BATTERIES FOR ENGINEERING APPLICATIONS

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BORN INNOVATIVE

TOPICS

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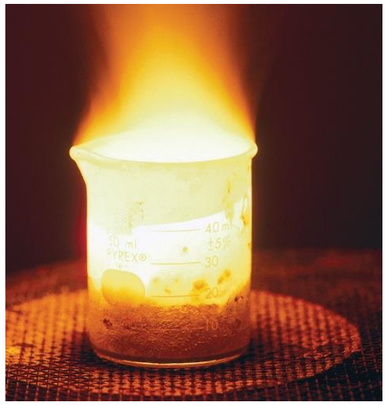
1. INTRODUCTION (terminology, battery construction and operation characteristics)
2. BATTERY TECHNOLOGIES (lead acid, Ni-MH, lithium ion, zebra, metal-air)
3. APPLICATIONS (Portability, renewal sources, Smart Grid, sizing and testing batteries, safety concerns)
4. NEXT GENERATION (battery challenges, new technologies, the future of energy storage)

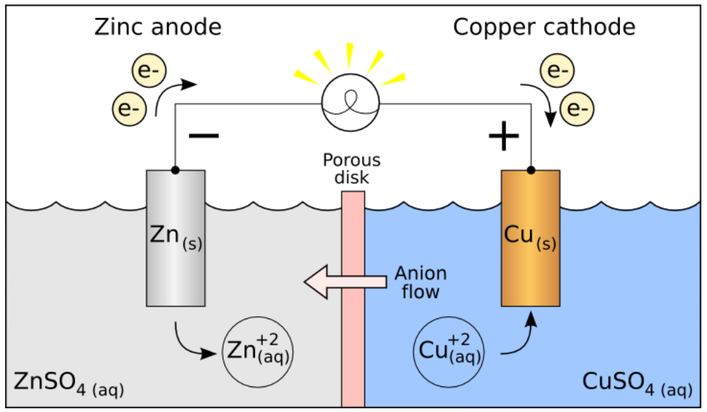
Battery Basic

What is a battery?

A battery is a device that converts chemical energy into electrical energy and vice versa

This device separates the anodic and cathodic reactions!





Basic background

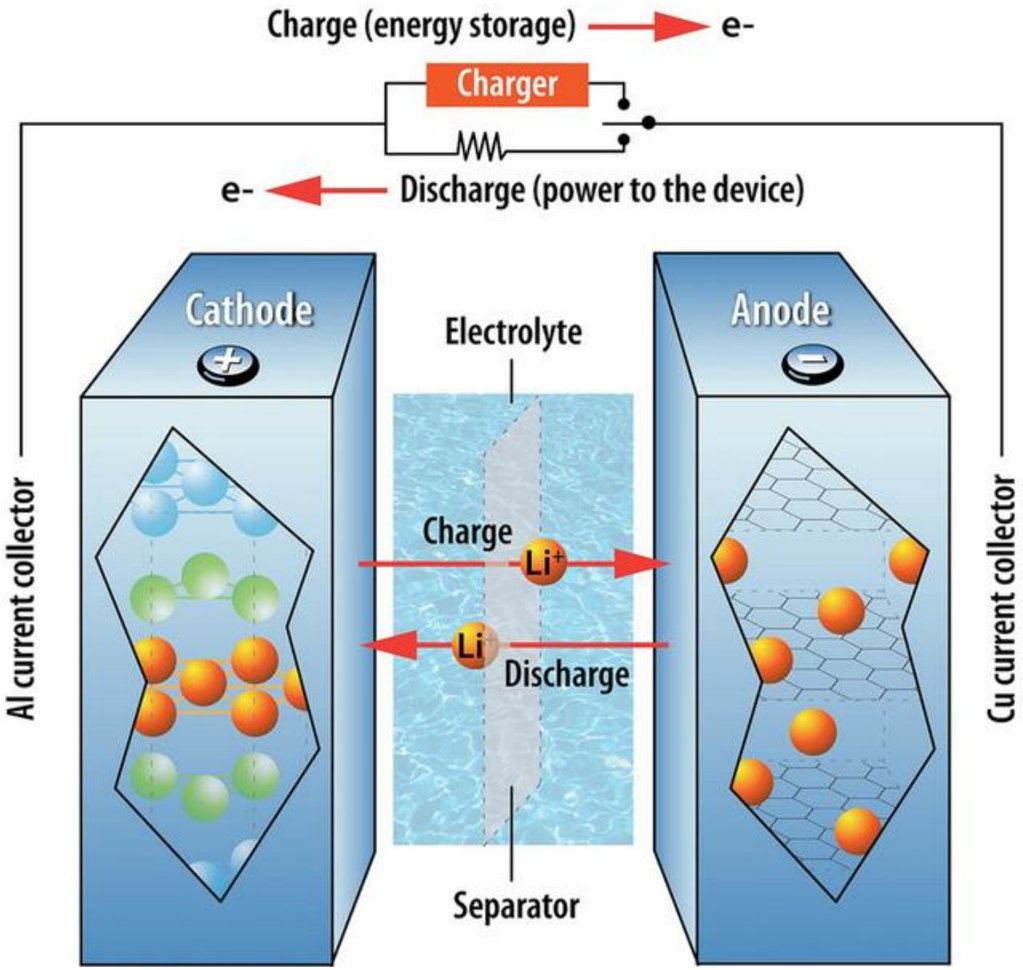
Construction characteristics. Variables used to characterize battery operating conditions, and describe the manufacturer specifications used to define battery nominal and maximum characteristics

Battery Basic – construction details

An **electrode** is an electronic conductor used to make contact with a nonmetallic part of a circuit.

The **electrolyte** is the non electronic conductor (to separate the oxidation and reduction reactions)

Finally the **separator** is a porous non conducting wall (to avoid internal short circuits)

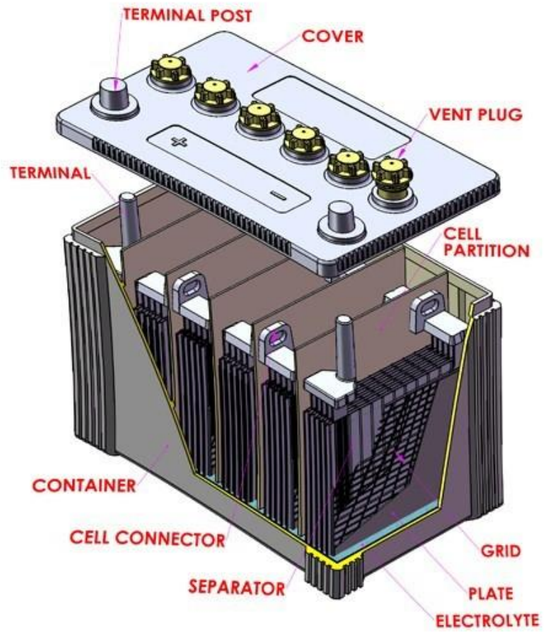


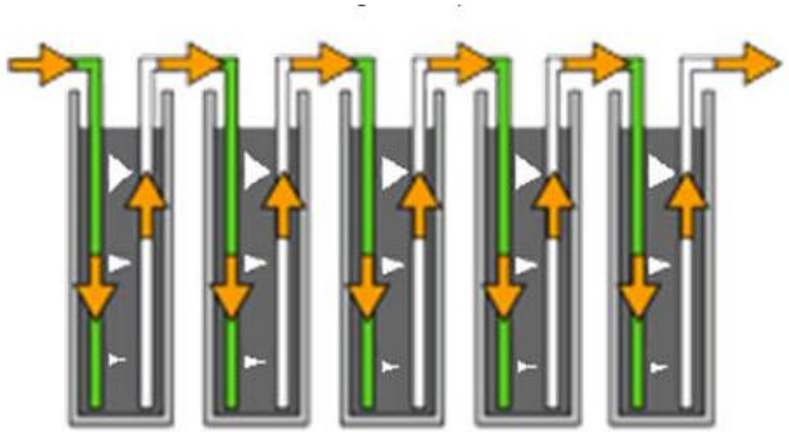
Battery Basic – Cell, modules and packs

A cell is the smallest, packaged form a battery can take.

A module consists of several cells generally connected in either series or parallel.

A battery pack is then assembled by connecting modules together, again either in series or parallel.





Battery Basic – Classification

Primary battery

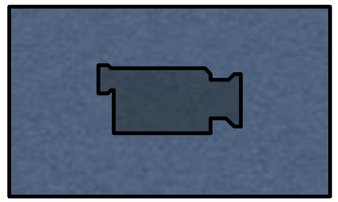
Secondary battery

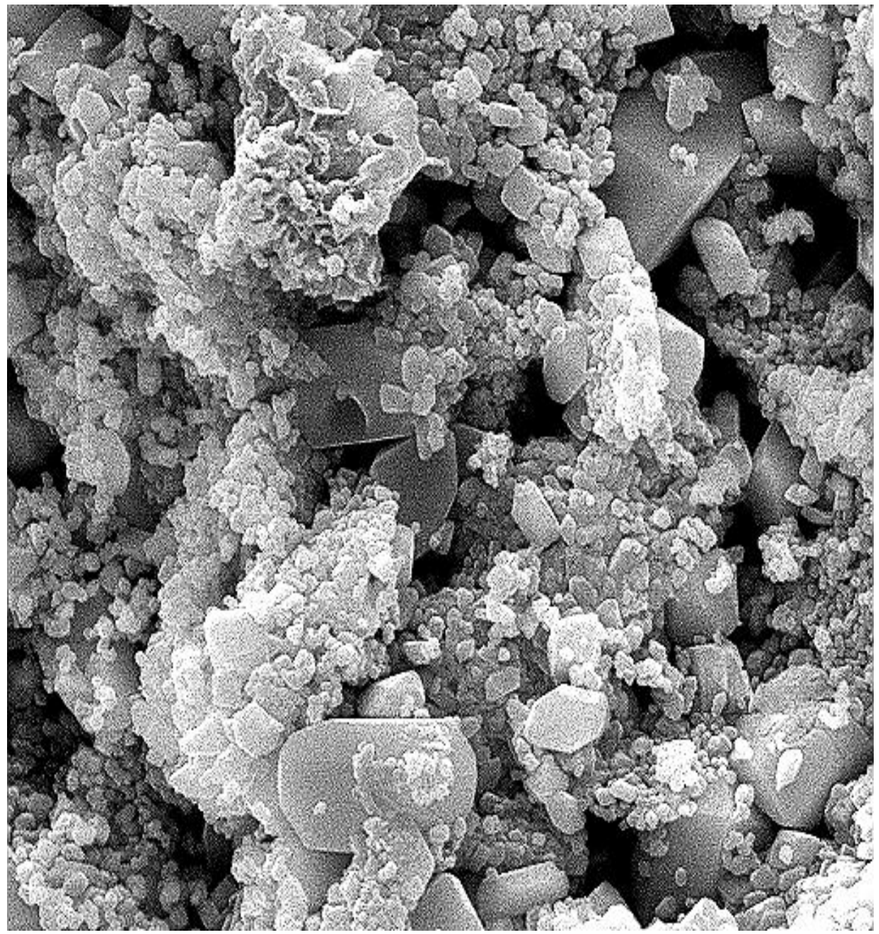
High power battery

High energy battery

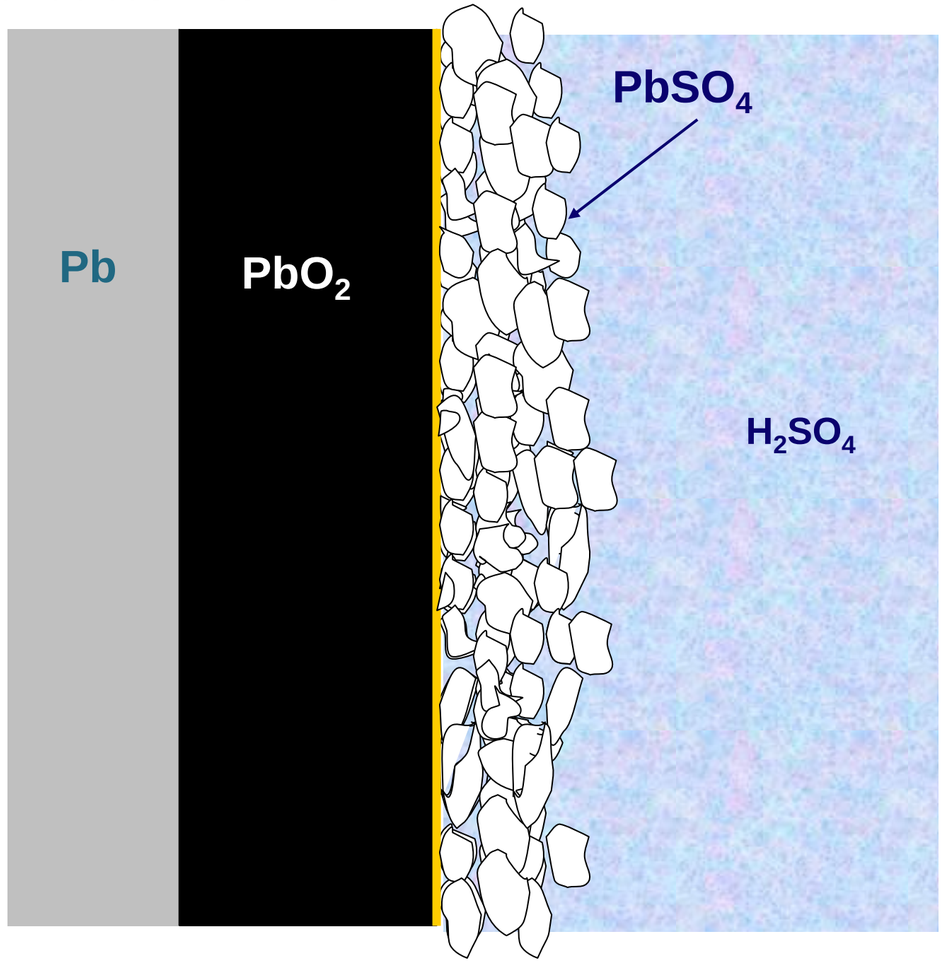
High durability battery

Reversible vs Irreversible chemical reactions





How a lead acid batteries work?



Battery Basic – Classification

Primary battery

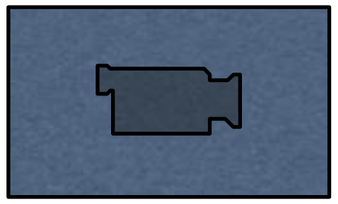
Secondary battery

High power battery

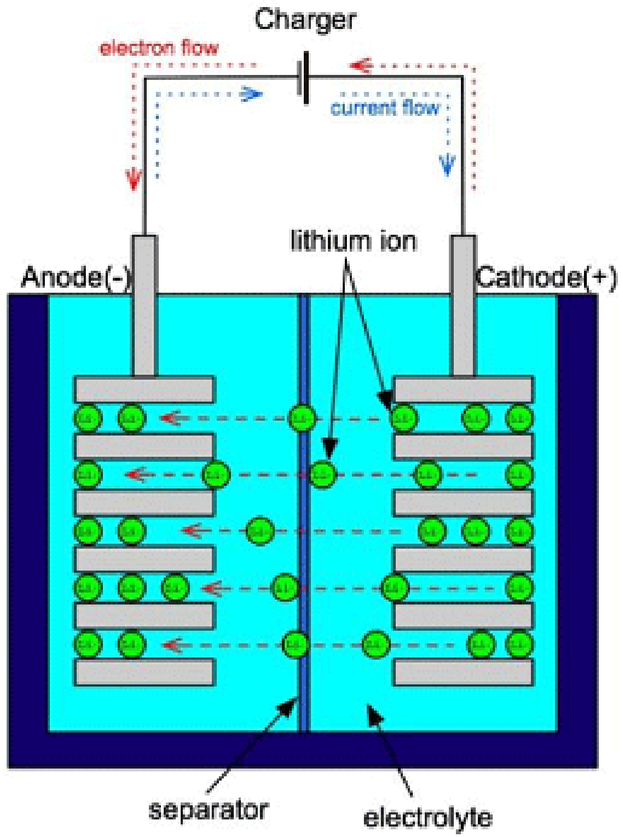
High energy battery

High durability battery

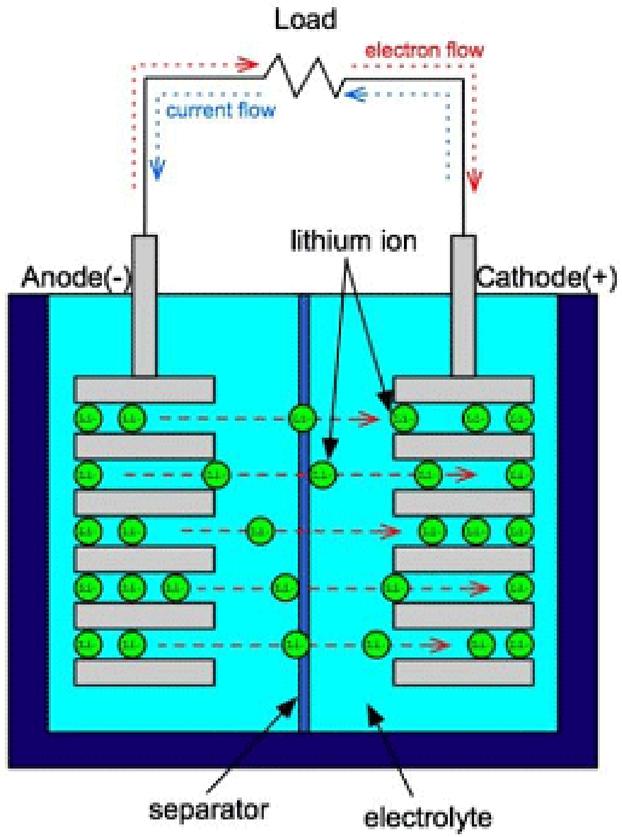
Reversible vs Irreversible chemical reactions



How a lithium ion batteries work?



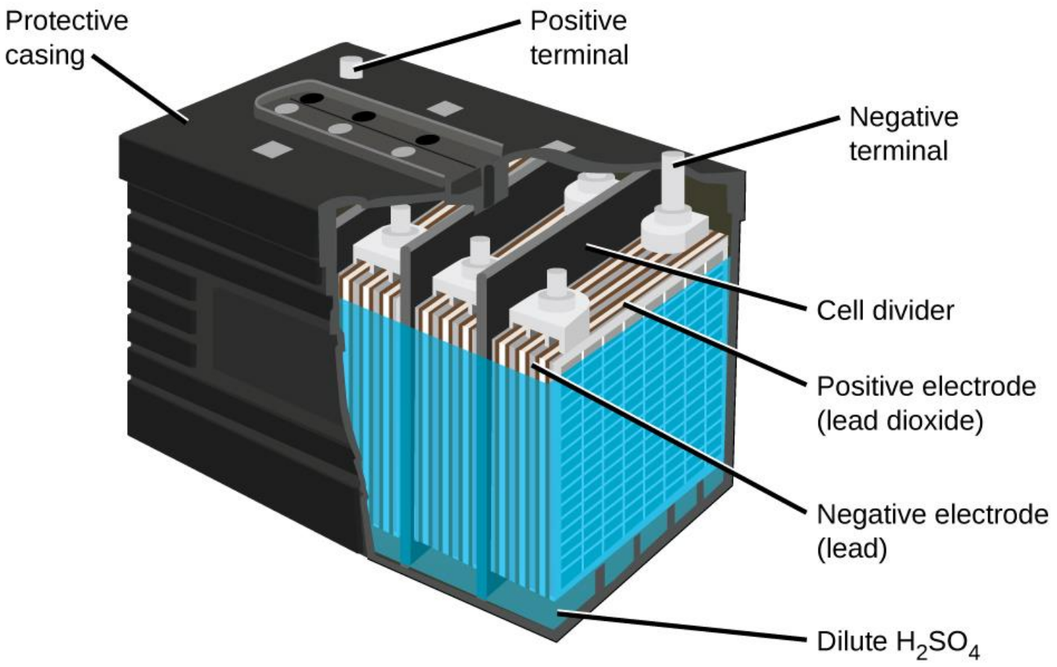
CHARGING



DISCHARGING

Battery Basic – Classification

What is a High power battery?

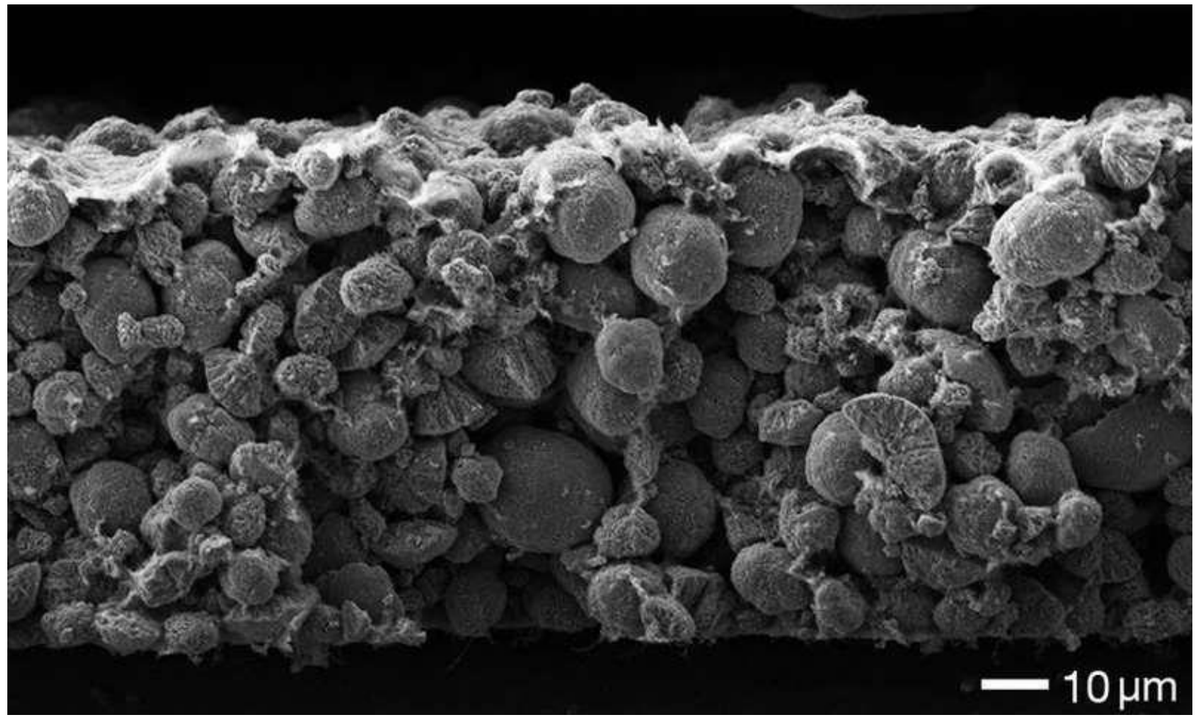


Many thin electrodes

High surface area

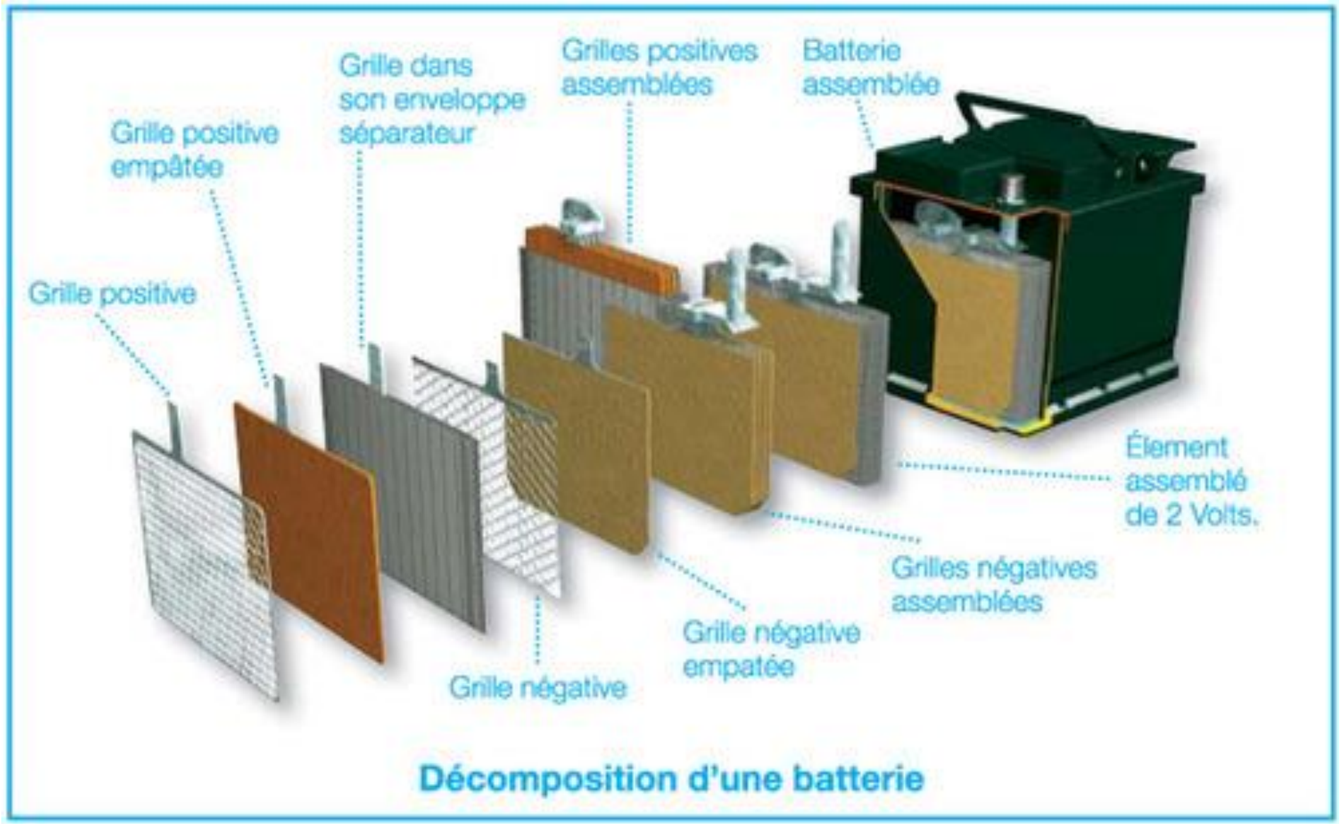
Low internal resistance

Cathode of a Nickel-Manganese-Cobalt-battery



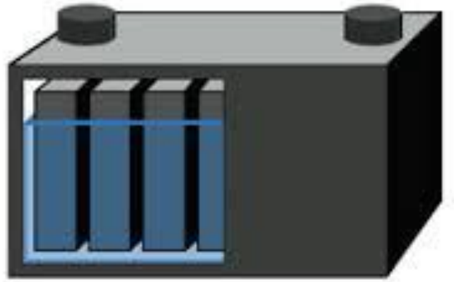
Battery Basic – Classification

What is a High energy battery?

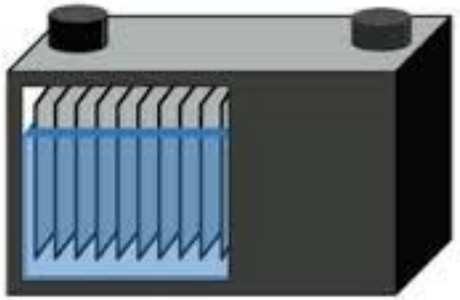


Few thick electrodes

More volume



Energy

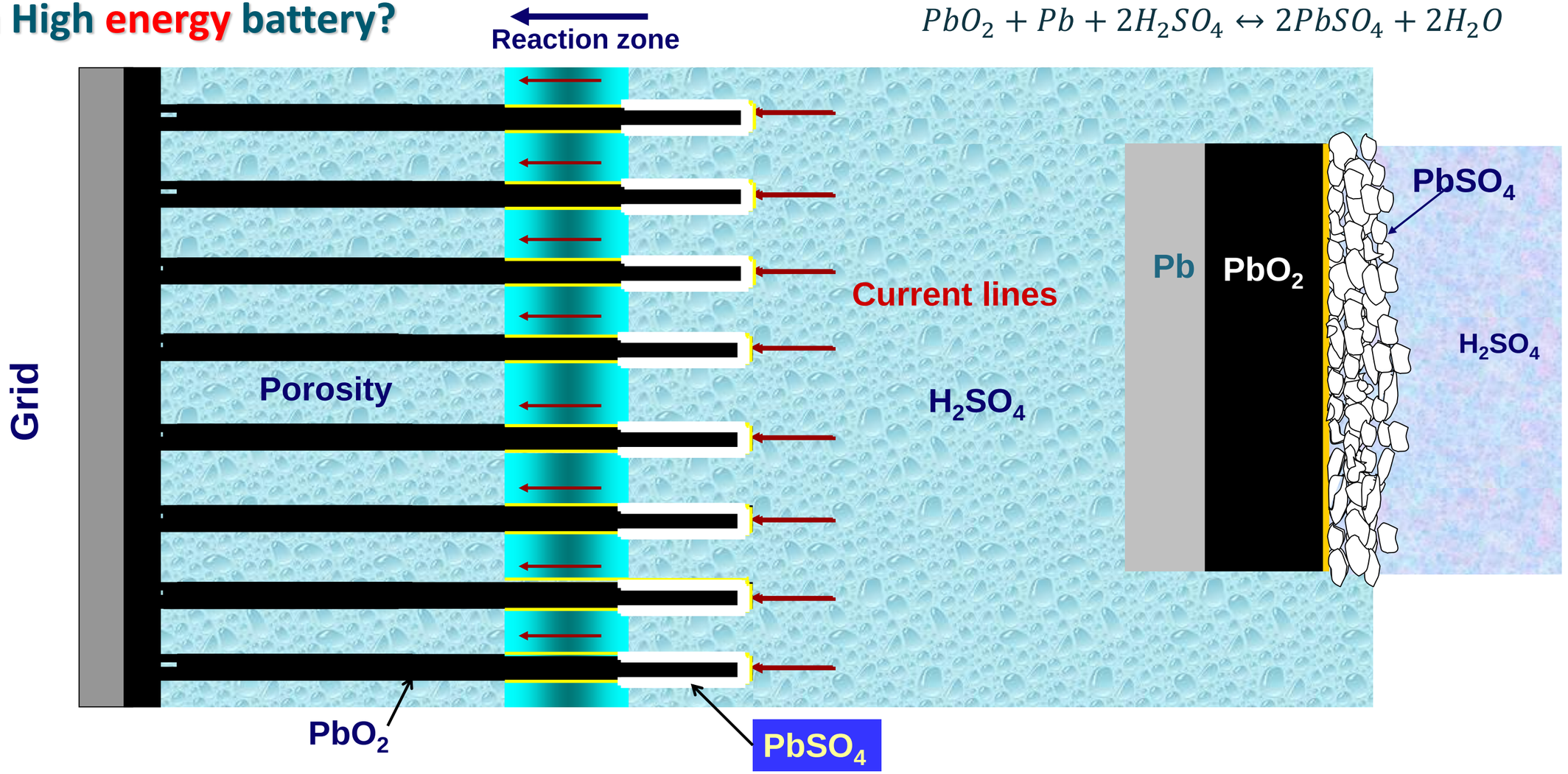


Power

Battery Basic – Classification

What is a High energy battery?

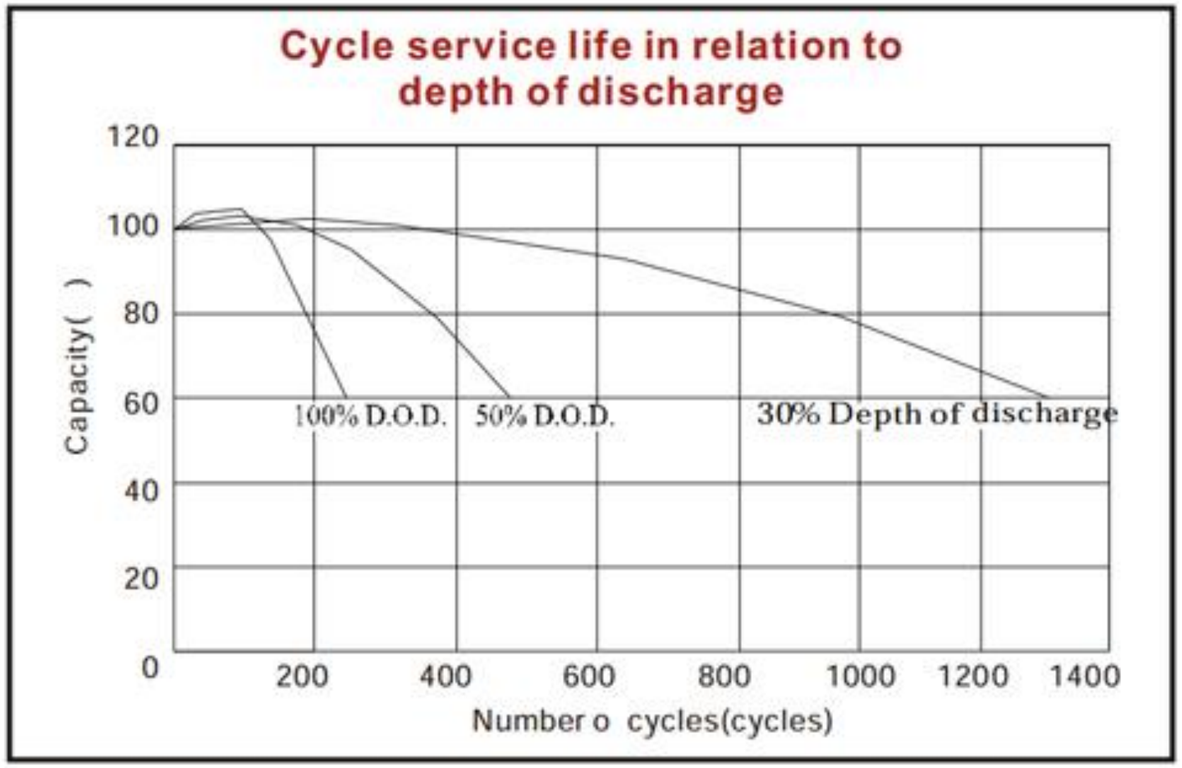
$$PbO_2 + Pb + 2H_2SO_4 \leftrightarrow 2PbSO_4 + 2H_2O$$



Battery Basic – Classification

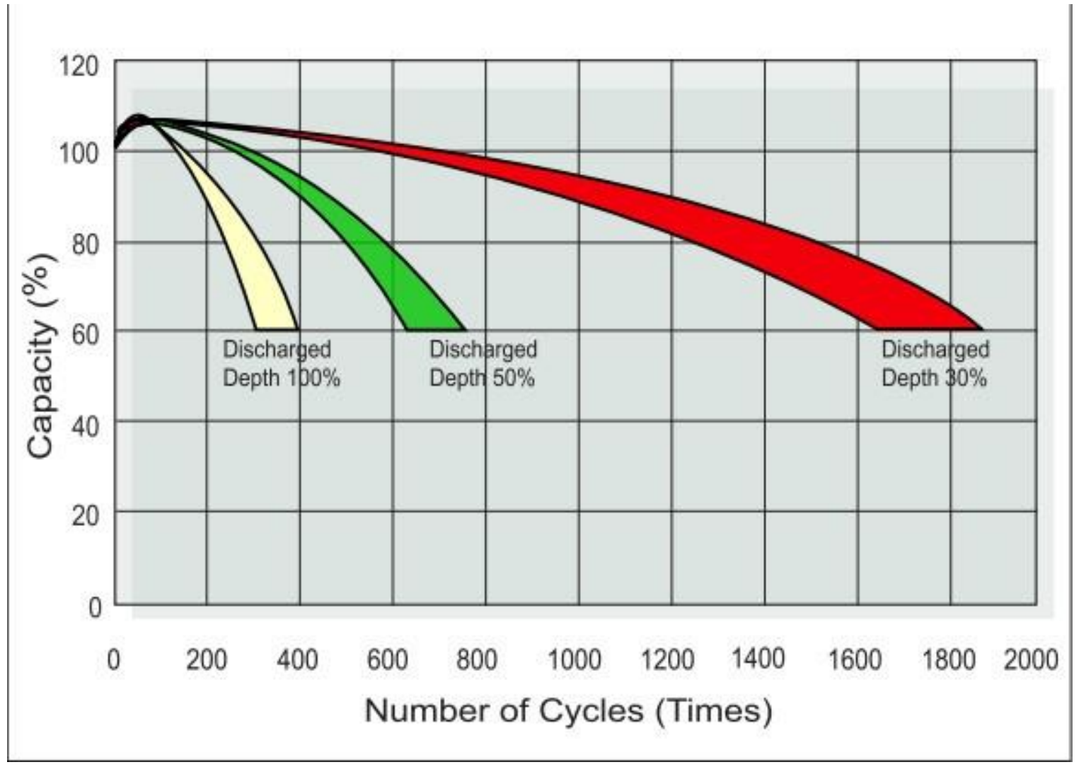
What is a High durability battery?

DoD vs Durability



Floating voltage vs Durability

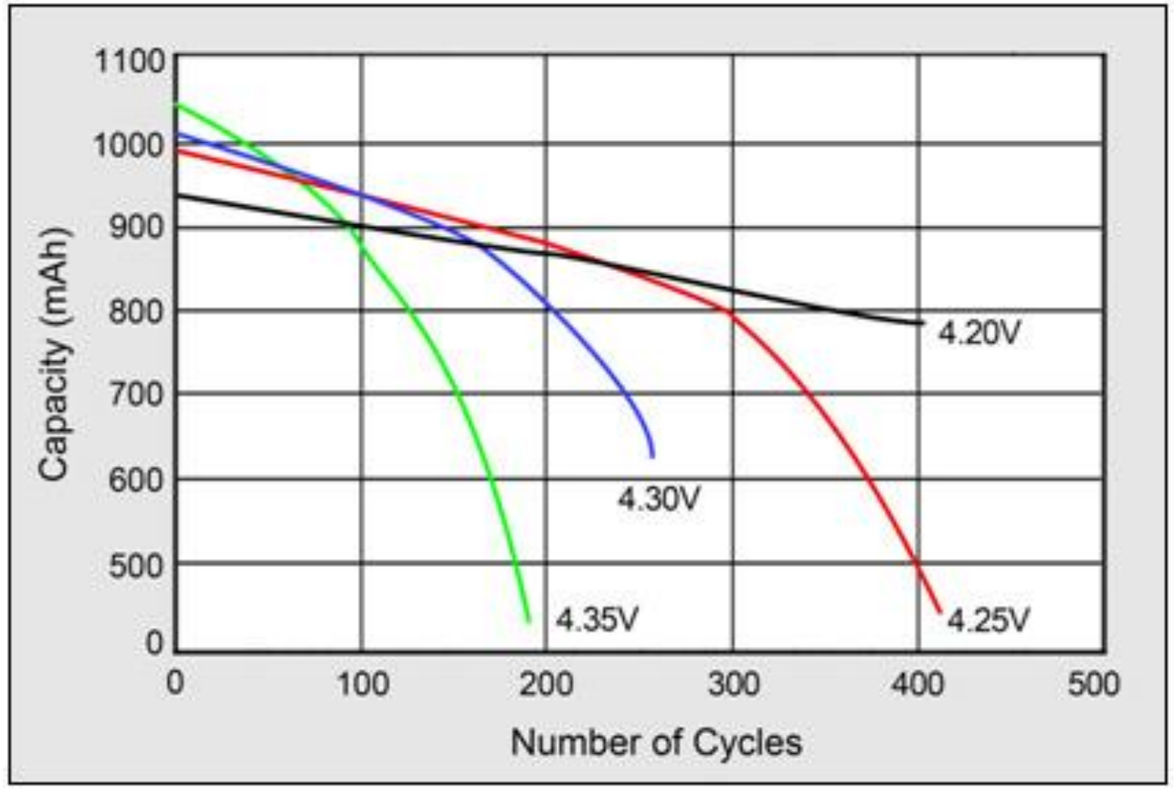
Lead acid (Water decomposition)



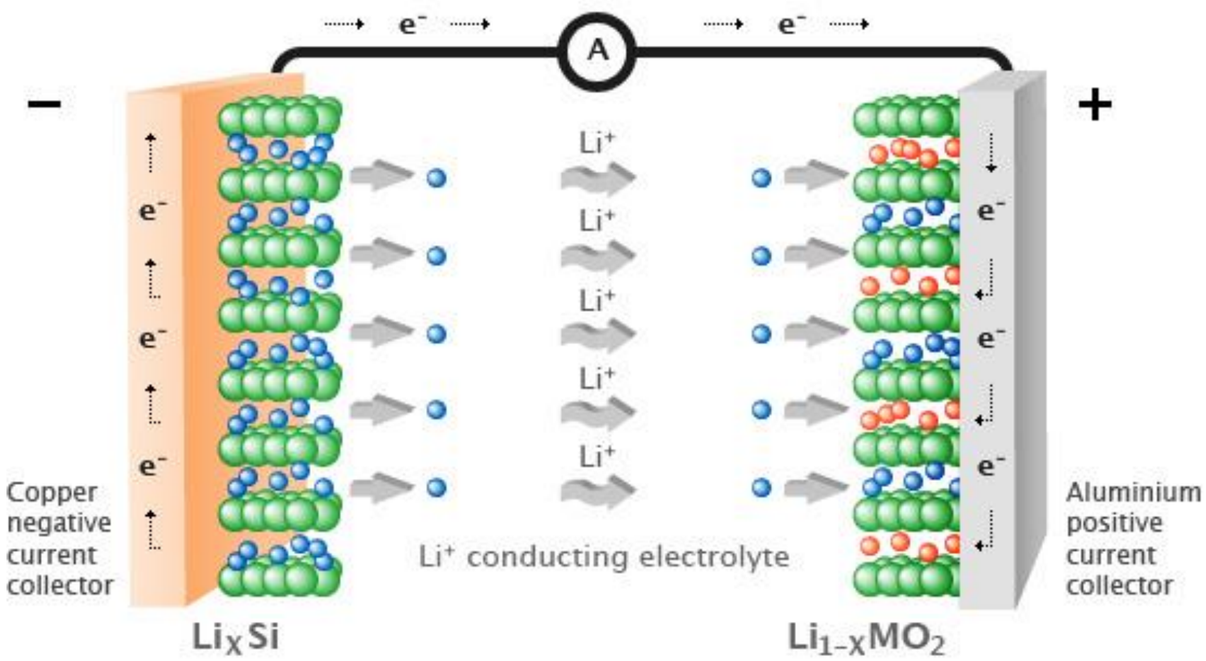
Battery Basic – Classification

What is a High durability battery?

charging voltage vs Durability

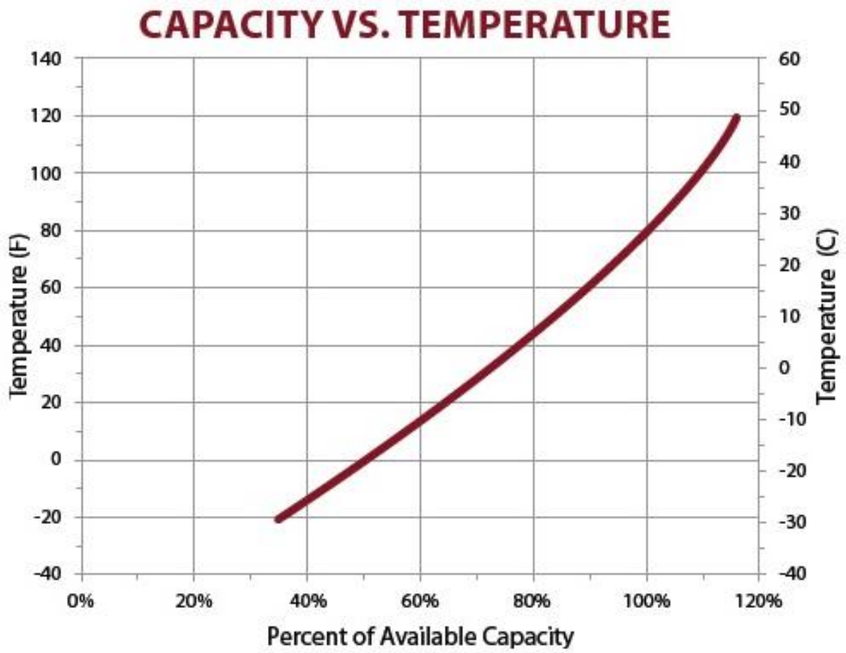


Li-ion (No parallel reaction)

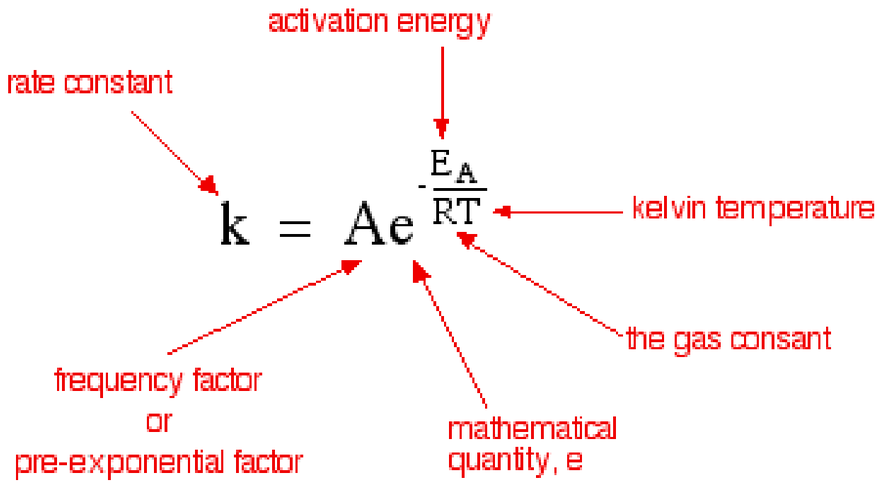


Battery Basic – Temperature

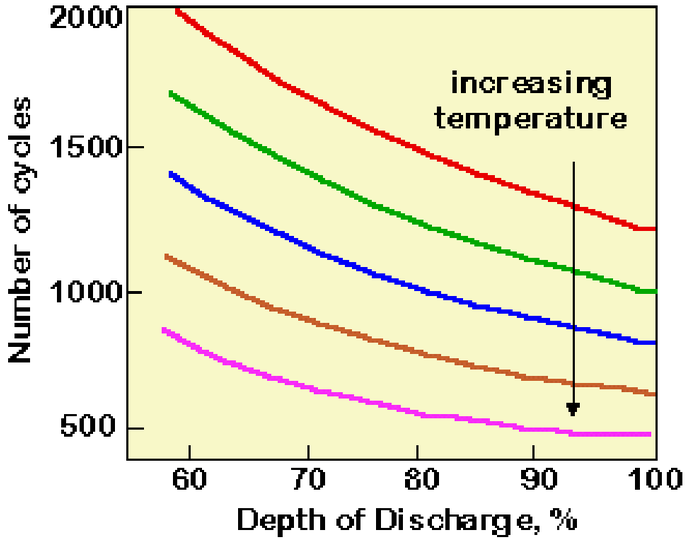
Temperature dependence?



Arrhenius law



The price is....

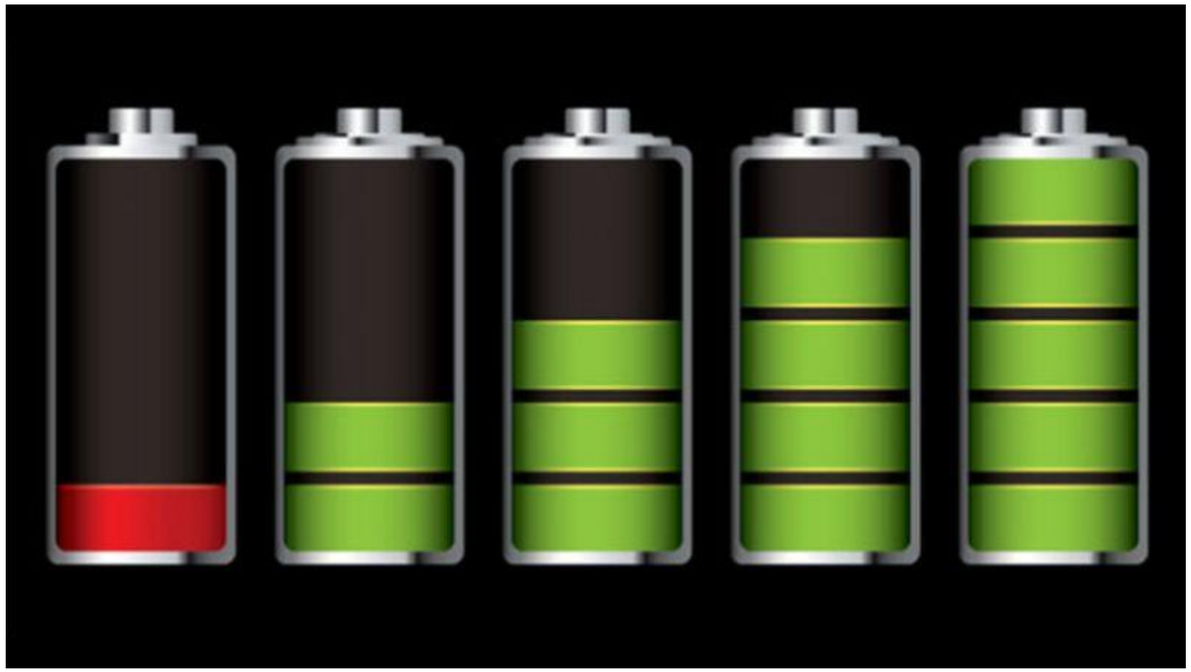


Battery Basic – Capacity

What is battery capacity?

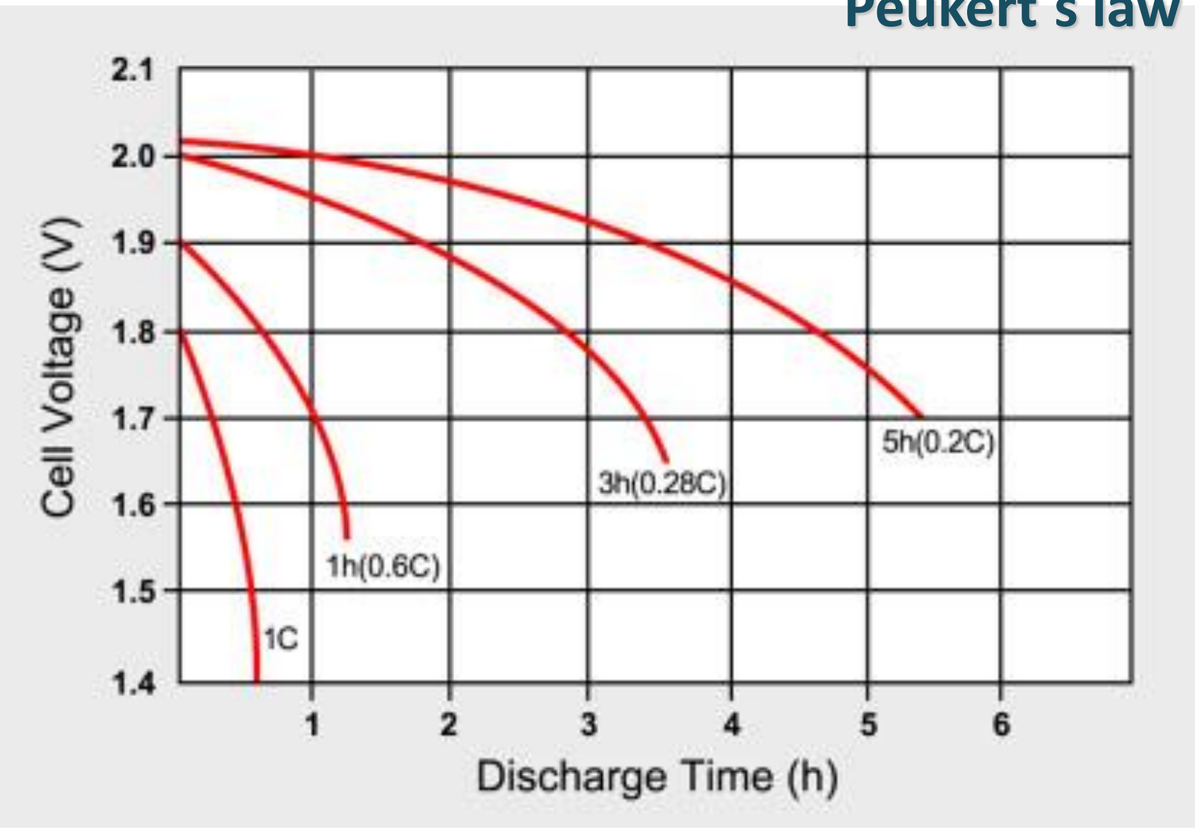
Is the amount of charge (Coulombs) available

Why Ah or mAh?



Capacity [C] = I [C/s] x t [s]

Peukert´s law



Battery Basic – Capacity

The problem of the discharge current

Peukert´s law $C = I^k t$

$$t_r = \left(\frac{C}{I_r t}\right)^k t_n$$

$$t_r = \left(\frac{100}{10\ 20}\right)^{1,4} 20$$

$$t_r = 7,6\ h$$

Peukert´s law example

Let's consider a flooded wet cell lead acid battery that has 20 hour discharge rating of 100 amp hours.

Based on this specification, we know that this battery will supply 5 amps for 20 hours while maintaining a voltage that is above 10.5 volts.

If we were to increased the discharge rate to 10 amps, we might **erroneously concluded** that the battery will last for 10 hours.

Using the equation for Peukert's law, we find that the battery will last significantly less than 10 hours.

In order to solve this equation we're going to need to know what the Peukert's exponent is. For a flooded battery, its typically going to be somewhere between 1.2 and 1.6. For this example, we're going to use 1.4.

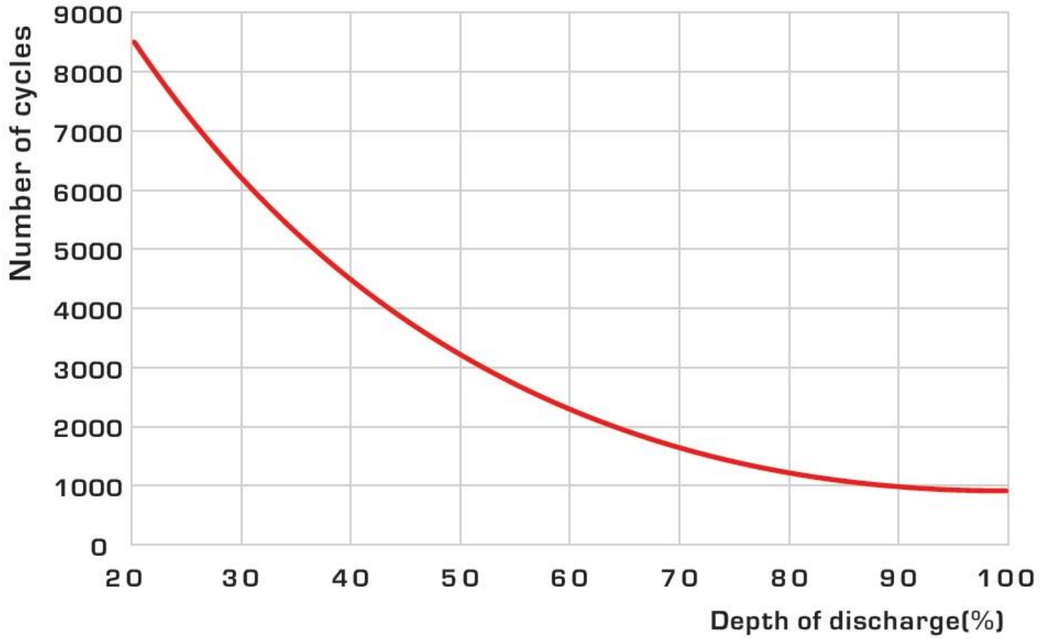
Battery Basic – Other Characteristics

Other battery characteristics

Reserve Capacity - RC

Cold Cranking Amperage - CCA

Energy throughput

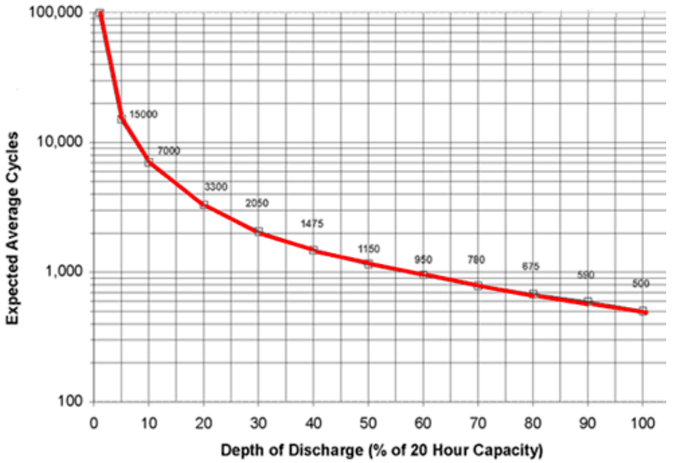


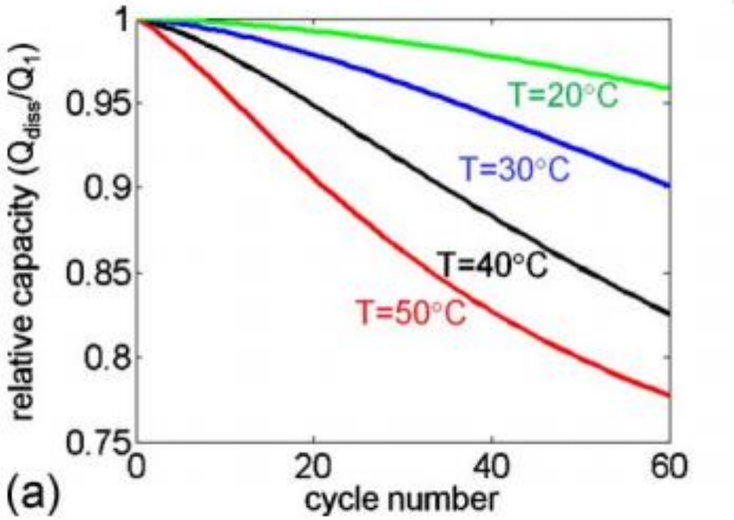
Where is the optimal battery size? (cost, life time, energy supplied)

Battery Basic – Other Characteristics

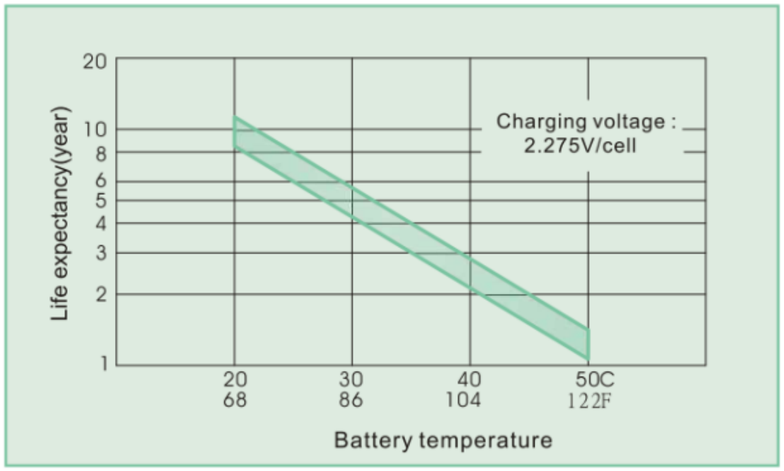
Other battery characteristics

- Life Time (many variables, many tricks)
- Floating Life Time
- Cycling Life Time

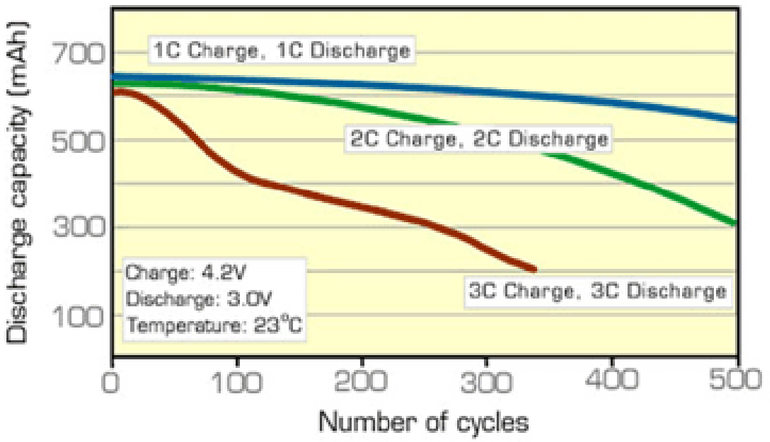


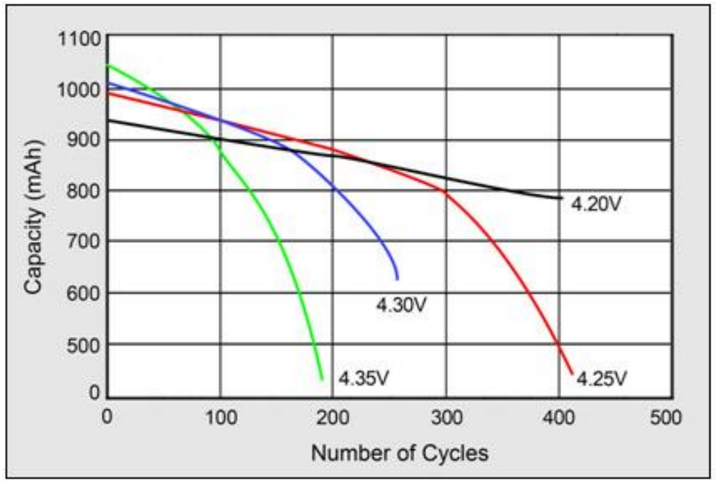


Effect Of Temperature On Long Term Float Life



Cycle Life at Various Charge / Discharge Rates

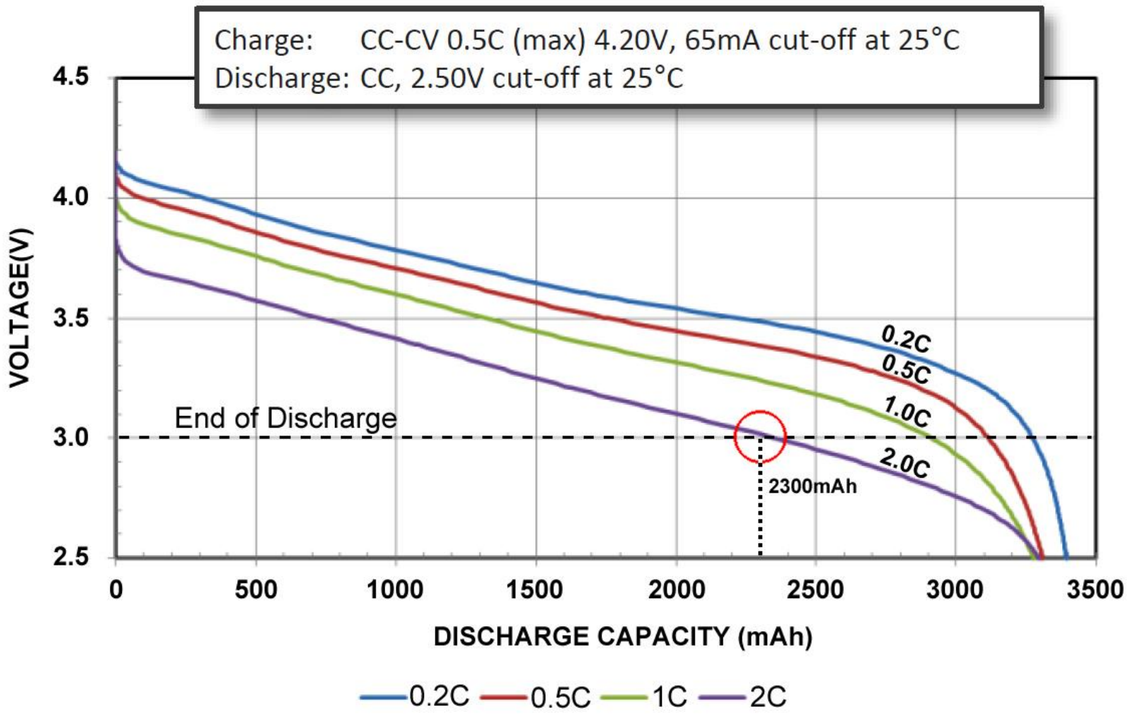


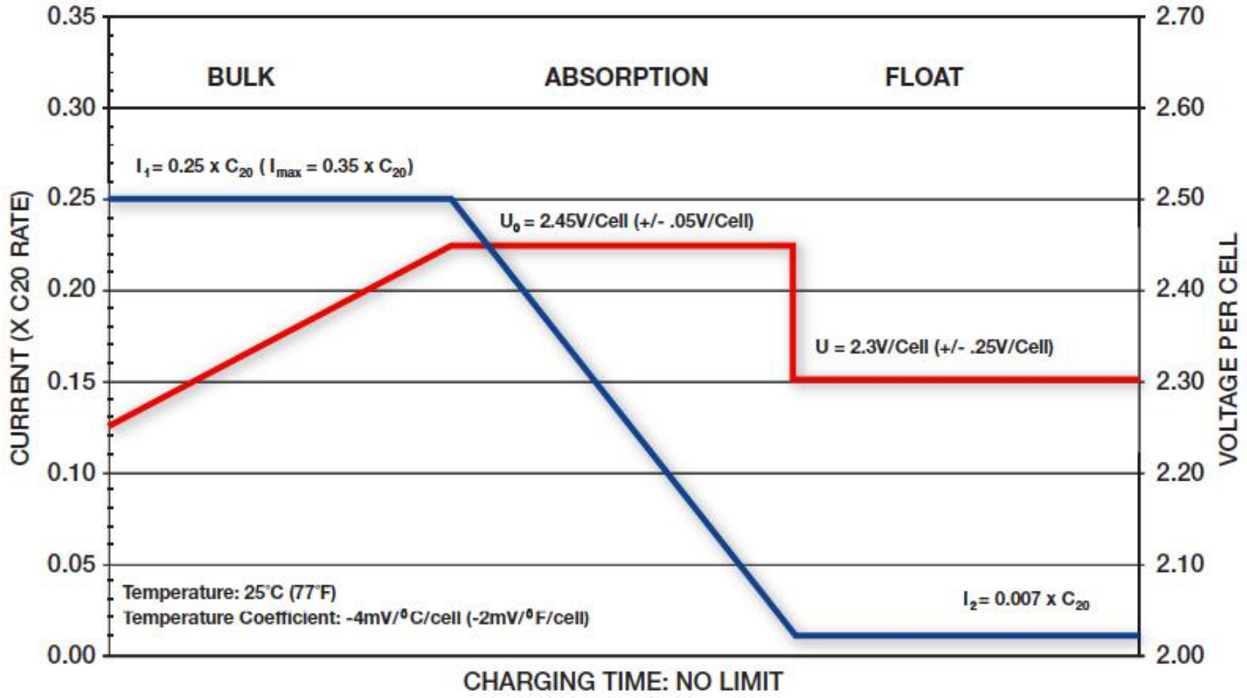


Battery Basic – Other Characteristics

Other battery characteristics

Battery Voltages: End Voltage, Charge Voltage, Floating Voltage…….and more

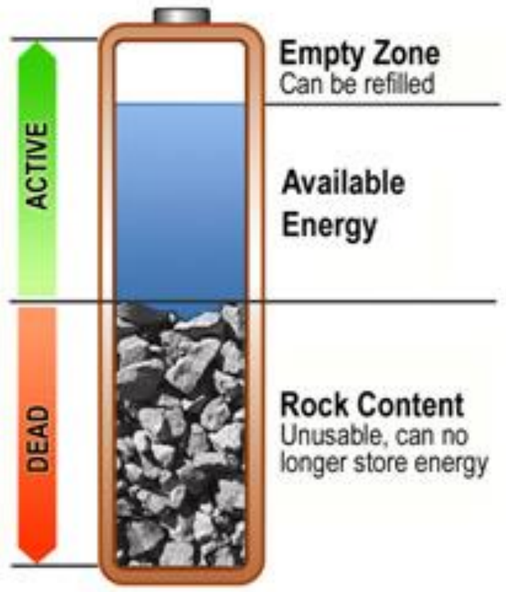


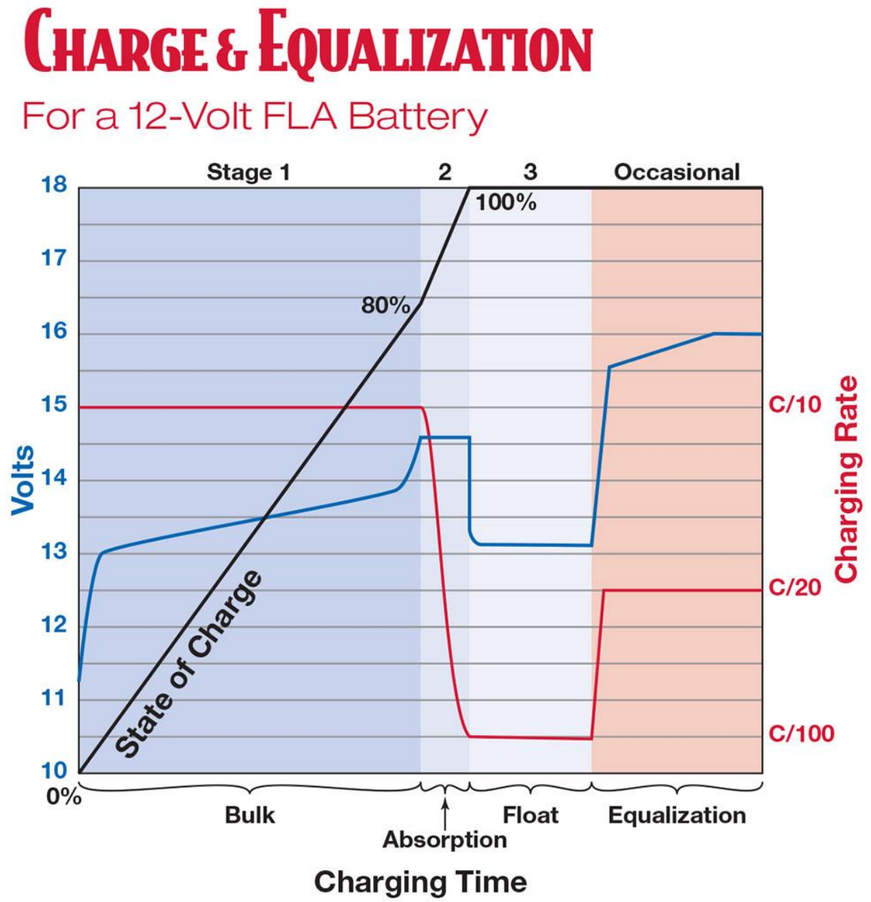


Battery Basic – Other Characteristics

Other battery characteristics

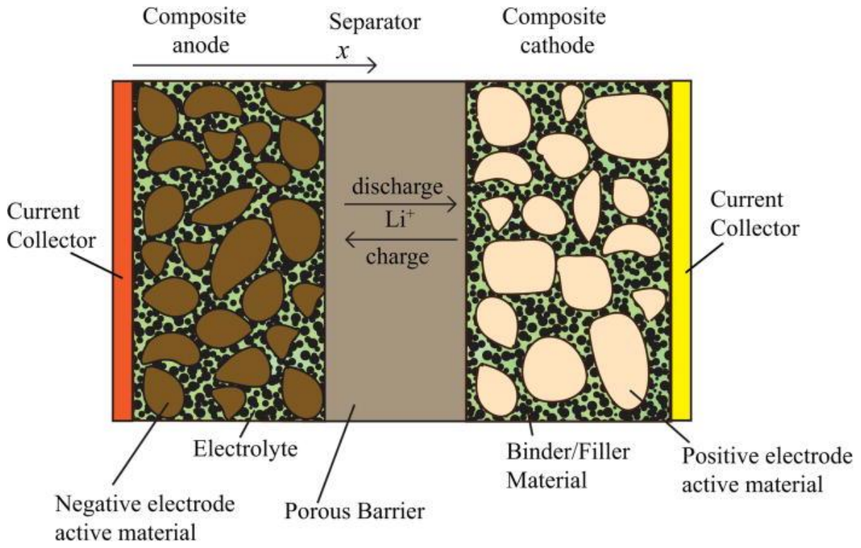
Battery Voltages: Equalization Voltage (just for some batteries)



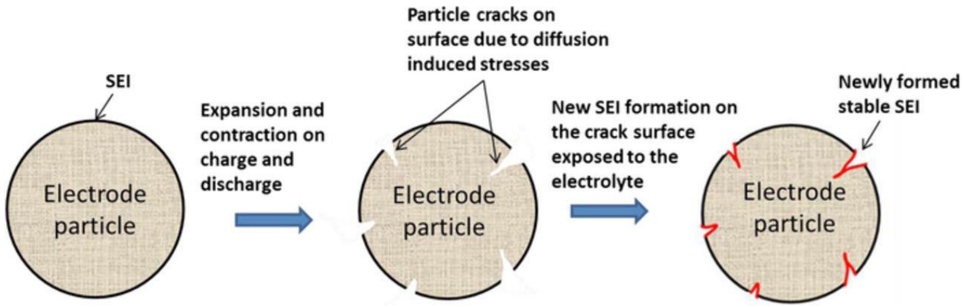


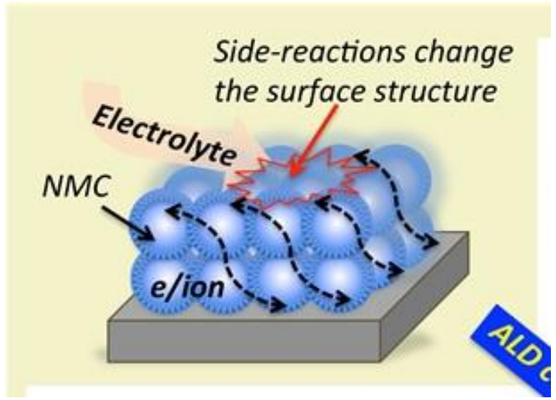
Battery Basic – Other Characteristics

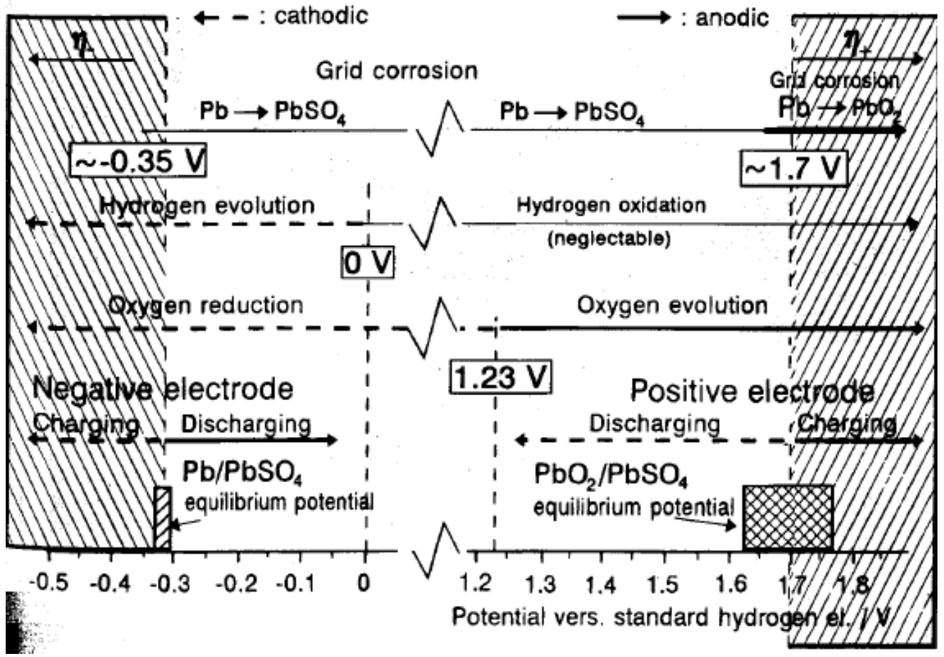
Other battery characteristics



Efficiency and parallel (side) reactions







Side reactions are always present

Battery Basic – Other Characteristics

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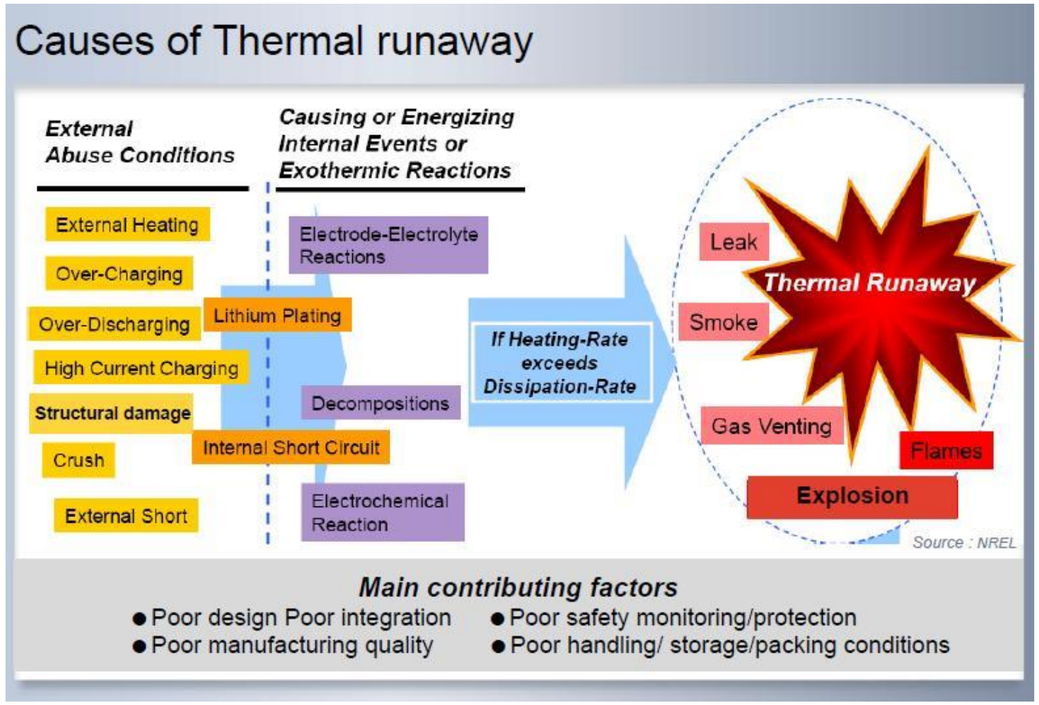
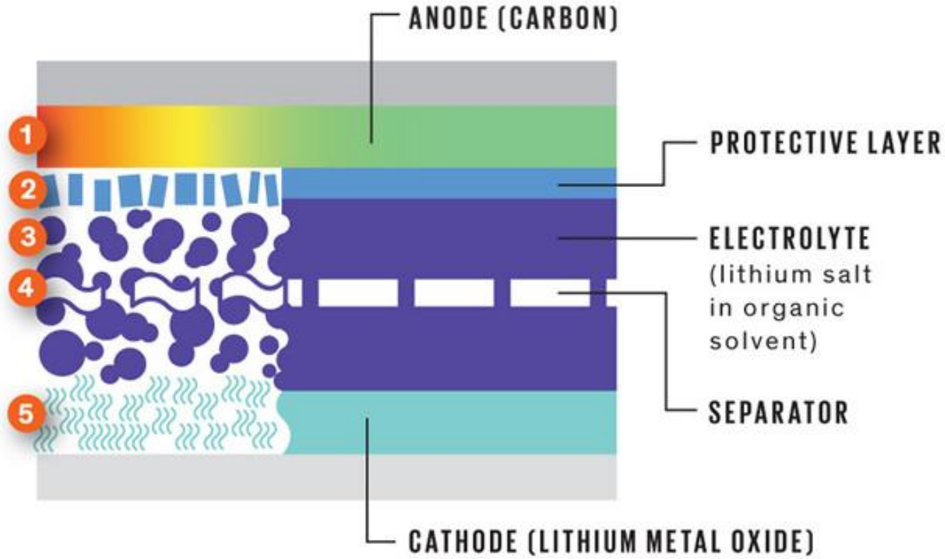
Other battery characteristics

Temperature problems (thermal run away in lithium ion batteries)



Thermal Runaway in a Lithium-Ion Battery

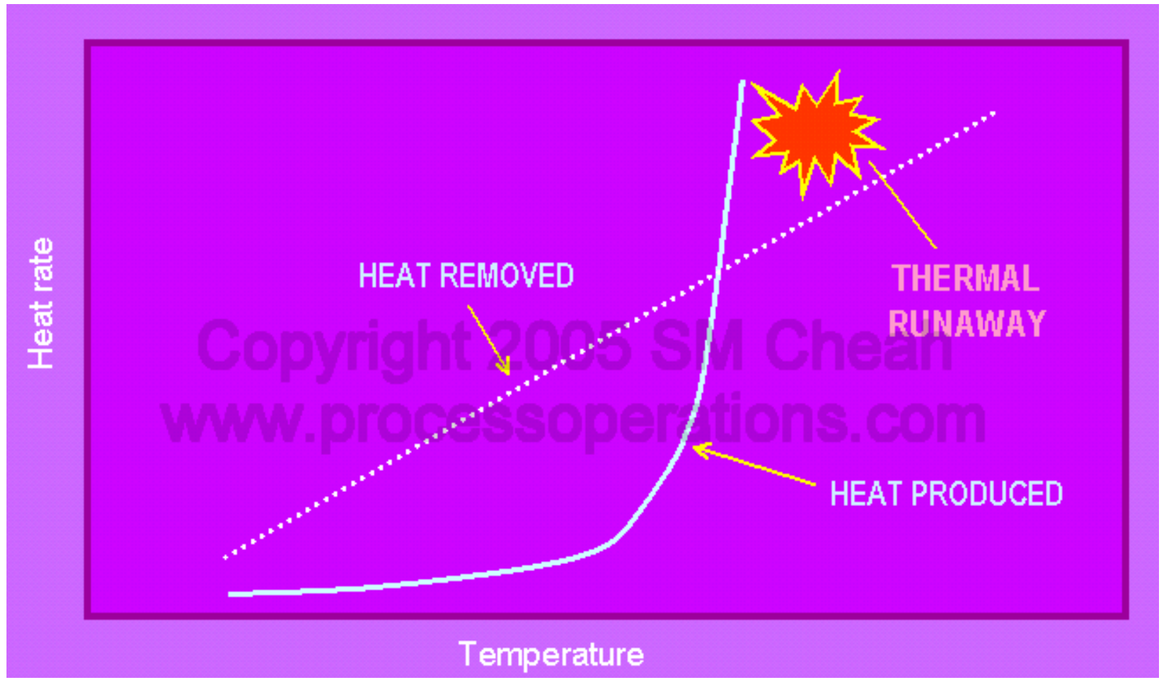
1. Heating starts.
2. Protective layer breaks down.
3. Electrolyte breaks down into flammable gases.
4. Separator melts, possibly causing a short circuit.
5. Cathode breaks down, generating oxygen.

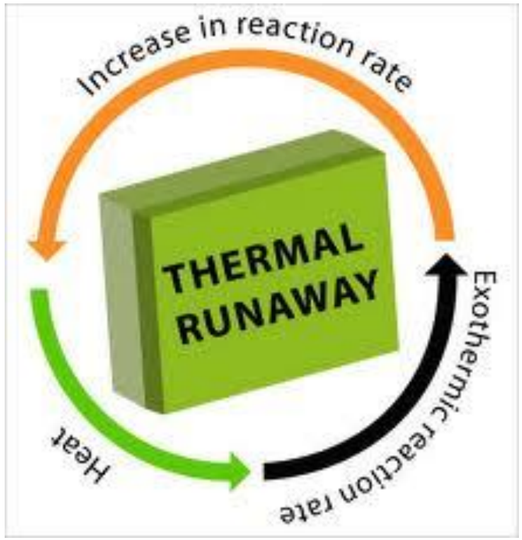


Battery Basic – Other Characteristics

Other battery characteristics

Temperature problems (thermal run away in lead acid batteries). VRLA vs Flooded





Battery Basic – Other Characteristics

Other battery characteristics

SoC SoH SoF

Internal Resistance (impedance)

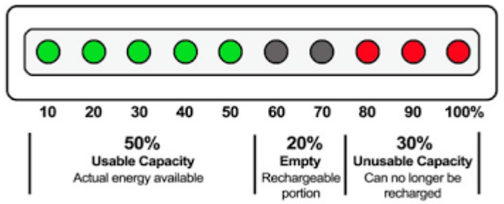
State of Function

State of Charge

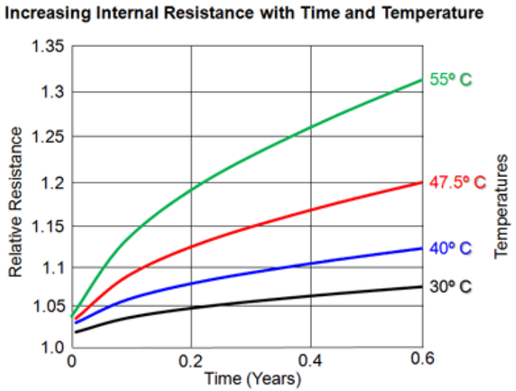
Battery State of Charge

Voltage	State of Charge
12.6+	100%
12.5	90%
12.42	80%
12.32	70%
12.20	60%
12.06	50%
11.9	40%
11.75	30%
11.58	20%
11.31	10%
10.5	0%

State of Health

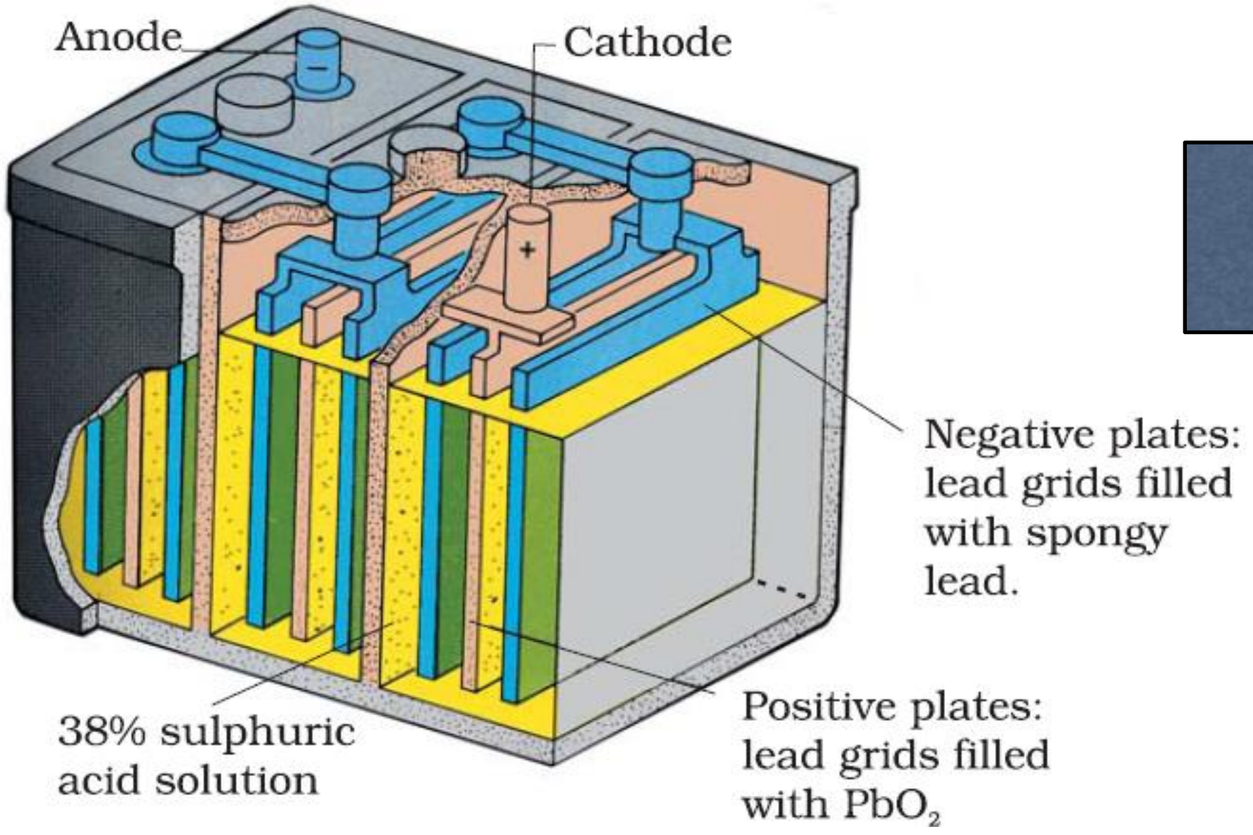


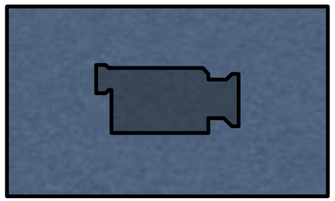
Internal resistance



General Construction Characteristics

Lead acid construction characteristics





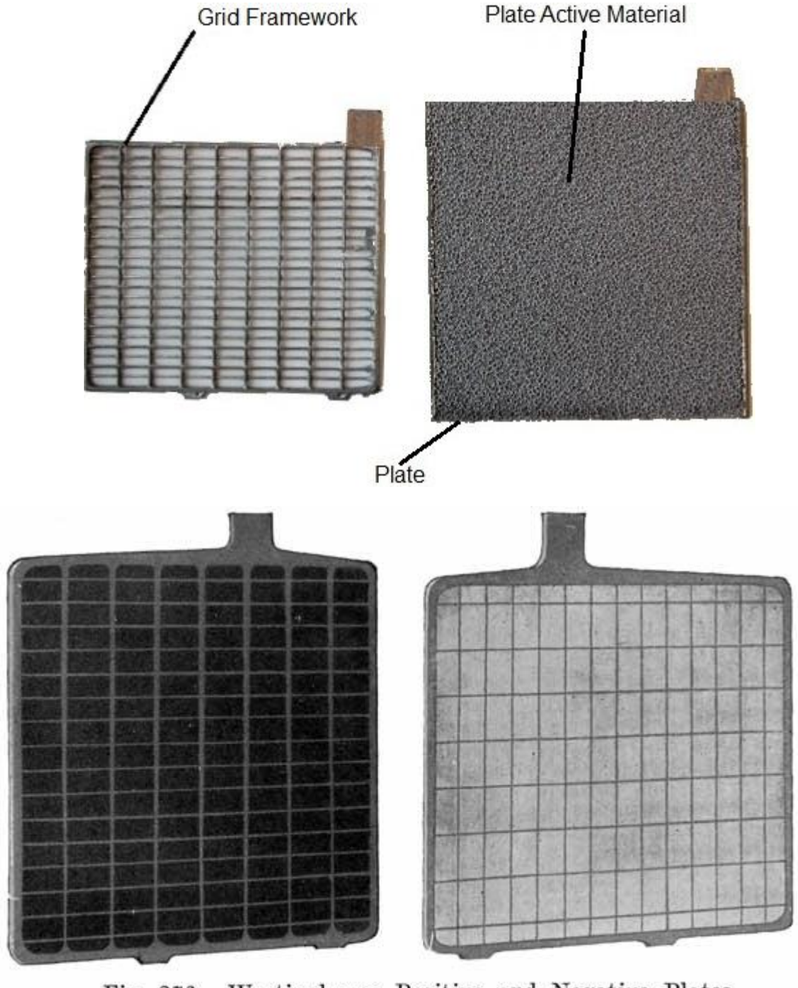
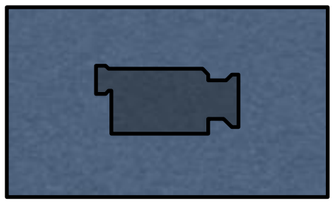
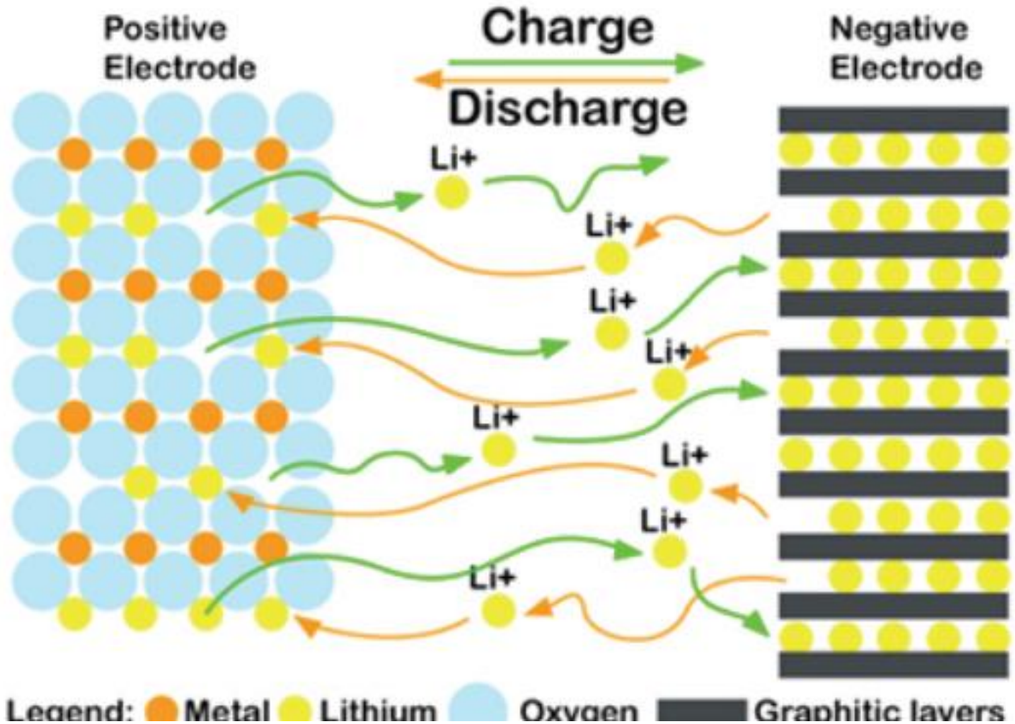


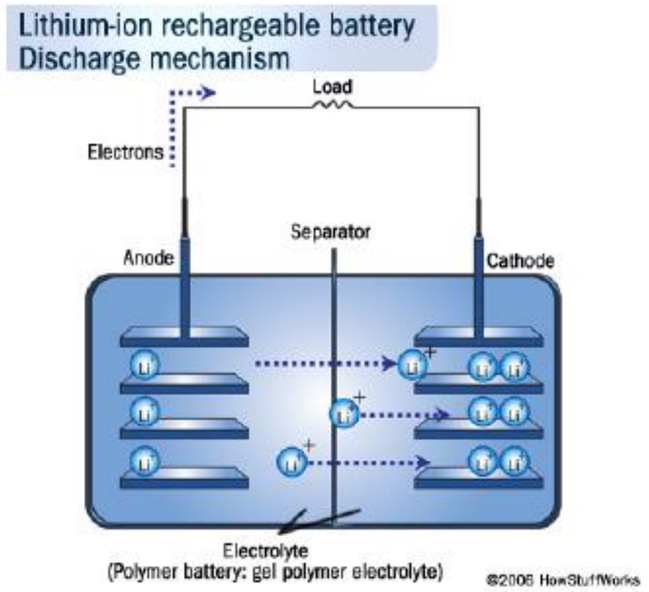
Fig. 276. Westinghouse Positive and Negative Plates

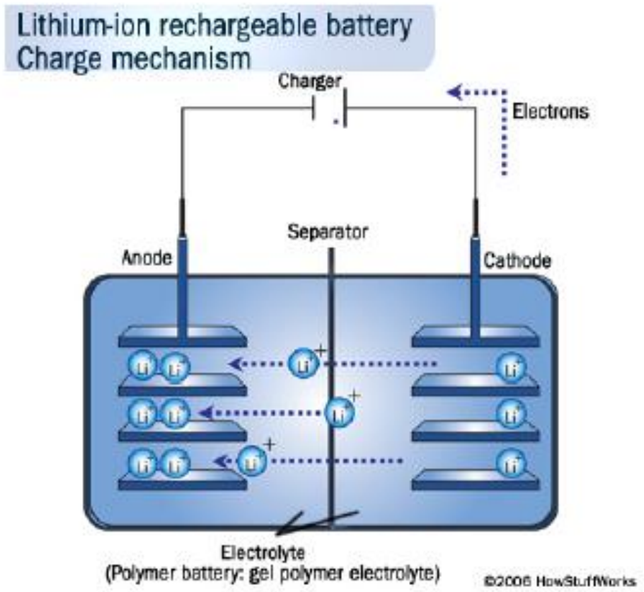
General Construction Characteristics

Lithium ion battery construction characteristics







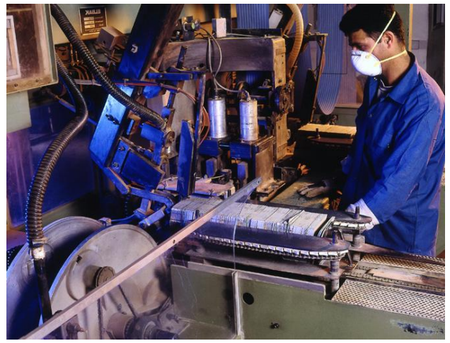


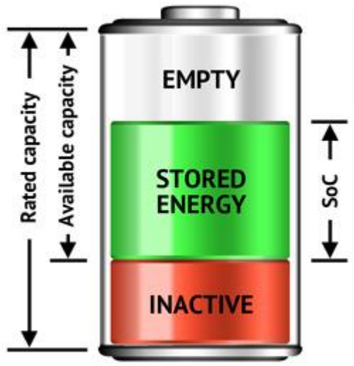
Battery Failure Mechanisms

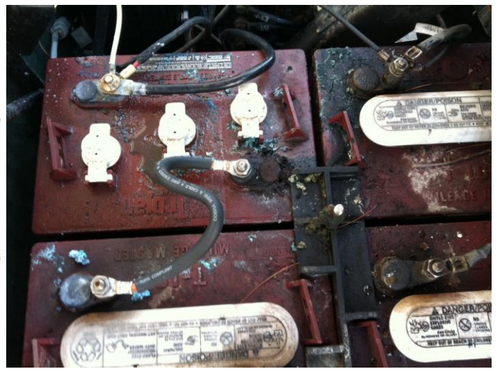
Why batteries fail

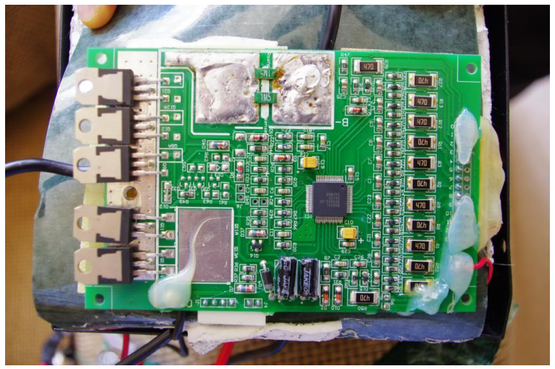
Batteries with different cell chemistries or constructions may fail in different ways.
Let outline some of the most common cell failures for lead acid and lithium ion batteries.

Cell design faults
Manufacturing processes out of control
Aging
Uncontrolled operation conditions (High temperature, etc.)
Abuse (Dropping, penetration, etc.)
External factors (BMS failure, sensor failures, etc.)





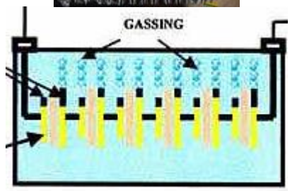


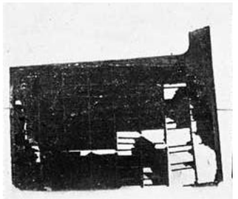


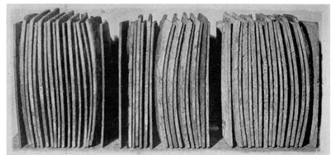
Lead Acid Battery Failure Mechanisms

Aging

- Sulfatation
- Drying
- Active material drop
- Corrosion
- Short circuit (due to growth)







Lithium ion Battery Failure Mechanisms

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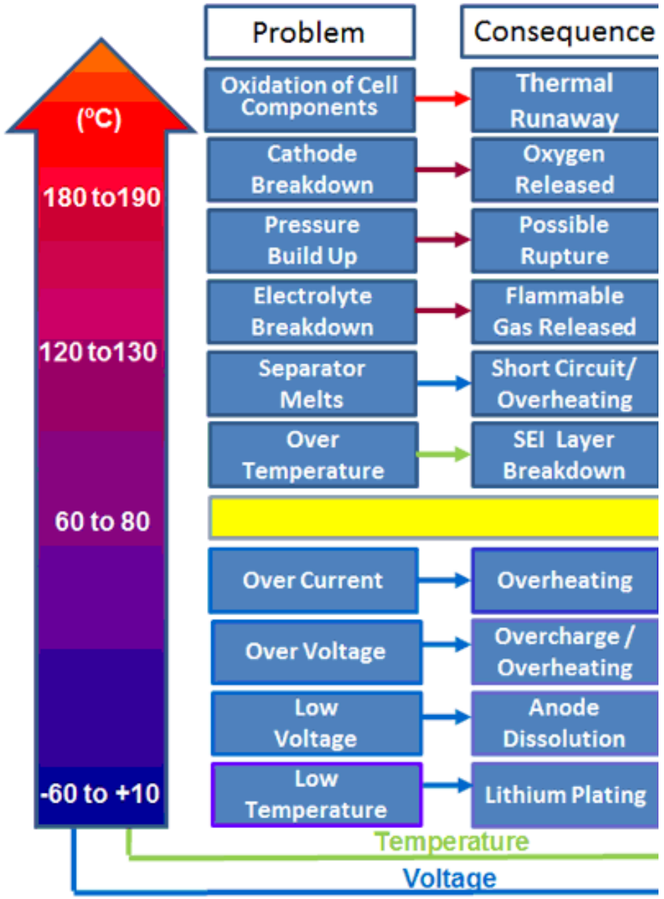
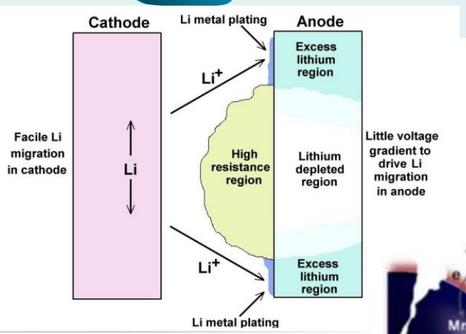
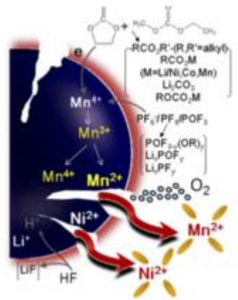
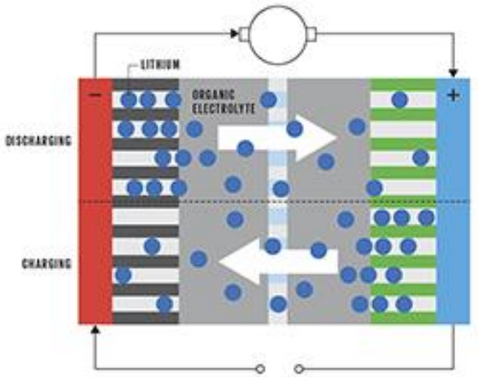
Li-ion battery aging

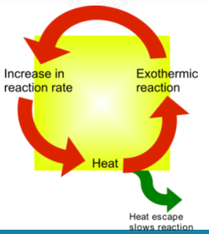


- Lithium plating
- Electrolyte decomposition
- Electrode breakdown
- Short circuit
- Thermal runaway









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THANK YOU