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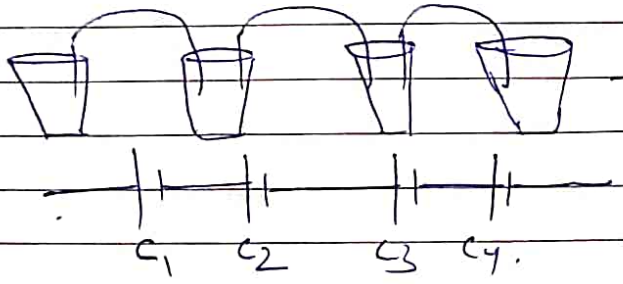
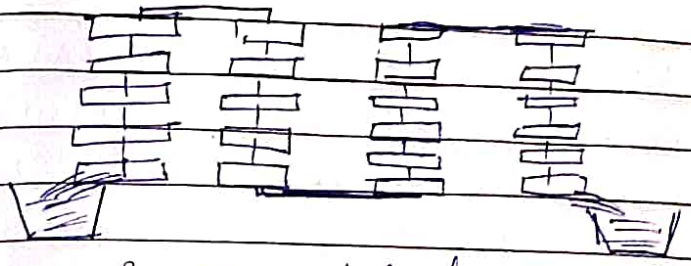
* History of Battery :→

(1) Volta discovered in 1800 that certain fluids would generate a continuous flow of electrical power when used as a conductor. This discovery led to the invention of first voltic cell, more commonly known as battery.
Volta learned further that the voltage would increase when volatic cell were stacked on top of each other.



Silver (A) & Zinc (Z) metals are immersed in cups filled with electrolyte & connected in series.



Silver & Zinc electrodes are connected in series, separated by paper soaked with electrolyte

* First recargable Battery

(A) First physician Gaston Plantae. invented first rechargeable battery based on Lead acid.

(B) In 1899, Waldmer Jugner from Sweeden invented the nickel cadmium (Ni-Cd) battery that used nickle as positive electrode (cathode) & cadmium as negative (anode) High material costs compared to lead Limited its use.

(C) For many years, Ni-cd was the only rechargeble battery for portable application

(D) The alternative is nickel-metal-hybride (Ni-MH) a more enviromentally friendly battery that is similar to Ni-Cd.

(C) Most research activities today revolve around improving lithium-based system, first commercialized by Sony in 1991. Besides powering cellular phones, laptops, digital cameras, power tools & medical devices, Lithium ion is also used of for EV & Satellite.

* Types of Energy Storage System :→.

→ Energy Storage System.

(A) Mechanical.
1. Pumped Hydroelectric.
2. Compressed Air.
3. Fly wheels.

(B) Thermals.
1. Cold
2. Heat

(C) Chemical.
1. Hydrogen cells
2. other fuel cells.

(D) Electrochemical.
1. Lead Acid.
2. Lithium Ion.
3. Other accumulator (NaS / NaNiCl)
4. Traditional flow batteries. (VRB, BR-Zn, Fe-Zn)
5. New Vanadium Redox Technology Hydrid Redox

(E) Electricals.
1. Supercapacitors
2. Superconducting Magnets.

* Super Capacitors :→.

→ A supercapacitors (or ultracapacitors) differ from an ordinary capacitor in two important ways; its plates have a much bigger area & distance between them is much smaller

→ Like an ordinary capacitor, a supercapacitor has two plates that are separated The plates are maed from metal coated with a porus substance such as powdery, activated charcoal, which efficiively. gives them a bigger area for storing much more charge.

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* Battery

1. A battery is a self contained, chemical power pack that can produce limited amount of Electrical energy when needed.
2. Battery converts stored chemical energy into Electrical energy, released over a period of days.
3. It is a combination of cells.
4. Battery capacity is expressed in Ahr.
5. It is Energy storage Medium.

* Why 'LI-Ion' Cells ?"

1. specific energy density is maximum in LI-Ion cell.
2. Life cycle is maximum in LI-Ion cells.
   1 cycle = 1 complete charge & Discharge.
   LI-Ion cell have 500 – 2000 cycle.
3.
4. fast charge in LI Ion cell like 1 hror less or charge 80% of capacity in 1 hr.
5. lead acid self discharge property is less than LI-Ion.
6. Trickle charging means charging a fully charged battery at a rate equal to self discharge rate, thus enabling the battery to remain at its fully charged level.
   LI Ion Battery cannot tolerate trickle charge
7. Self discharge is Less in LI-Ion Batt

Li Ion

Specification	Lead Acid	Ni Cd	Ni MH	Cobalt-	Manganese	Phosphate
(Wh/kg) Specific Energy Density	30-50	45-80	60-120	150-190	100-135	90-120
Internal Resistance (mΩ)	<100 12V Pack	100-200 6V pack	200-300 6V pack	150-300 3.2V	25-75 per cell	25-50 per cell
Life cycle (80% discharge)	200-300	1000	300-500	500-1000	500-1000	1000-2000
Fast-charge Time	8-16h	1h typical	2-4h	2-4hr	1hr or less	1hr or less
Overcharge Tolerance	High	Moderate	Low	Low Cannot tolerate	trickle charge	
Self-discharge / month	5%	20%	30%	<10%		

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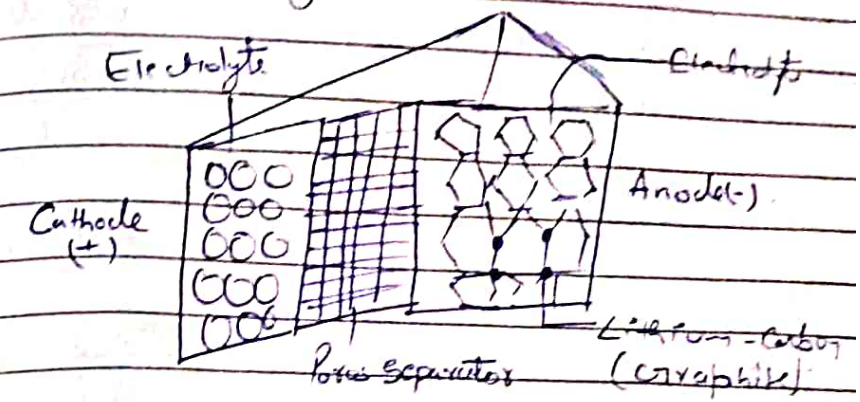
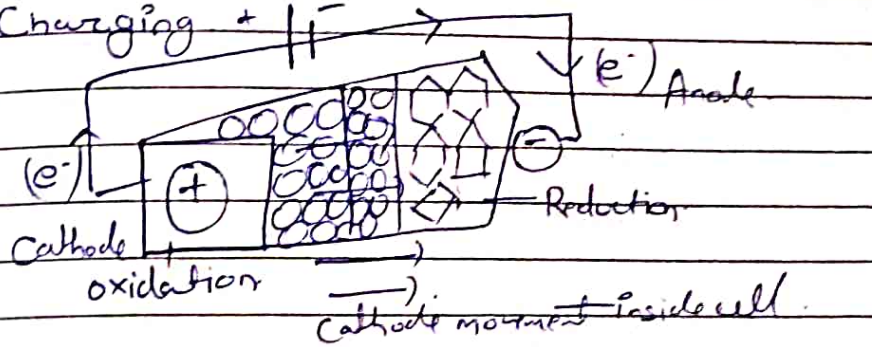
* Li Ion Working

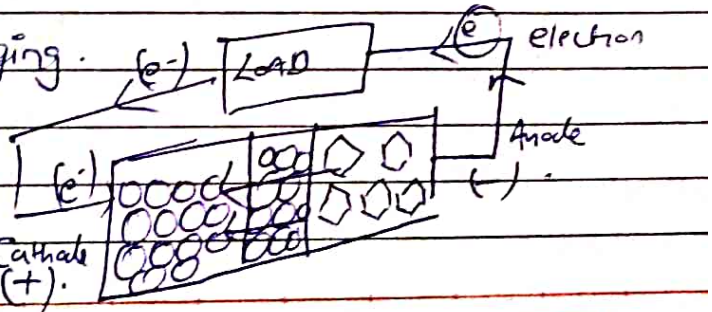


→ Battery charging & discharge operation.

(A) Charging



(B) Discharging.



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Chemical reaction Inside LI-ION BATTERY.

→ Reduction takes place at the cathode. There, cobalt oxide combines with lithium ions to form Lithium Cobalt oxide. ($LiCO_2$)

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

→ Oxidation takes place at the anode, There the graphite intercalation compound LiC_6 forms graphite (C_6) & lithium ions.

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

Here is the Charging.

$$LiCoO_2 + C_6 \longrightarrow LiC_6 + CoO_2$$

Discharging.

$$LiC_6 + CoO_2 \longrightarrow C_6 + LiCoO_2$$

Battery Terminology :→

① ~~Amphere Hour or Ampere-Hour~~
A unit of measurement of battery's electrical stroge capacity. Current multiplied by time in hours equal amphere-hours.

2. Energy Density :→
It is the measure of how much energy a battery contains in proportion to its weight. This measurement is typically presented in Watt-hours per kilogram (Wh/Kg) & watt-hour is a measure of electrical energy that is equivalent to the consumption of one watt for one hour.

3. Power density :→
It is measure of how quickly the energy can delivered, rather than how much stored energy is available.

+ Lithium Cobalt oxide (LCO).

→ Voltages : 3.60V nominal ; typical operating range 3.0-4.2V/cell
→ Specific energy Capacity :→ 150-200 Wh/kg . Specialty Cells provide upto 240 Wh/kg .
→ Charges (C-rate) - 0.7-1C , charges to 4.20V (most cells) ; 5h charge typical. Charge current above 1C shortens Battery life
→ Discharge (C-rate) - 1C ; 2.50V Cut off . Discharge current above 1C shortens battery life.

→ Cycle life . → 500 - 1000 , related to depth of discharge , load, tempr.

→ Thermal runaway → 150°C (302°F) full charge promotes thermal runaway.

→ Application :→ Mobile phone , tablets, laptops , Cameras .

+ Lithium Manganese oxide.

① Voltages :→ 3.70V (3.80V) nominal ; typically operating range 3.0 - 4.2V/cell

② Specific energy (capacity) - 100-150 Wh/kg.

3. charge (C-rate) - 0.7 - 1C typical , 3C maximum charges to 4.20V

4. Discharge (C-rate) - 1C ; 10C possible with some cells , 30C pulse (5s) , 2.50V cut-off.

5. Cycle life :→ 300-700 (related to depth of discharge & tempr).

6. Thermal run-away : → 210°C (410°F) typical . High charge promote thermal runaway.

$ Cost :→ $420 per kWh (Source : RW TH Anchor

§ Application :→ E-bikes , medical device , EVs , Industrial .

+ Lithium Iron Phosphate.

Voltages :→ 3.20, 3.30V nominal, typical operating range 2.5 — 3.65 V/cell.

Specific energy (capacity) :→ 90 — 120 Wh/kg.

Charge C-rate :→ 1C typical, charges to 3.65V, 3h charge time typical.

Discharge (rate) :→ ~~1C typical~~; 3.00V cutt off) high discharge rate shorten battery life. 1C, 25C on some cells; 40A pulse (2S); 2.50V cutt off.

~~Cycle life~~ 500 (lower rate 2V cutt damage)

Cycle life :→ 2000 & higher (related to depth of discharge & temp)

Thermal run away :→ 270°C (518°F) very safe Battery even if full charged.

Lithium Nickle Cobalt Aluminium oxide (NCA).

1. Voltages :- 3.60V nominal, typical operating range 3.0 – 4.2V/cell.
2. Specific energy :- 200–260 Wh/kg predictable.
3. Charge (C-rate) → 0.7C, Charges to 4.20V (most cells), 3h charge typical, fast charge possible with some cells.
4. Discharge (C-rate) → 1C typical; 3.00V cut off; high discharge rate shortens battery life.
5. Cycle life :- 500 (related to depth of discharge, temp^{re})
6. Thermal runaway :- one of safest Li-Ion batteries
7. Cost → $1005 per kWh (Source: RWTH, Aachen)
8. Application :- UPS, electric power train (Mitsubishi iMiEV, Honda fit EV).

Lithium Titanate (LTO).

1. Voltages :- 2.40V nominal; typical operating range 1.8 – 2.85 V/cell.
2. Specific energy (capacity) :- 50–80 Wh/kg.
3. Charge (C-rate) :- 1C typical; 5C maximum, Charges to 2.85V.
4. Discharge (C-Rate) → 10C possible, 30C 5s pulse. 1.80V cut off on LCO/LTO.
5. Cycle life – 3000–7000
6. Thermal runaway :- one of safest Li-Ion Batteries.
   → 150°C (302F) typical, high charge prevents thermal runaway.
   → $350 per kWh (Source: RWTH, Aachen)
   → Medical device, industrial, electric power train tesla.

* Comparision of Different Lithium cell

Battery	Specific Power	Specific Energy	Safety	Life span	Cost	Performance
LCO	Low	High	Low	Low	Low	Moderate
LMO	Moderate	Moderate	Moderate	Low	Low	Low
LNMCO	Moderate	High	Moderate	Mod	L	M
LIP	H	L	H	H	L	M
LNCAO	M	H	L	M	M	M
LT	M	L	H	H	H	H

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* Cell Types - Form factors.

→ Types of Li Ion interm of physical appearance

1. Cylendrical Cell
   - Those type of cell suited for automated manufacturing.
2. They offer high mechanical stability.
3. Round shape of cell distributes pressure uniformly over its circumfe.
4. Good thermal Management

Application → Medical equipment, laptop, ebikes, power tools

Other energy.

3.8V
1.5Ah.

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