Lithium Ion Batteries

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Team 1

Why batteries?

The world needs compact energy storage

Devices need electricity when not plugged in

Can be used as power backups

Advantages of Li+

High Energy density

Low self discharge (under half NiCd and NiMH)

Minimal memory effect

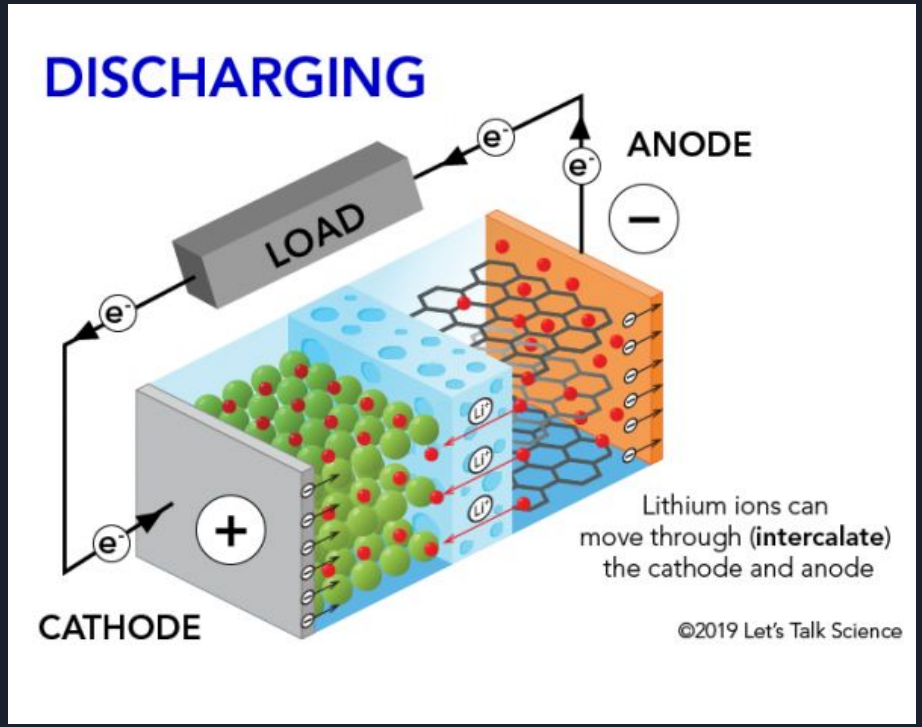
Longer lifespan than other common compositions

Individual cells

Consists of

- Cathode
- Anode
- Electrolyte

Materials for all of the components can be tweaked to alter the performance of the battery



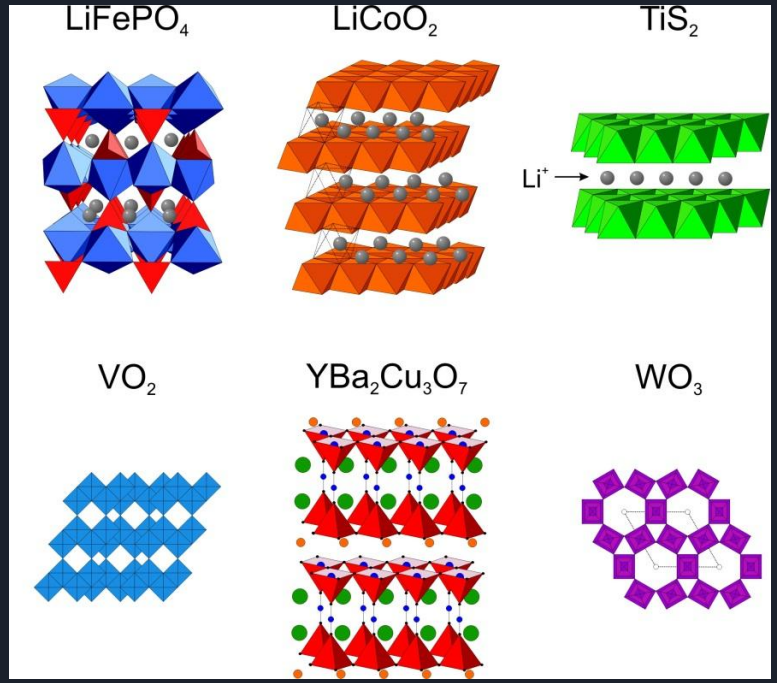
Cathode

Positive Electrode

Household batteries mark the cathode with +

Typically a Metal Oxide Crystal with Lithium Metal inserted

Absorbs Electrons that are made by the battery



Common Cathode Materials

Different Cathode materials can provide

- higher energy densities
- higher current output
- more charge cycles

Chemistry	Nominal V	Charge V limit	Charge & Discharge C-rates	Energy Density Wh/kg
Cobalt	3.60V	4.20V	1C limit	110-190
Manganese (spinel)	3.7-3.80V	4.20V	10C cont. 40C pulse	110-120
NCM (nickel-cobalt manganese)	3.70V	4.10V*	~ 5C cont. 30C pulse	95-130
Phosphate	3.2-3.30V	3.60V*	35C cont.	95-140

* Higher voltages provide more capacity but reduce cycle life

Electrolyte

Chemical Separator

usually a lithium salt

Permeable for lithium ions but not electrons

Originally these were only permeable in one direction

Today they are bi-directional

Common Electrolytes

Most common by far is Lithium Hexafluorophosphate

Other additives can be placed in solution with the salt to decrease the deposition rate or increase the reaction rate

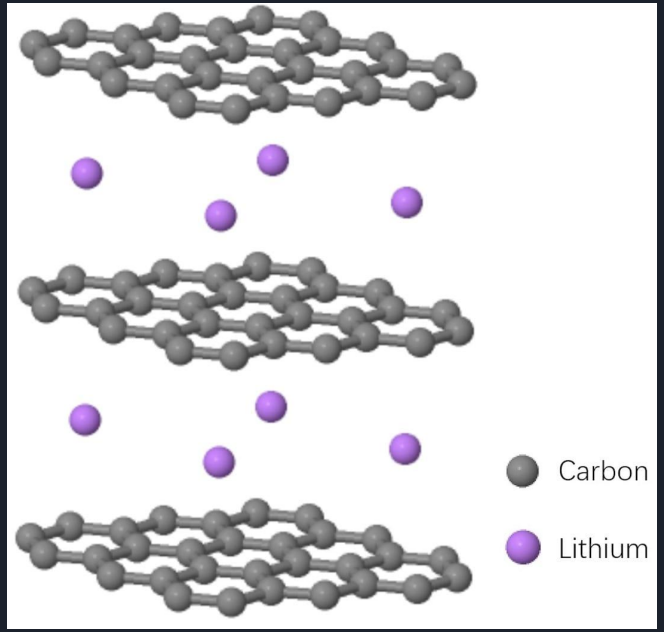
Increasingly common is solid electrolytes that limit the degradation of the battery and are much safer.

Anode

Negative Electrode

Emitter for the electrons generated

Almost always made of graphite due to its ability to place lithium ions between layers and its high conductivity



Other Anodes

Graphite anodes require six carbon atoms per lithium ion

This is a waste of space and energy density

Silicon can be used as it binds to more lithium

- This is expensive and dangerous as it expands while discharging

Usually silicon is added to the graphite as an impurity of around 3% to increase energy density

Also use lithium titanate to decrease charge time

Electrochemistry

Two reactions happen

The first one is a reaction at the anode

$$\mathrm{LiC_6} \rightleftharpoons \mathrm{C_6} + \mathrm{Li^+} + \mathrm{e^-}$$

This generates an electron and a positively charged lithium ion and releases the chemical potential as electrical potential

Electrochemistry

The second reaction happens at the cathode

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

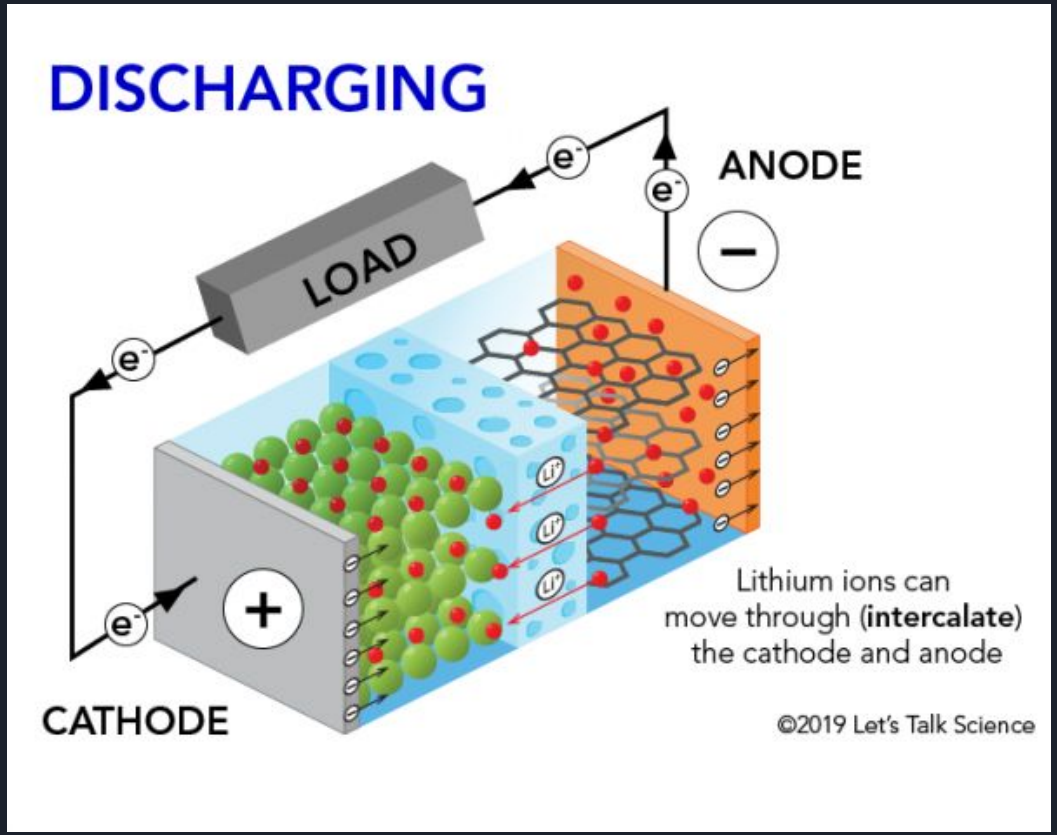
The metal oxide and lithium ion react with the electron and form the multi metal oxide

Electrochemistry

The reaction rate at the cathode is determined by the availability of electrons

Larger resistances in the external circuit that connects the cathode and anode limit how many electrons flow to the cathode

This means the discharge rate is determined by the resistance of the external circuit


DISCHARGING
ANODE
LOAD
CATHODE
Lithium ions can move through (intercalate) the cathode and anode
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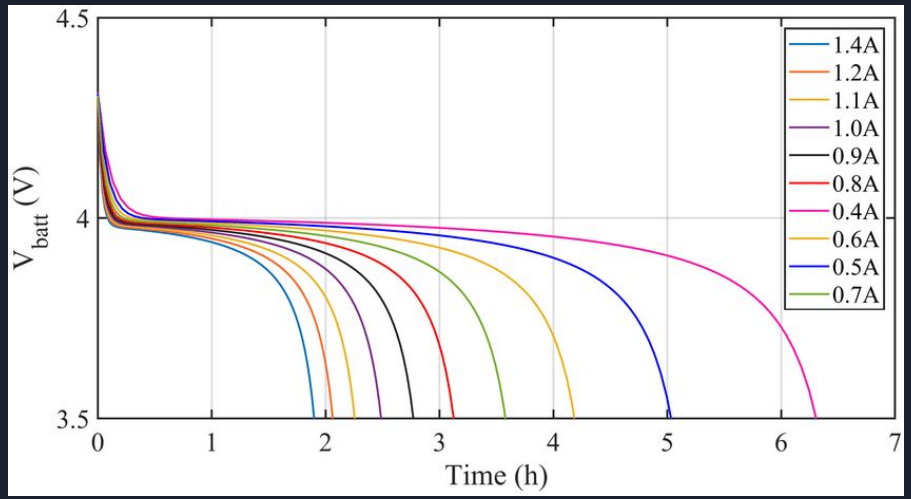
What determines Voltage?

The voltage is intrinsic to the reaction and is based on the compounds used.

The voltage is slightly dependant on concentration

Because of this the voltage can change as the battery is discharged

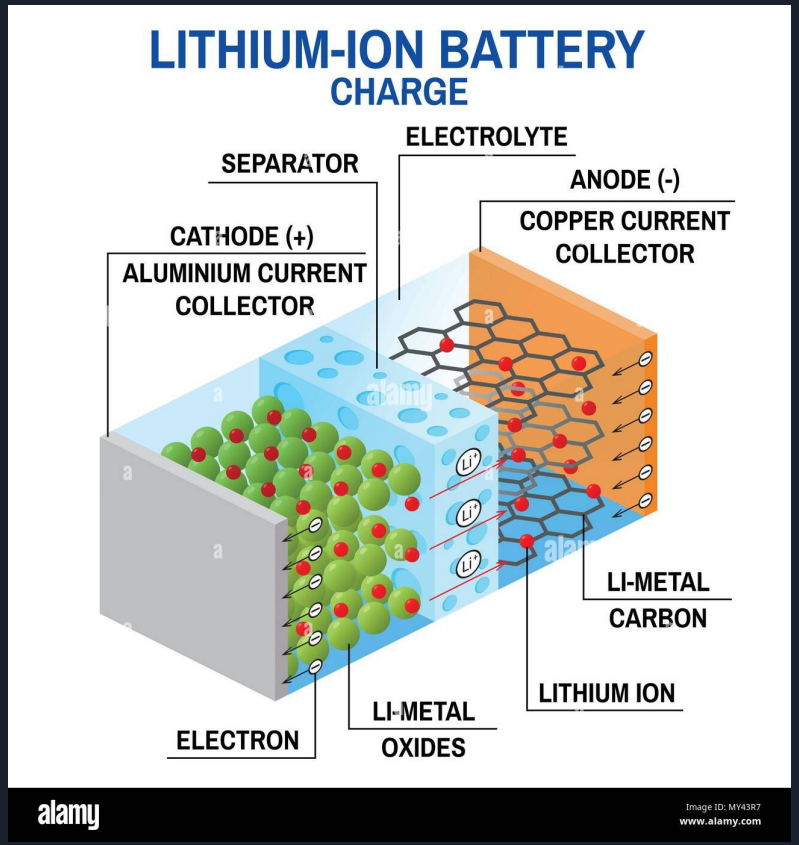


Charging

A higher voltage than the discharge voltage is applied

This supplies enough energy to cause the reactions to reverse

The electrons then leave the metal oxide and return to the graphite sheets



Format of cells

Putting two cells in series will cause their voltages to add

Putting two cells in parallel will cause their capacities to add

Commonly abbreviated with S and P

Ex. 4s2p

Allows operation at higher voltages and load requirements

More efficient than one big battery

Charging Multi-Celled batteries

Requires 3 steps

Constant current charging

Voltage balancing so all the cells are the same voltage

Constant Voltage charging

Lifetime performance

Lifetime of the battery is determined by

- Temperature of the battery
  - Reaction is exothermic so it heats the battery
- Reaction is 100% reversible
  - Some of the lithium is deposited on the electrodes and is lost
- Charge and discharge current
  - Increasing these also increases the rate of deposition

References

https://www.energy.gov/science/doe-explainsbatteries

https://batteryuniversity.com/article/bu-204-how-do-lithium-batteries-work

https://www.targray.com/li-ion-battery/cathode-materials

https://en.wikipedia.org/wiki/Lithium-ion_battery