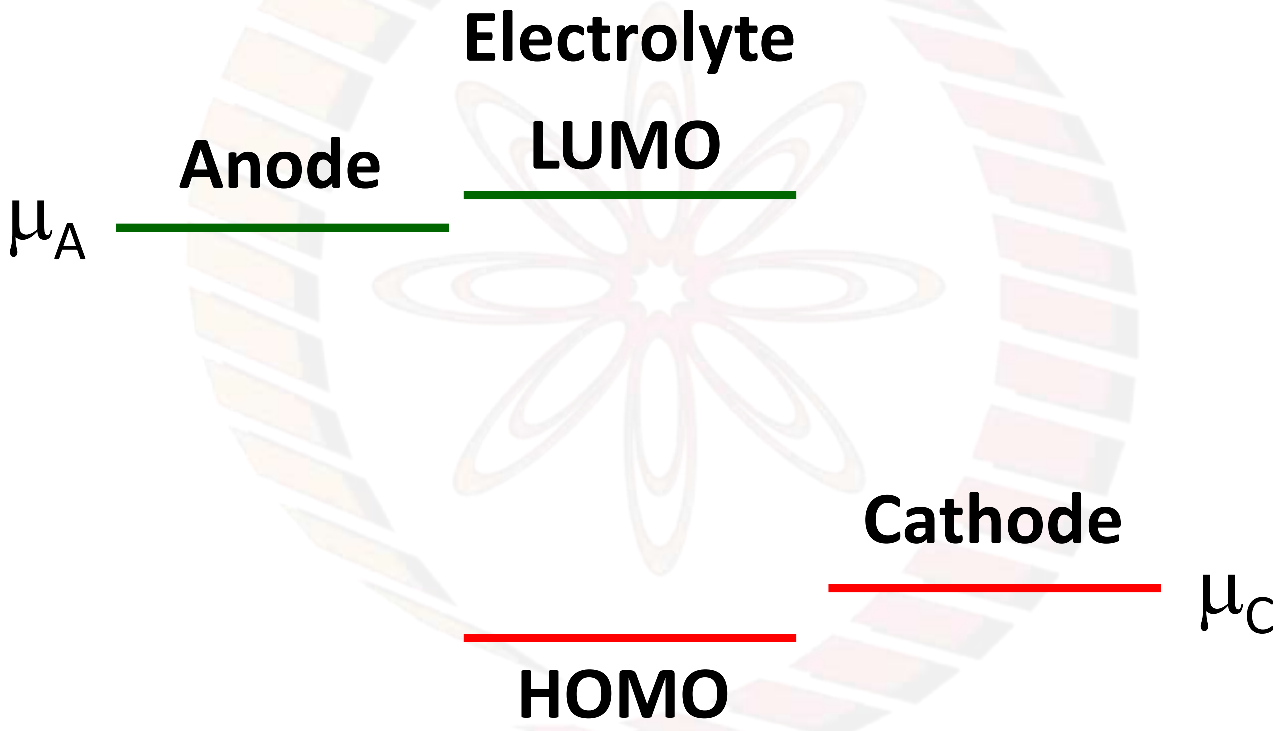


Stage 1

Intercalaction



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) Intecalation and host compounds make Li-ion batteries safe
4) HOMO and LUMO of electrolyte important in determining electrolyte stability window

Supercapacitors

Supercapacitors,
Electric Double Layer Capacitor
Ultracapacitor

Learning Objectives

1) What is a Supercapacitor
2) How does it differ from a capacitor
3) What type of applications is it suited for
4) Typical Materials used

Supercapacitor

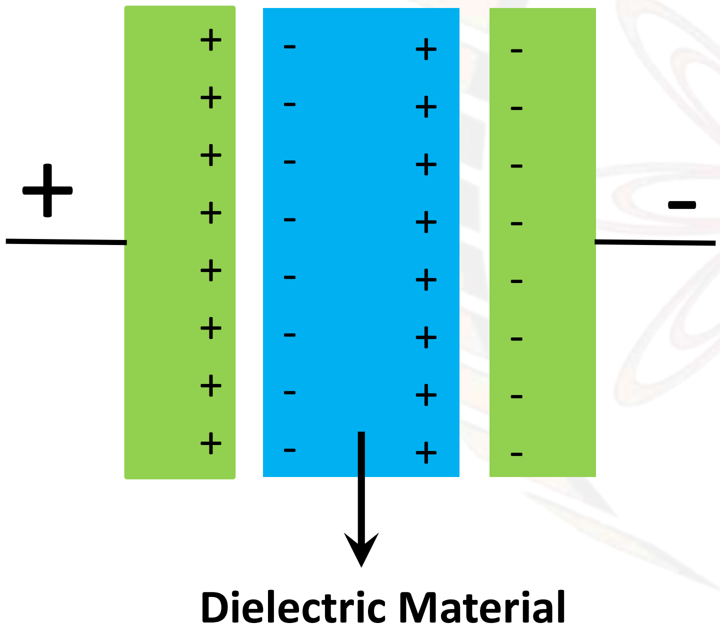
- High capacitance
- High energy density
- Lower Voltage
- High cycle life
- Charge and discharge much faster than batteries
- Bridges the gap between capacitors and rechargeable batteries

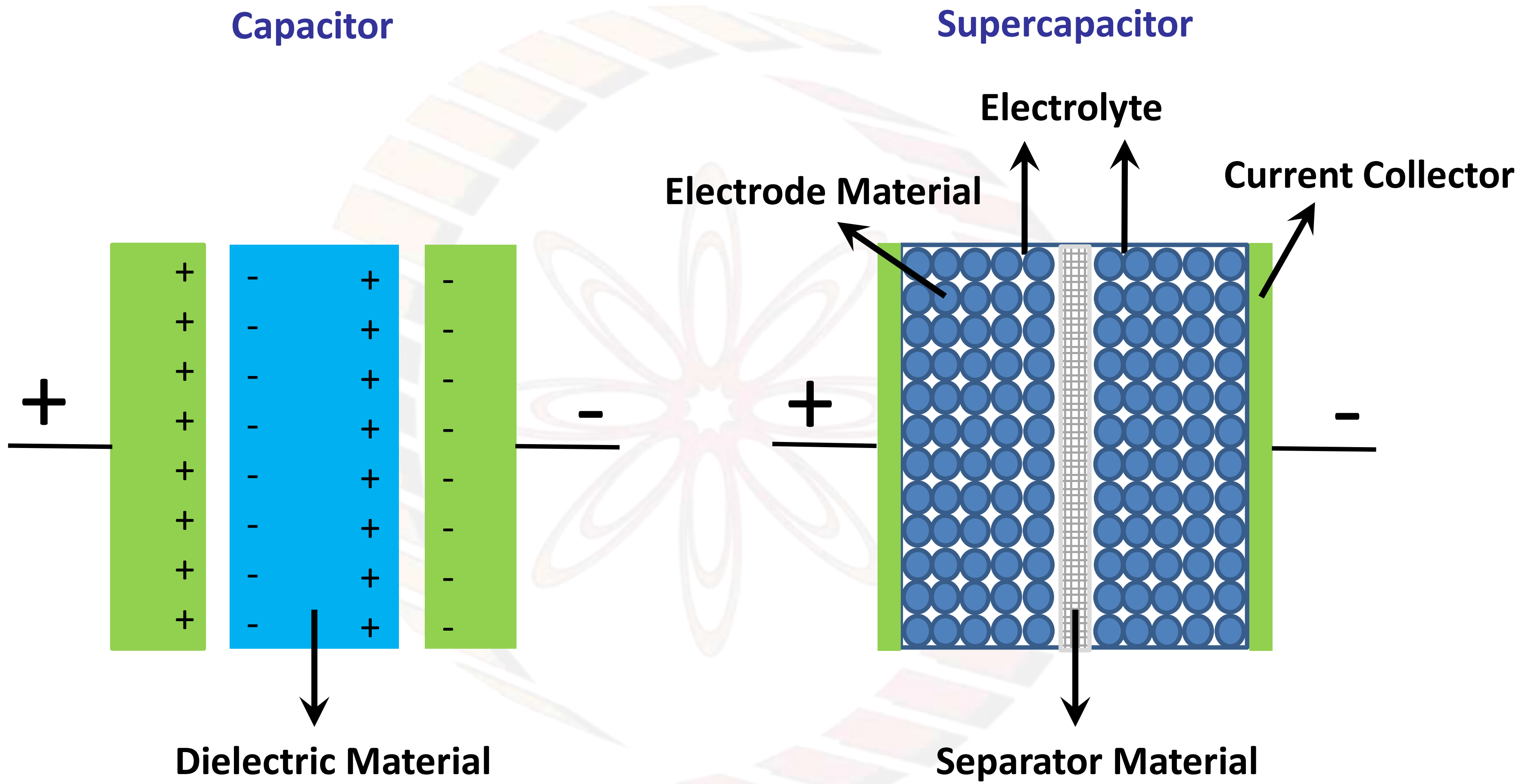
Supercapacitor

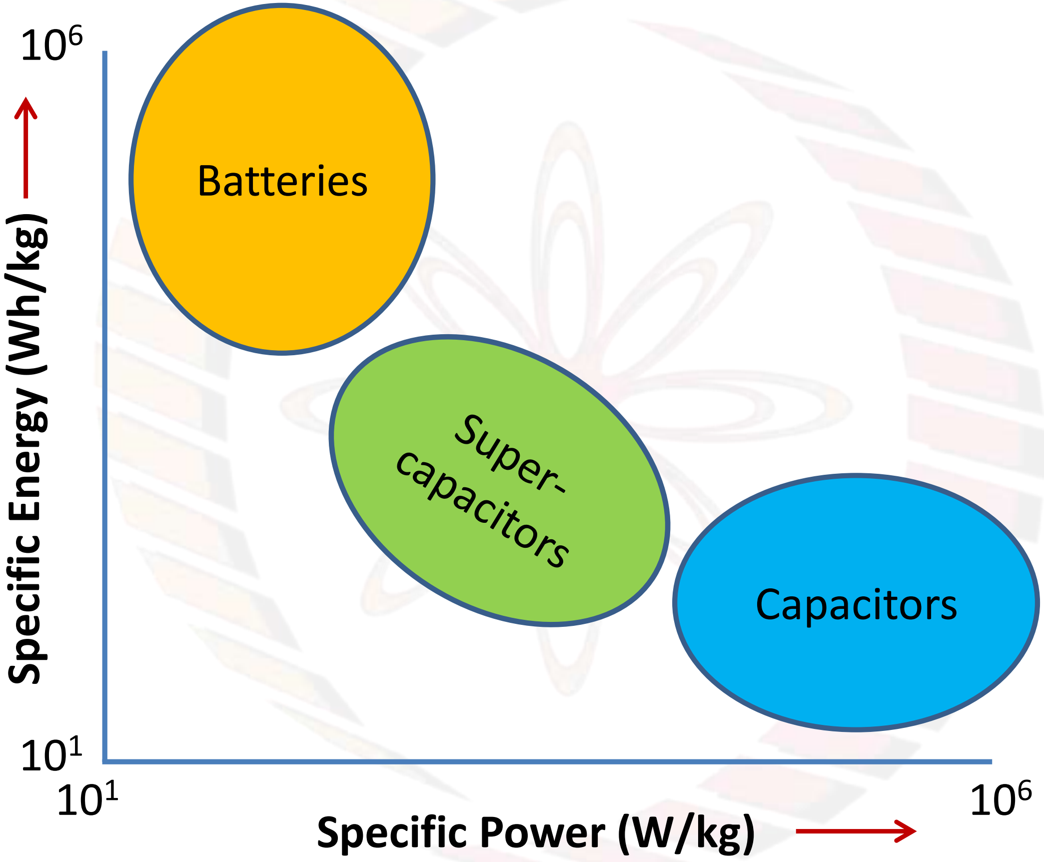
- Regenerative braking
- Loading and unloading activities
- Start-Stop of electric vehicles

Supercapacitor:	**Electrical energy, uses ions**
Battery:	**Chemical energy, uses ions**
Capacitor:	**Electrical energy, uses electrons**

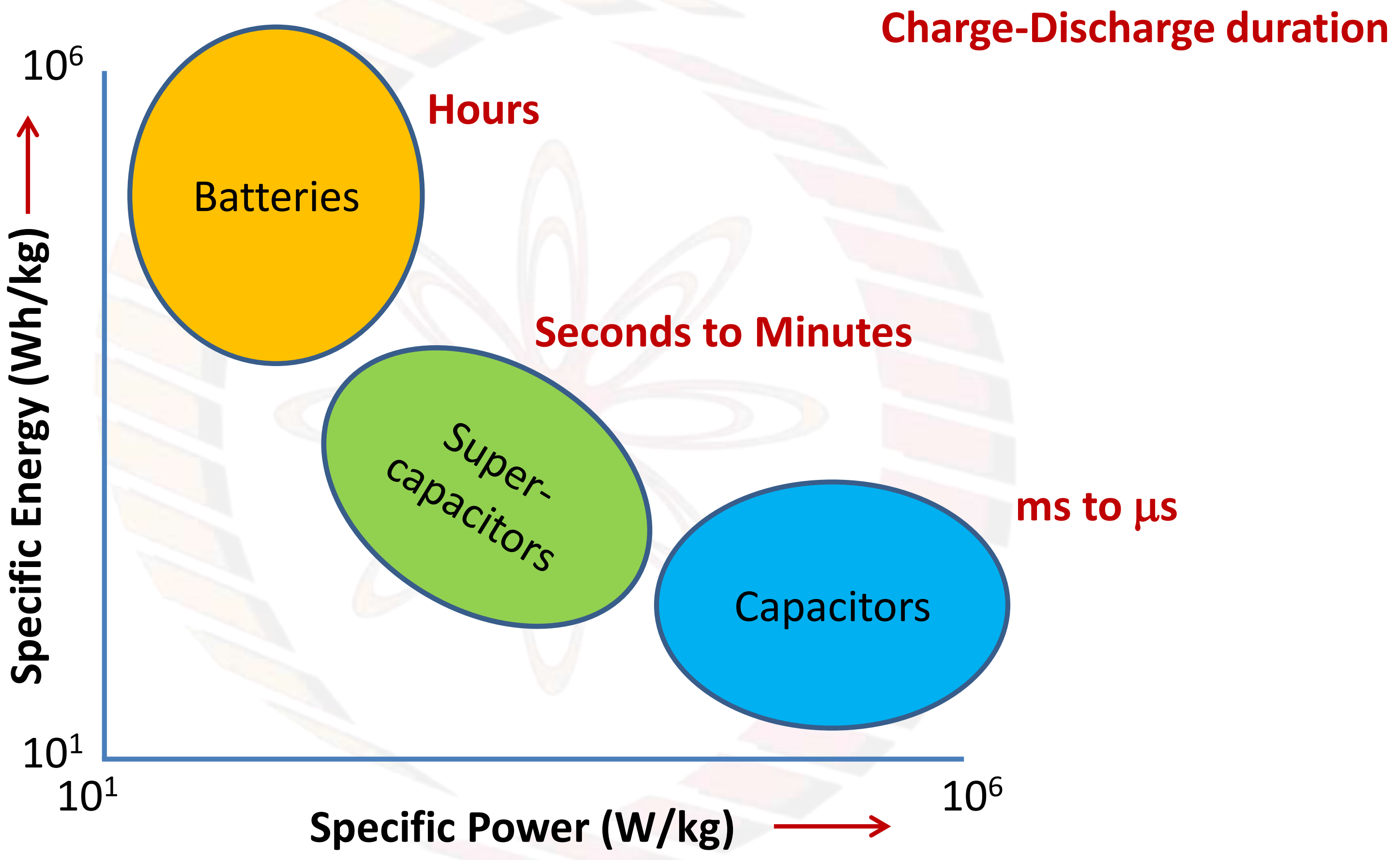
Capacitor



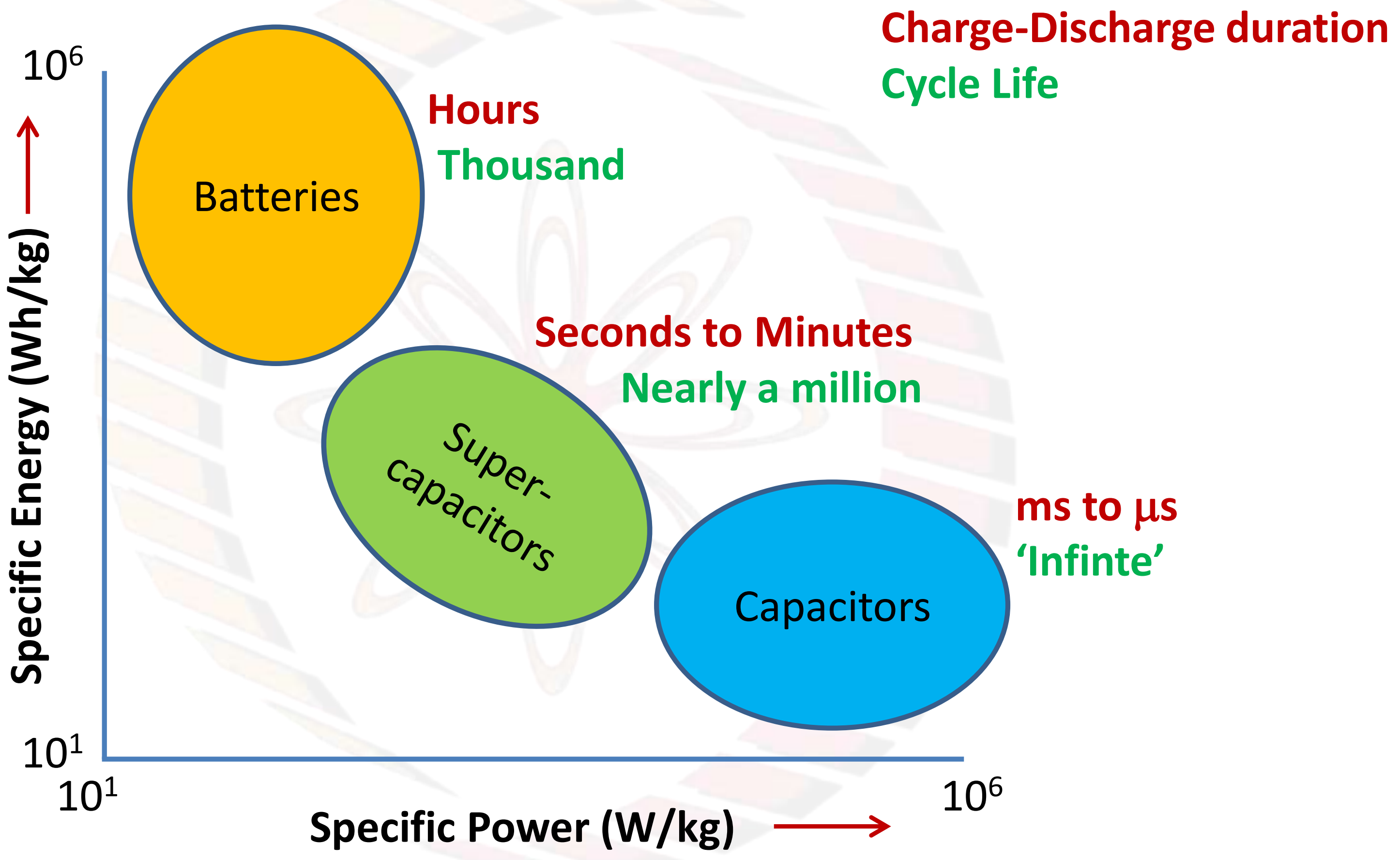

Capacitor
Supercapacitor
Electrolyte
Electrode Material
Current Collector
+
-
+
-
Dielectric Material
Separator Material



10^6
Specific Energy (Wh/kg)
10^1
10^1
Specific Power (W/kg)
10^6
Batteries
Super-capacitors
Capacitors



Charge-Discharge duration
Hours
Seconds to Minutes
ms to µs
Batteries
Super-capacitors
Capacitors
Specific Energy (Wh/kg)
Specific Power (W/kg)
10^6
10^1
10^1
10^6


Charge-Discharge duration
Cycle Life
10^6
Specific Energy (Wh/kg)
Batteries
Hours
Thousand
Seconds to Minutes
Nearly a million
Super-capacitors
ms to μs
'Infinte'
Capacitors
10^1
10^1
10^6
Specific Power (W/kg)

Materials Used:

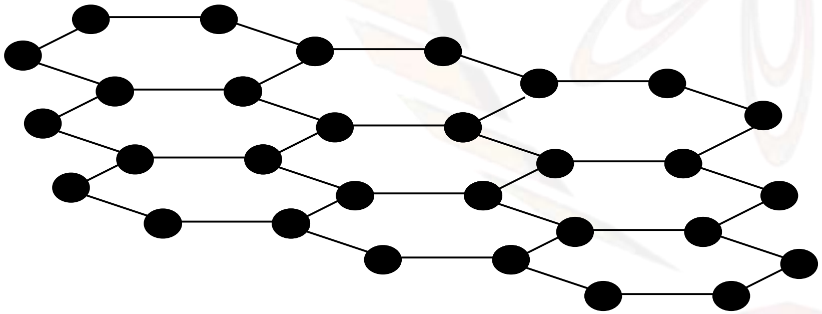
Electrode:

Activated carbon, Graphene, Carbon nanotubes

Activated Carbon: Natural carbons and polymers heat treated in inert atmosphere

Graphene can restack

Carbon nanotubes – cylindrical surface is used



Materials Used:

Electrolyte:

Aqueous electrolytes:	Voltage restricted to 1.23 V
Organic electrolytes:	Lower conductivity (Propylene Carbonate)
Ionic liquids:	Organic salts with no solvents and melting point below 100 °C

Conclusions

1) Supercapacitors bridge the gap between capacitors and batteries
2) High surface area carbon materials used in electrodes
3) Aqueous, organic as well as ionic liquids considered as electrolytes