Batteries

DSE-III

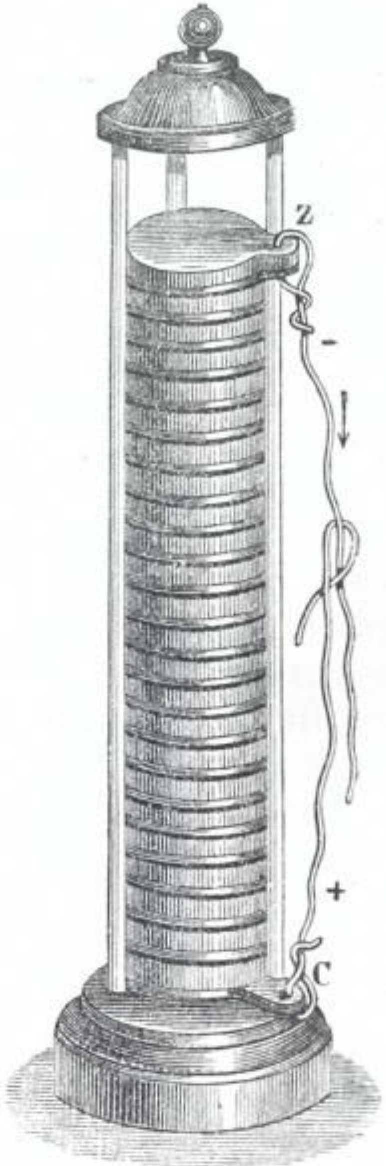
NNSC,
B. J. SAIKIA

Syllabus

Primary and secondary batteries,
battery components and their role, Characteristics of Battery.
Working of following batteries: Pb acid, Li-Battery,
Solid state electrolyte battery. Fuel cells, Solar cell and polymer cell.

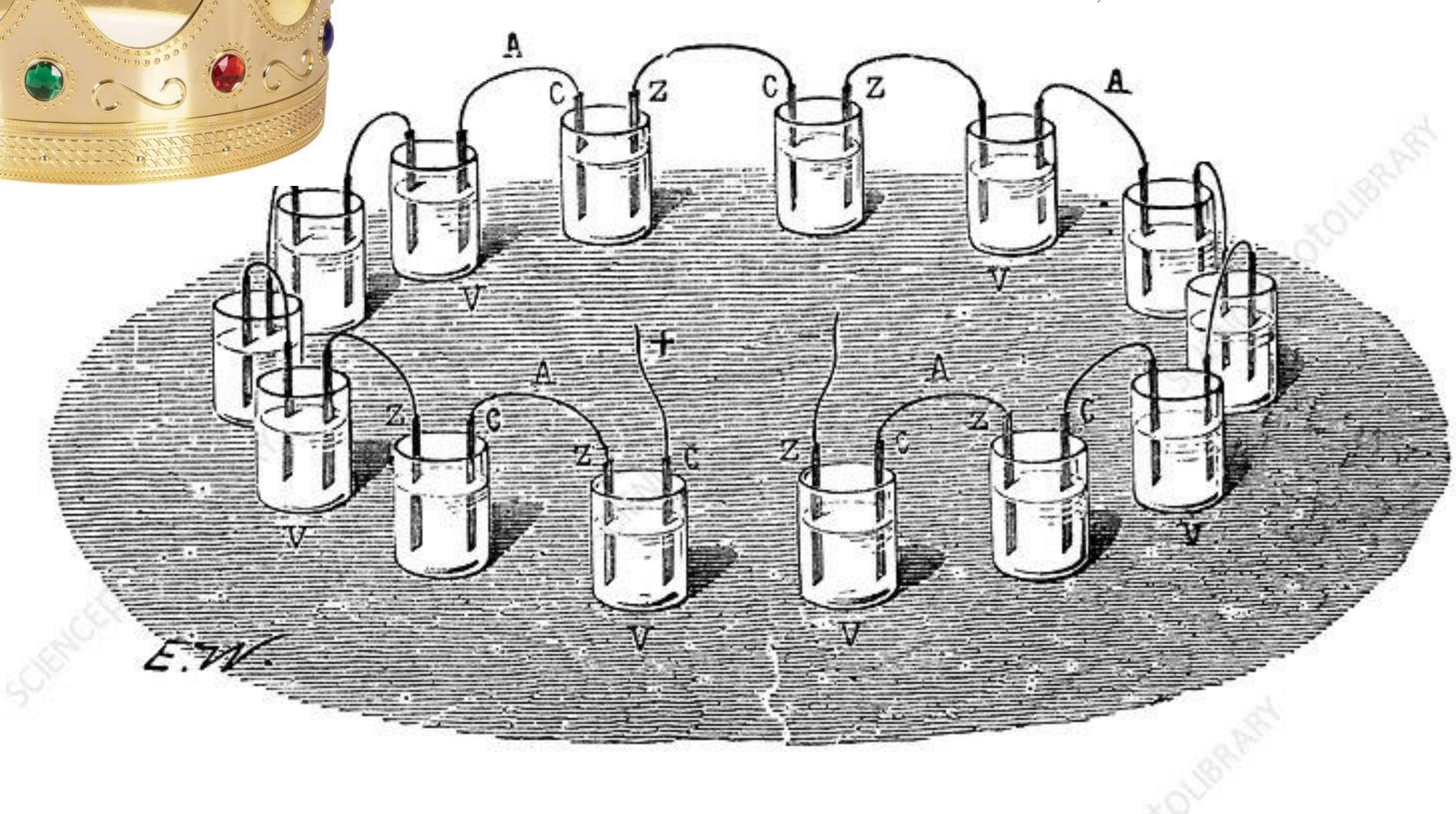

Repco
BESCO
EXTRA HEAVY DUTY
SUPERCHARGE
GOLD
36 Series
POWER
CHARGE
HEAVY DUTY LOW MAINTE
REID

Batteries provided the main source of electricity before the development of electric generators and electrical grids around the end of the 19th century. Successive improvements in battery technology facilitated major electrical advances, from early scientific studies to the rise of telegraphs and telephones, eventually leading to portable computers, mobile phones, electric cars, and many other electrical devices.



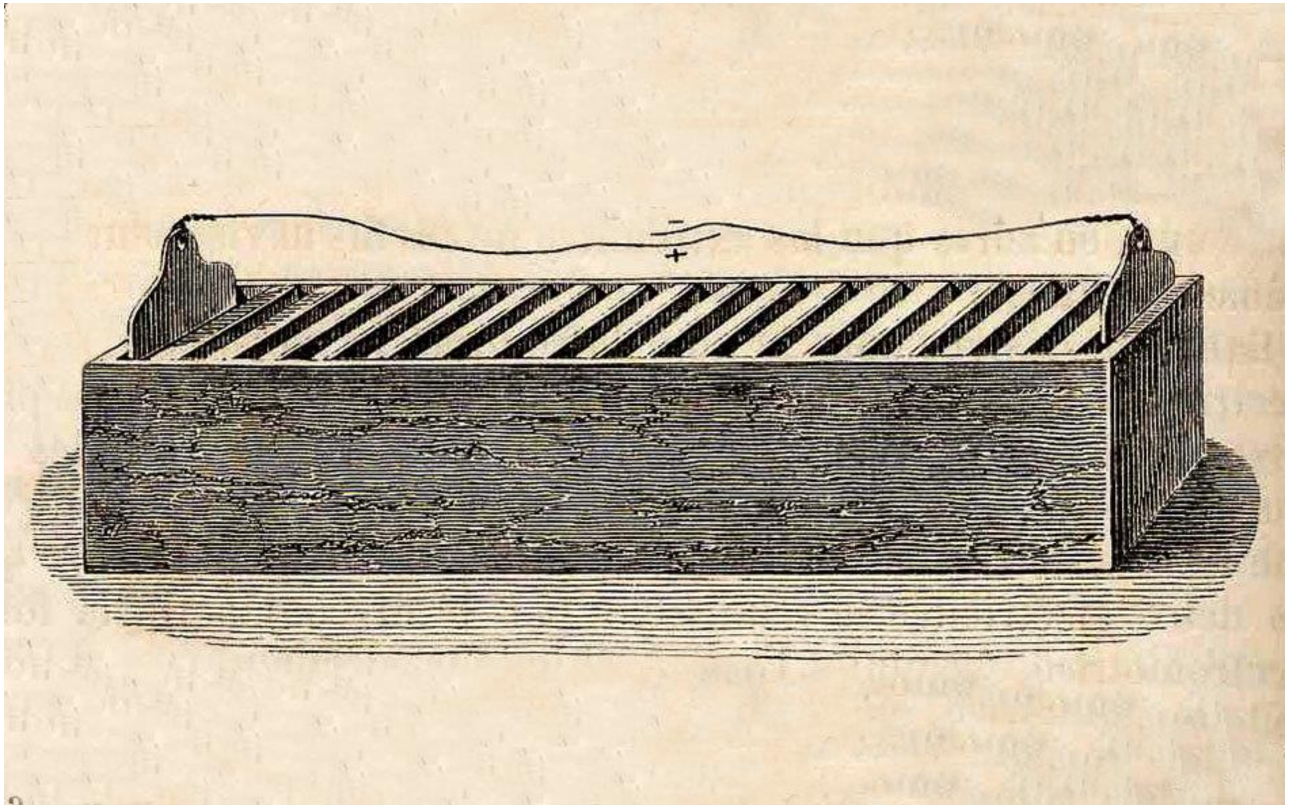
The Italian inventor Alessandro Volta invented the first battery in 1799. Volta's battery was called a "pile" and was a stack (or pile) of discs made of two types of metal—one copper, the other zinc. The discs were separated from each other by a piece of cloth or cardboard that had been soaked in salt water. Volta found that this wet stack of "dissimilar metals" created a small electric current, and this current could be drawn off through wires and used for experiments. However, a pile could generate only a small voltage of 1-2 volts. Several piles—a "battery" of them—could be assembled side by side and connected to each other with metal strips to create a high power energy source. Volta gave his name to units of electrical energy, the "volt."

Volta's original pile models had some technical flaws, one of them involving the electrolyte leaking and causing short-circuits due to the weight of the discs compressing the brine-soaked cloth. Volta himself invented a variant that consisted of a chain of cups filled with a salt solution, linked together by metallic arcs dipped into the liquid. This was known as the Crown of Cups. These arcs were made of two different metals (e.g., zinc and copper) soldered together. This model also proved to be more efficient than his original piles, though it did not prove as popular



Volta's 'Crown of Cups' battery. Historical illustration of a version of the 'Crown of Cups' battery described in 1800 by Italian physicist Alessandro Volta (1745-1827). This device consists of a series of containers (cells) holding brine and electrodes consisting of plates of zinc (Z) and copper (C, sometimes silver). Metal hoops (A) connect the cells in a series. When the ends are connected (centre), electricity flows.

A Scotsman named William Cruickshank also solved this problem by laying the elements in a box instead of piling them in a stack. This was known as the trough battery



Problem with Volta's batteries:

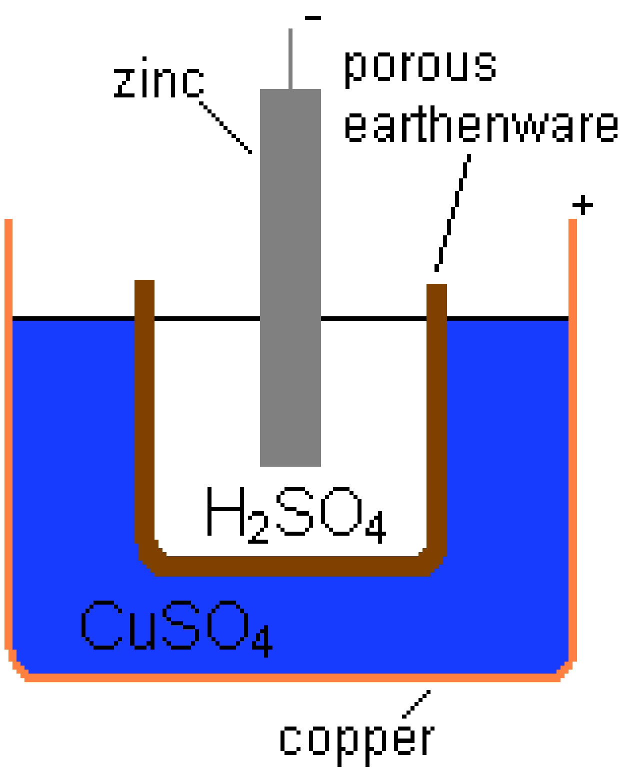
Short battery life

Caused by :

1. The first was that the current produced electrolyzed the electrolyte solution, resulting in a film of hydrogen bubbles forming on the copper, which steadily increased the internal resistance of the battery

2. local action, wherein minute short-circuits would form around impurities in the zinc, causing the zinc to degrade.

John Frederic Daniell found a way to solve the hydrogen bubble problem in the Voltaic Pile by using a second electrolyte to consume the hydrogen produced by the first. In 1836, he invented the Daniell cell, which consists of a copper pot filled with a copper sulfate solution, in which is immersed an unglazed earthenware container filled with sulfuric acid and a zinc electrode. The earthenware barrier is porous, which allows ions to pass through but keeps the solutions from mixing.



Schematic representation of Daniell's original cell

"Battery is a device that constitutes two or more number of galvanic cells connected in series or parallel or both which convert chemical energy into electrical energy through electrochemical reaction."

Or

The arrangement of two or more cells normally coupled in series to produce higher potential is called battery. Example: Lead – Acid Battery, Nickel – cadmium battery, etc.

Historically the term "battery" specifically referred to a device composed of multiple cells; however, the usage has evolved to include devices composed of a single cell.


NOKIA
BL-5C


EVEREADY
HEAVY DUTY LEAKPROOF


Panasonic
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Made in Japan
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ALKALICELL
POWER
SUPER ALKALINE
BATTERY
1604A 9V
GP

CLASSIFICATION OF BATTERIES

- Electrochemical cells or batteries are identified as primary (non-rechargeable) or secondary (rechargeable) depending on their capability of being electrically recharged. The batteries are classified as:
- 1. Primary batteries (non-rechargeable)
- 2. Secondary batteries (chargeable)
- 3.Fuel cell or flow batteries

Primary Batteries

- These are not rechargeable batteries, because the cell reactions are irreversible, i.e., when most of the reactant parts have been converted to products, no more electricity is produced and the battery becomes dead and are to be discarded after the use. Such batteries are called primary batteries.
- Example: Zn–MnO_2, Li–MnO_2, etc.

Secondary Batteries

- These are rechargeable batteries, because the cell reaction are reversible. They are also called storage batteries, as they are the storage devices for electrical energy. The discharged cell can be recharged by passing current through it in the direction opposite to that of discharge current.
- Example: Lead – Acid Battery, Mi–Cd battery, etc.

Primary Batteries

I. Primary Batteries (or) Primary Cells :-

Primary cells are those cells in which the chemical reaction occurs only once and the cell becomes dead after sometime and it cannot be used again. These batteries are used as source of dc power.

Eg. Dry cell (Leclanche Cell) and Mercury cell,lithium cell.

Requirements of Primary cell:

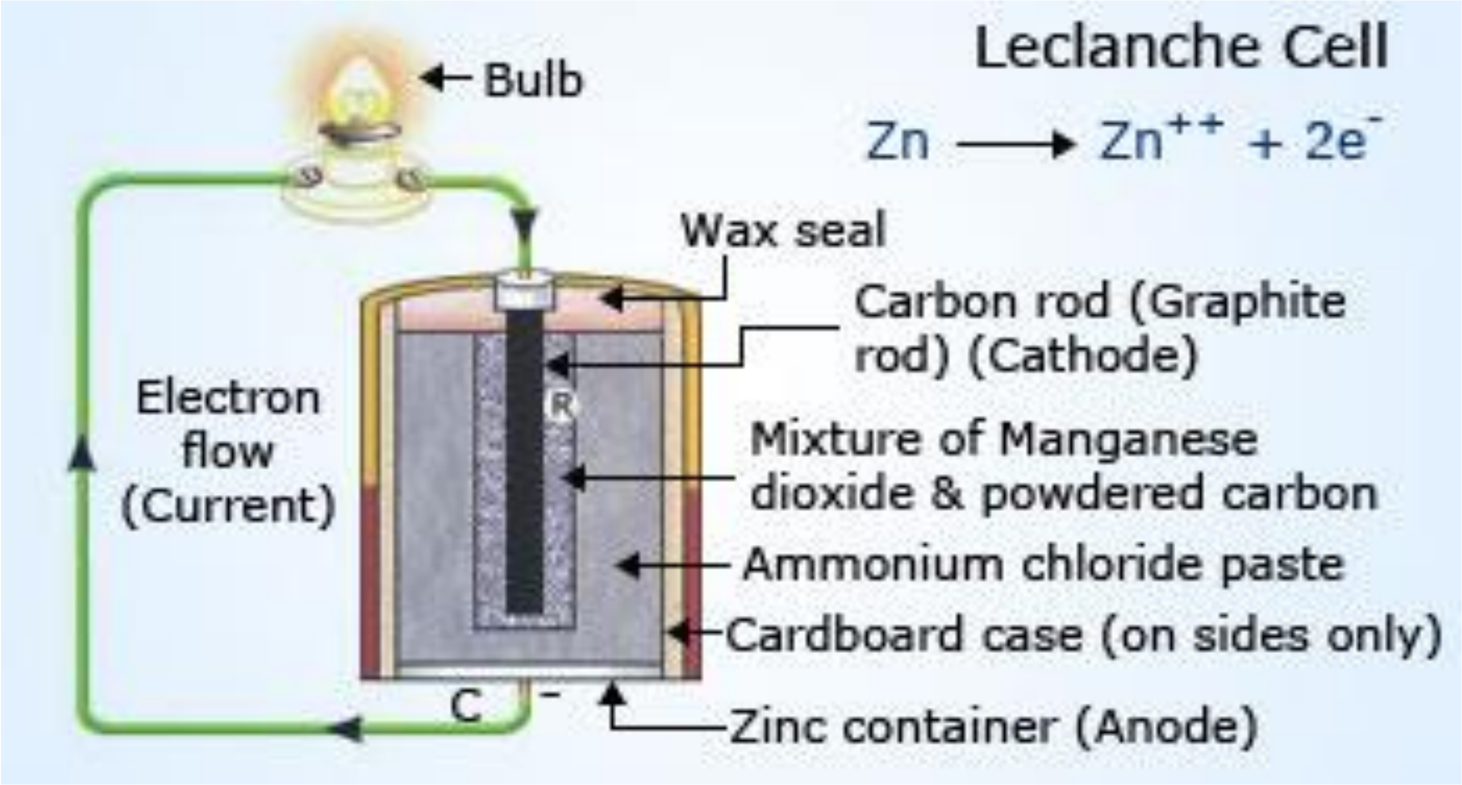
It should satisfy these requirements

1) It must be convenient to use.
2) Cost of discharge should be low.
3) Stand-by power is desirable.

Dry cell (Leclanche Cell)

It consists of a cylindrical Zinc container that acts as an anode. A graphite rod placed in the centre (but not touching the base) acts as a cathode. The space between anode and cathode is packed with the paste of NH4Cl and ZnCl2 and the graphite rod is surrounded by powdered MnO2 and carbon as shown in Figure. The cell is called dry cell because of the absence of any liquid phase, even the electrolyte consists of NH4Cl ,ZnCl2 and MnO2 to which starch is added to make a thick paste which prevents leakage. The graphite rod is fitted with a metal cap and the cylinder is sealed at the top with a pitch.

Laclanche cell (Dry cell)



Anode: Zinc container
Cathode: Graphite rod
Electrolyte: NH_4Cl+ $ZnCl_2$+MnO_2 (Moist)

The redox reaction in a Leclanché cell involves the two following half-reactions:

- anode $Zn \rightarrow Zn^{2+} + 2e^-$
- cathode $2\ MnO_2 + 2NH_4^+ + 2e^- \rightarrow 2\ Mn_2O_3 + 2\ NH_3 + H_2O$

The ammonia, forms a complex ion with Zn2+, from ZnCl2
: $Zn^{2+} (aq) + 2NH_3 (aq) + 2Cl^- (aq) \rightarrow Zn(NH_3)_2Cl_2(s)$

Overall Cell reaction:

$2MnO_2 (s) + 2NH_4Cl(aq) + Zn(s) \rightarrow Zn(NH_3)_2Cl_2(s) + H_2O (l) + Mn_2O_3(s)$

Ecell = 1.5 V

NB: The term "depolarizer" has been used to denote a substance used in a primary cell to prevent a buildup of hydrogen gas bubbles. A battery depolarizer takes up electrons during discharge of the cell; therefore, it is always an oxidizing agent. Manganese dioxide, used in the Dry cell as a depolarizer. Since MnO_2 is a very poor conductor, charcoal is added to increase the conductivity

Limitations:

- Internal resistance of the cell is high
- Cell can not supply continuous current for long time but is used only for intermittence use.
- At high current drain, $NH_3(g)$ builds up causing drop in voltage,
- Short shelf life because zinc anode reacts with the acidic NH4 $^{+}$ ions.
- $Zn \rightarrow Zn^{2+} + 2e^-$
- $2NH_4^+ + 2e^- \rightarrow 2\ NH_3$ (internal circuit)

Advantages:

1) These cells have voltage ranging from 1.25v to 1.50v.
2) Primary cells are used in the torches,radios,transistors,hearing aids,pacemakers,watches etc.
3) Price is low.

Disadvantages:

These cells does not have a long life, because the acidic NH4Cl corrodes the container even when the cell is not in use.

Polarization is not the only disadvantage of a dry cell; these batteries tend to have poor shelf life because the zinc anode will slowly react with ammonium ions even when not connected to an external circuit. Storing a dry cell in a refrigerator will decrease the rate of this reaction and extend the shelf life of the battery significantly.

An **alkaline battery** is a type of primary battery that derives its energy from the reaction between zinc metal and manganese dioxide.

In an alkaline battery, the negative electrode is zinc and the positive electrode is manganese dioxide (MnO_2). The alkaline electrolyte of potassium hydroxide is not consumed during the reaction, only the zinc and MnO_2 are consumed during discharge. The alkaline electrolyte of potassium hydroxide remains, as there are equal amounts of OH^- consumed and produced.

The half-reactions are:

$$Zn_{(s)} + 2OH^-_{(aq)} \rightarrow ZnO_{(s)} + H_2O_{(l)} + 2e^- \ [E_{oxidation}° = -1.28 \text{ V}]$$

$$2MnO_{2(s)} + H_2O_{(l)} + 2e^- \rightarrow Mn_2O_{3(s)} + 2OH^-_{(aq)} \ [E_{reduction}° = +0.15 \text{ V}]$$

Overall reaction:

$$Zn_{(s)} + 2MnO_{2(s)} \rightleftharpoons ZnO_{(s)} + Mn_2O_{3(s)} \ [e° = +1.43 \text{ V}]$$

Comparison Table Between Zinc and Alkaline

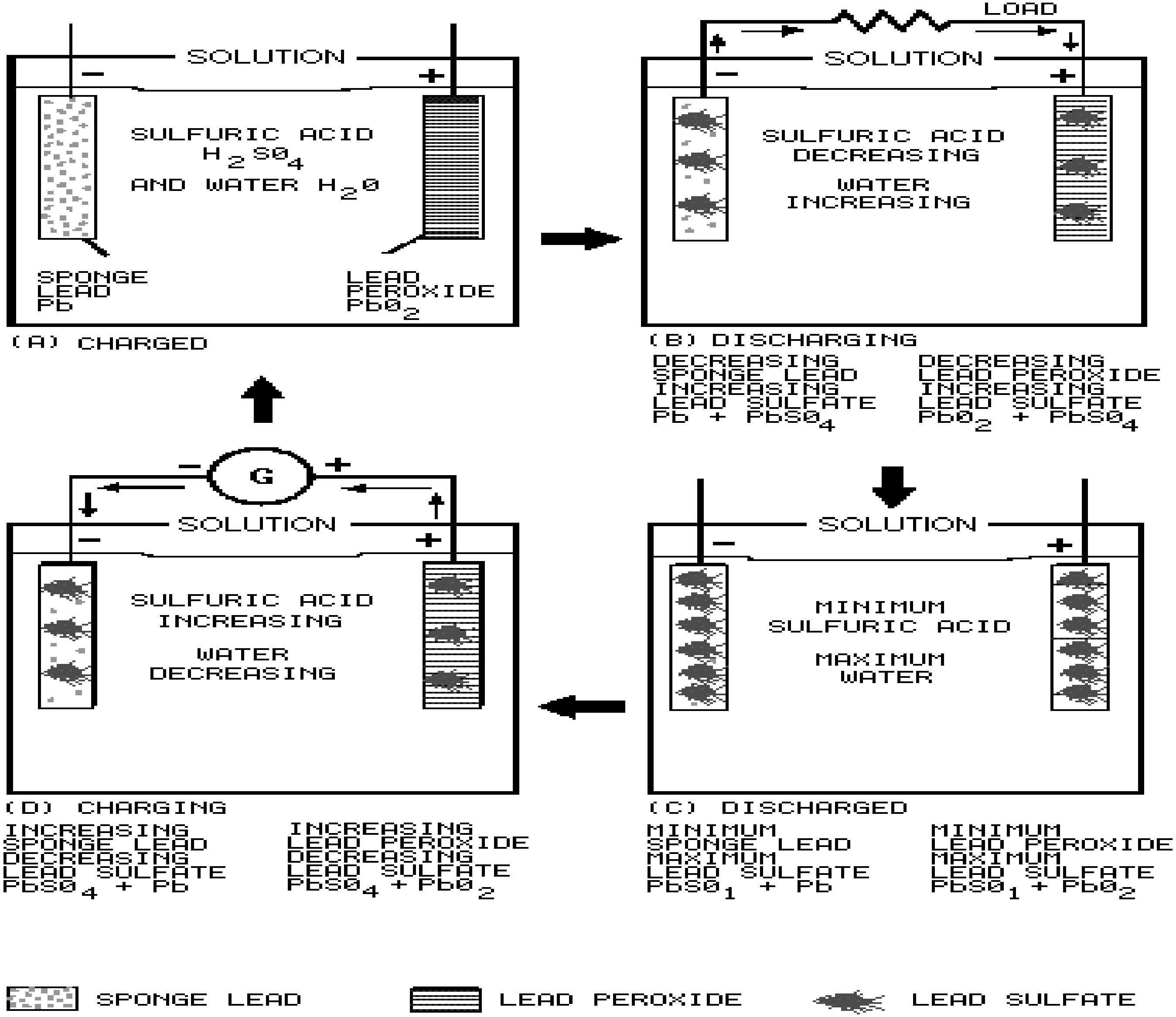
Parameters of Comparison	Zinc	Alkaline
Acidic use	The acidic electrolyte is used in zinc batteries.	While in alkaline batteries, a basic electrolyte is used.
Capacity	Zinc batteries have a much lower capacity.	Alkaline batteries have a higher capacity.
Use of can	The anode of the zinc battery is the can which is one of its crucial parts.	Alkaline batteries use zinc powder and that too, which is within the can.
Shelf life	The shelf life of zinc batteries is lower.	The shelf life of alkaline batteries is longer as compared to zinc batteries
Leakages	Zinc batteries are prone to some leakage.	Alkaline batteries are developed with the anti-leak technology, so it does not leak at all.

NB: Shelf life: The length of time a product may be stored without becoming unsuitable for use or consumption.

Secondary batteries:

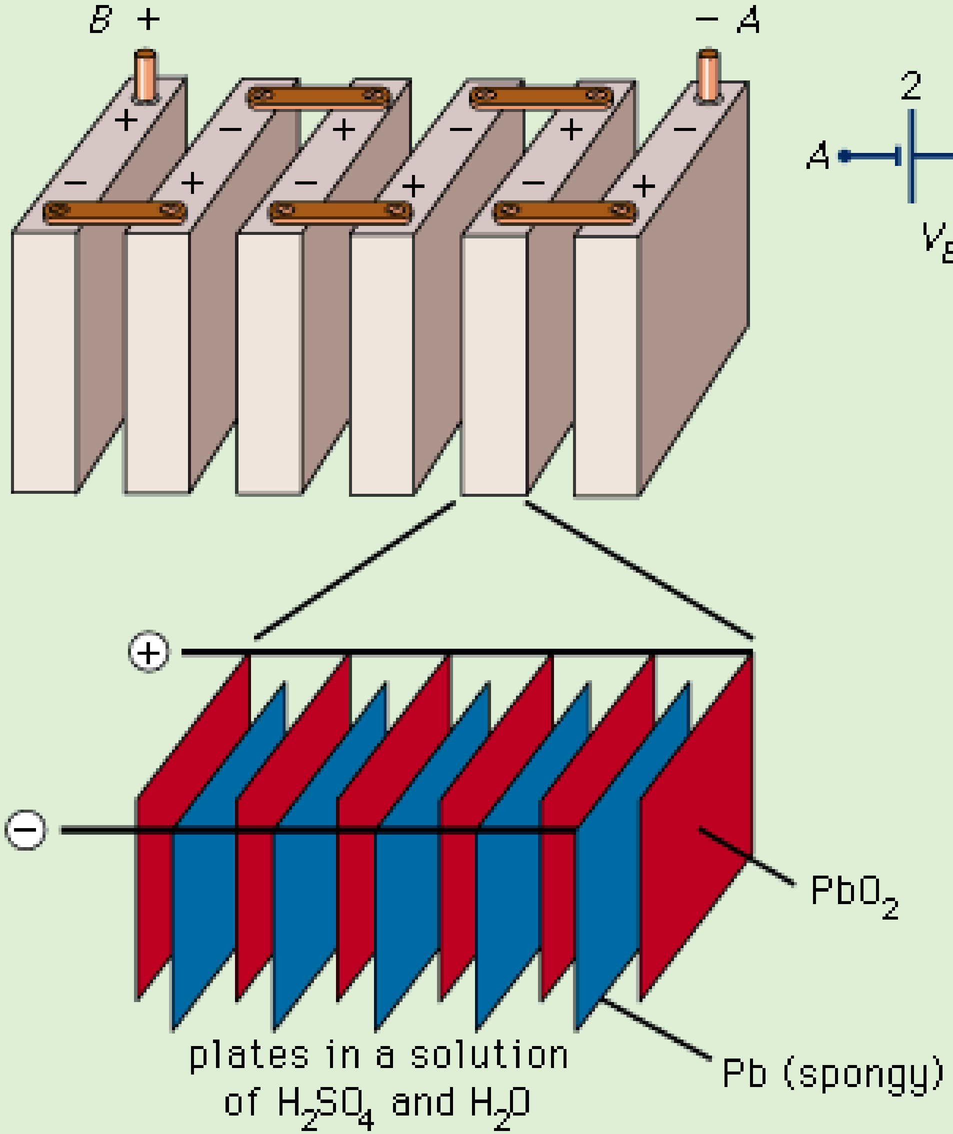
a. Lead storage batteries:

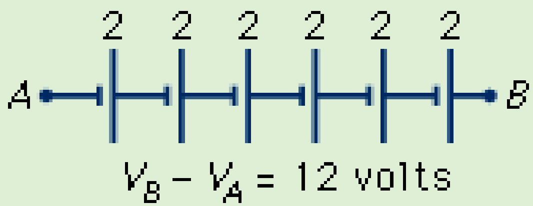
Lea


SOLUTION
SULFURIC ACID
H2SO4
AND WATER H2O
SPONGE
LEAD
Pb
LEAD
PEROXIDE
PbO2
(A) CHARGED
LOAD
SOLUTION
SULFURIC ACID
DECREASING
WATER
INCREASING
(B) DISCHARGING
DECREASING
SPONGE LEAD
INCREASING
LEAD SULFATE
Pb + PbSO4
DECREASING
LEAD PEROXIDE
INCREASING
LEAD SULFATE
PbO2 + PbSO4
G
SOLUTION
SULFURIC ACID
INCREASING
WATER
DECREASING
(D) CHARGING
INCREASING
SPONGE LEAD
DECREASING
LEAD SULFATE
PbSO4 + Pb
INCREASING
LEAD PEROXIDE
DECREASING
LEAD SULFATE
PbSO4 + PbO2
SOLUTION
MINIMUM
SULFURIC ACID
MAXIMUM
WATER
(C) DISCHARGED
MINIMUM
SPONGE LEAD
MAXIMUM
LEAD SULFATE
PbSO1 + Pb
MINIMUM
LEAD PEROXIDE
MAXIMUM
LEAD SULFATE
PbSO1 + PbO2
SPONGE LEAD
LEAD PEROXIDE
LEAD SULFATE

Sealed Lead Acid Battery

- The sealed lead-acid battery consists of six cells mounted side by side in a single case. The cells are coupled together, and each 2.0V cell adds up to the overall 12.0V capacity of the battery.
- A completely charged lead-acid battery is made up of a stack of alternating lead oxide electrodes and sponge lead (Pb), isolated from each other by layers of porous separators.
- All these parts are placed in a concentrated solution of sulfuric acid.
- Inter cell connectors connect the positive end of one cell to the negative end of the next cell hence the six cells are in series.





A The battery consists of six two-volt cells connected in series.

B Each component cell is composed of several negative and positive electrodes made of pure spongy lead and lead oxide, respectively; the electrodes, connected in parallel, are immersed in a dilute solution of sulfuric acid.

Chemical Reaction for Discharging

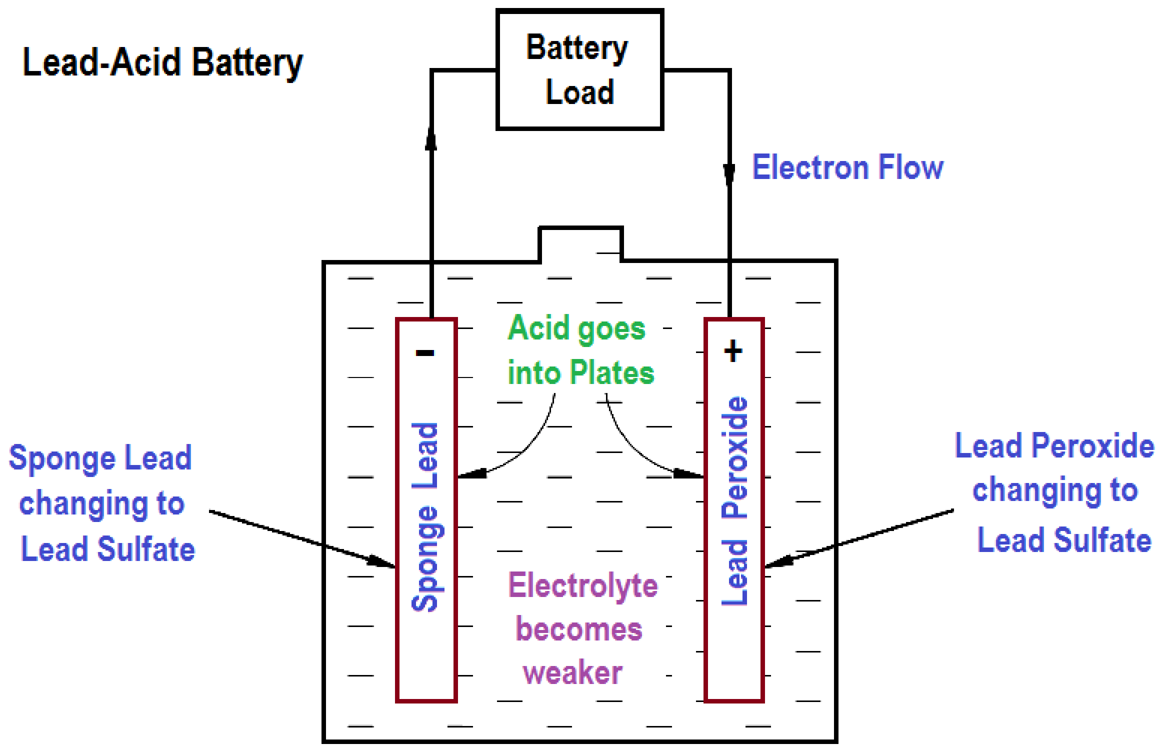
When the battery is discharged, it acts as a galvanic cell and the following chemical reaction occurs.

Negative. (anode/oxidation half cell)

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

Positive. (cathode/ reduction half cell)

$PbO_2(s) + SO_4^{2-}(aq) + 4H^+{}_{(}aq) + 2e^- \rightarrow PbSO_4(s) + 5H_2O(l)$ (reduction)



Chemical Reaction for Recharging

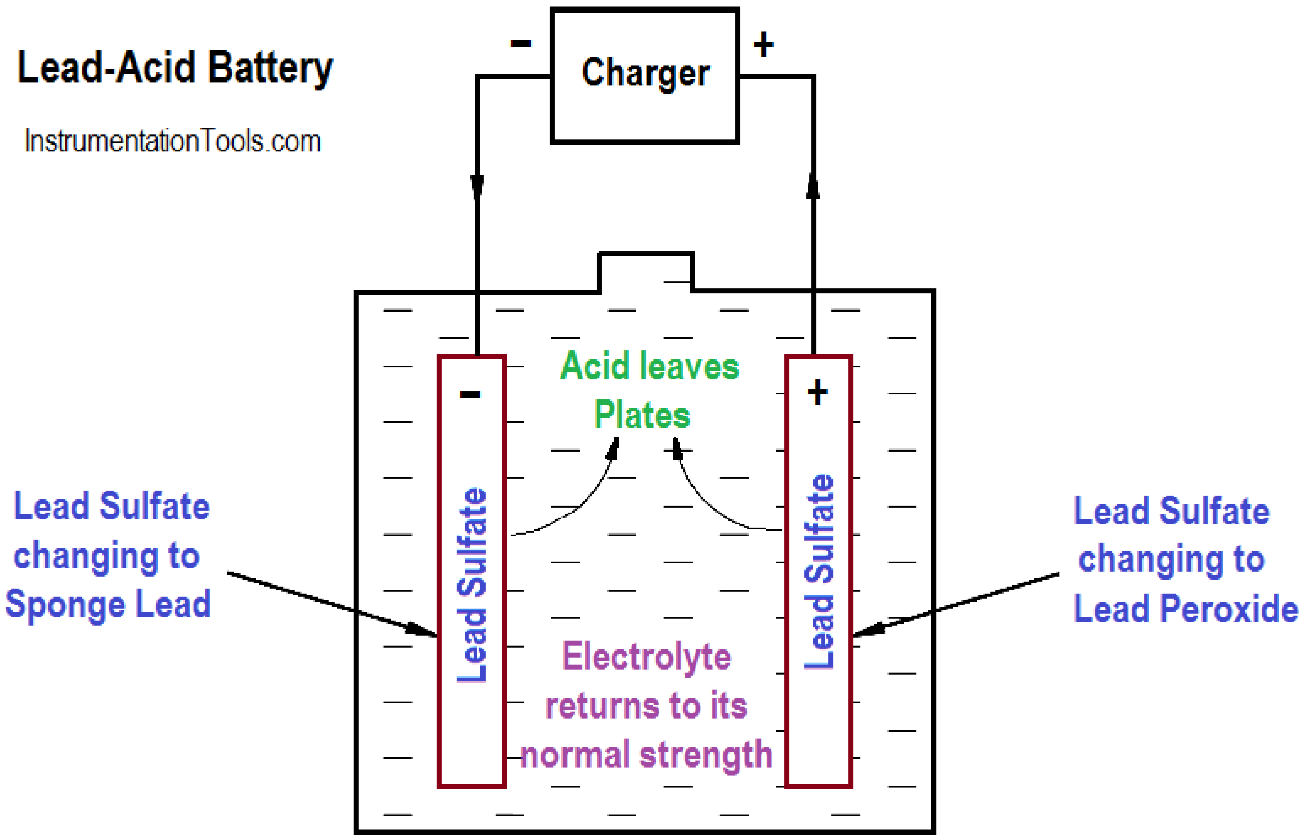
The chemical reaction that takes place when the lead-acid battery is recharging can be found below.

Negative:(reduction/cathode)

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

Positive:(oxidation/anode)

$PbSO_4(s) + 5H_2O(l) \rightarrow PbO_2(s) + H_2SO_4(aq) + 4H^+(aq) + 2e^-$



- While recharging, the automobile battery functions like an electrolytic cell. The energy required to drive the recharging comes from an external source, such as an engine of a car. It is also important to note that overcharging of the battery could result in the formation of by-products such as hydrogen gas and oxygen gas. These gases tend to escape from the battery, resulting in the loss of reactants.

The electrolyte in a lead-acid battery plays a direct role in the chemical reaction. The specific gravity decreases as the battery discharges and increases to its normal, original value as it is charged.

Since specific gravity of a lead-acid battery decreases proportionally during discharge, the value of specific gravity at any given time is an approximate indication of the battery's state of charge.(measured using a hygrometer)

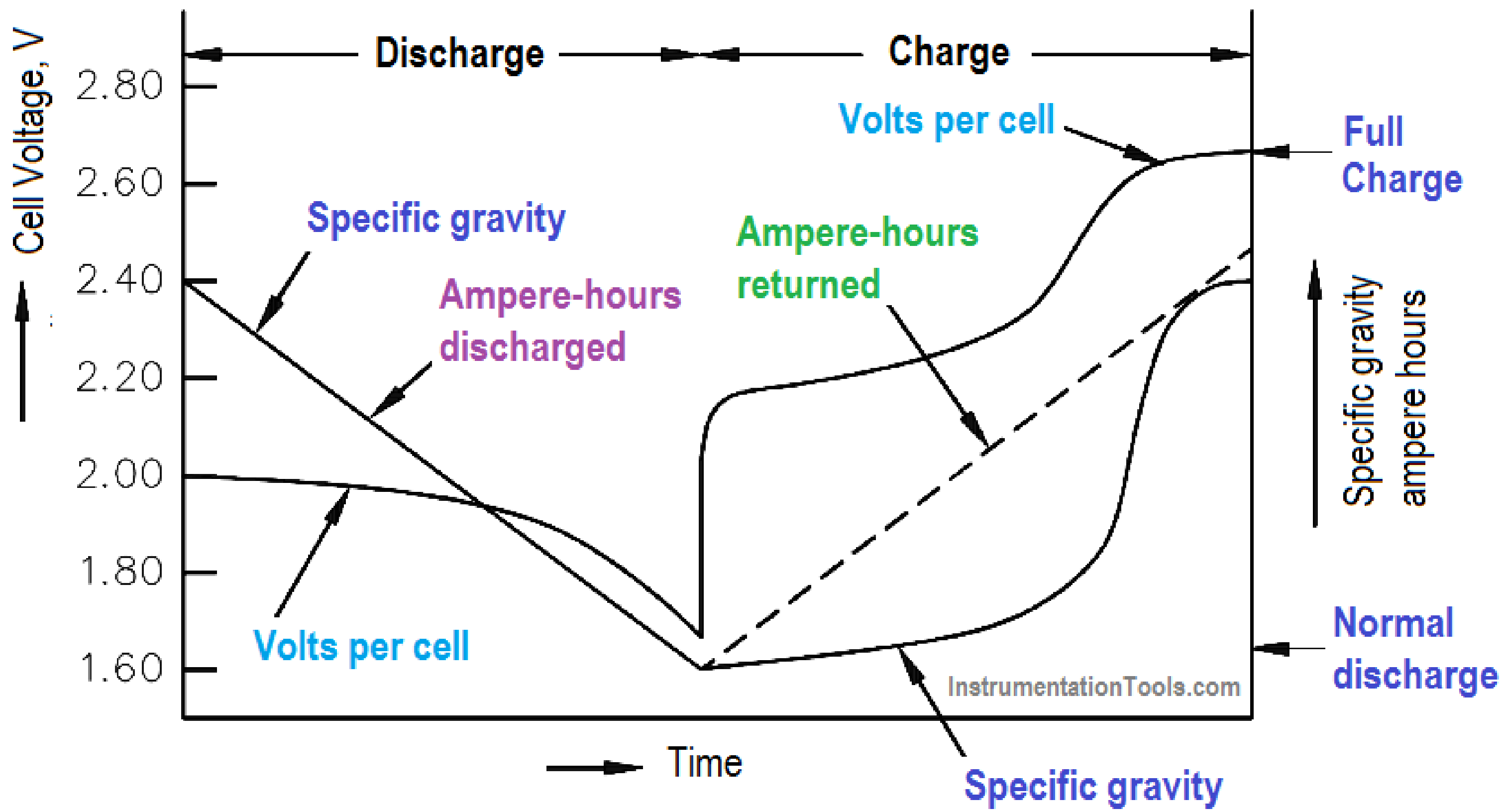


Figure : Voltage and Specific Gravity During Charge and Discharge

- **Discharge Chemistry**
- In the discharged state, both the positive and negative plates become lead(II) sulfate ($PbSO_4$). The electrolyte loses much of its dissolved sulfuric acid and becomes primarily water. The discharge process is driven by the conduction of electrons from the negative plate back into the cell at the positive plate in the external circuit.
- Negative plate reaction: $Pb(s) + HSO_4^-(aq) \rightarrow PbSO_4(s) + H^+(aq) + 2e^-$
- Positive plate reaction: $PbO_2(s) + HSO_4^-(aq) + 3H^+(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l)$
- Combining these two reactions, one can determine the overall reaction:
- $Pb(s) + PbO_2(s) + 2H^+(aq) + 2HSO_4^-(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$
- **Charge Chemistry**
- This type of battery can be recharged. In the charged state, each cell contains negative plates of elemental lead (Pb) and positive plates of lead(IV) oxide (PbO_2) in an electrolyte of approximately 4.2 M sulfuric acid (H_2SO_4). The charging process is driven by the forcible removal of electrons from the positive plate and the forcible introduction of them to the negative plate by the charging source.
- Negative plate reaction: $PbSO_4(s) + H^+(aq) + 2e^- \rightarrow Pb(s) + HSO_4^-(aq)$
- Positive plate reaction: $PbSO_4(s) + 2H_2O(l) \rightarrow PbO_2(s) + HSO_4^-(aq) + 3H^+(aq) + 2e^-$
- Combining these two reactions, the overall reaction is the reverse of the discharge reaction:
- $2PbSO_4(s) + 2H_2O(l) \rightarrow Pb(s) + PbO_2(s) + 2H^+(aq) + 2HSO_4^-(aq)$
- Notice how the charging reaction is the exact opposite of the discharge reaction.

During discharging:

1. Both of the plates are covered with PbSO4.
2. Specific gravity of sulfuric acid solution falls during reaction at PbO_2 plate due to formation of water
3. As a result, the rate of reaction falls which implies the potential difference between the plates decreases during discharging process.

During charging:

1. Lead sulfate anode gets converted into lead peroxide.
2. Lead sulfate of cathode is converted to pure lead.
3. Terminal potential of the cell increases.
4. Specific gravity of sulfuric acid increases.

The decrease in specific gravity on discharge is proportional to the ampere-hours discharged. While charging a lead-acid battery, the rise in specific gravity is not uniform, or proportional, to the amount of ampere-hours charged

Example:

A lead-acid battery reads 1.175 specific gravity. Its average full charge specific gravity is 1.260 and has a normal gravity drop of 120 points (or.120) at an 8 hour discharge rate.

Solution:

Fully charged – 1.260

Present charge – 1.175

The battery is 85 points below its fully charged state. It is therefore about 85/120, or 71%, discharged.

Battery components and their role

Cells are comprised of 3 essential components:

The **Anode**

It is the negative or reducing electrode that releases **electrons** to the external circuit and oxidizes during and electrochemical reaction.

The **Cathode**

It is the positive or oxidizing electrode that acquires electrons from the external circuit and is reduced during the electrochemical reaction.

The **Electrolyte**

It is the medium that provides the *ion* transport mechanism between the cathode and anode of a cell. Electrolytes are often thought of as liquids, such as water or other solvents, with dissolved salts, *acids*, or *alkalis* that are required for *ionic conduction*. Many batteries including the conventional (AA/AAA/D) batteries however contain solid electrolytes that act as ionic conductors at room temperature.

Anode material should exhibit the following properties

- ✓Efficient reducing agent
- ✓High coulombic output
- ✓Good conductivity
- ✓Stable
- ✓Ease of fabrication
- ✓Low cost
- ✓Metals such as Zinc and Lithium are often used as anode materials.

Cathode material should exhibit the following properties

- Efficient oxidizing agent.
- Stable when in contact with electrolyte
- Useful working voltage
- Ease of fabrication
- Low cost
- Metallic oxides such as are often used as cathode materials

Electrolytes should exhibit the following properties

- Strong ionic conductivity
- No electric conductivity
- Non-reactivity with electrode materials
- Properties resistance to temperature fluctuations
- Safeness in handling
- Low cost
- *Aqueous* solutions such as dissolved salts, acids, and alkalis are often used as electrolytes

- COMPARISON BETWEEN FUEL CELL AND BATTERIES
- Fuel Cell Batteries
- 1. Reactants (fuel and oxidant) are not part of
- the cell they are supplied from outside.
- 2. Do not store chemical energy.
- 3. The electrodes are charged with catalyst.
- 4. The electrodes in some cases are not consumed
- during production of energy.
- 5. Products are continuously removed from a
- fuel cell.
- 6. Produce current on their own.
- 1. All reactants are integral parts of it.
- 2. Store chemical energy.
- 3. The electrodes are not helped with catalyst.
- 4. The electrodes are consumed during
- production of energy.
- 5. Products are not removed.
- 6. Require recharging from external source of
- electric current.

Li-ion Battery

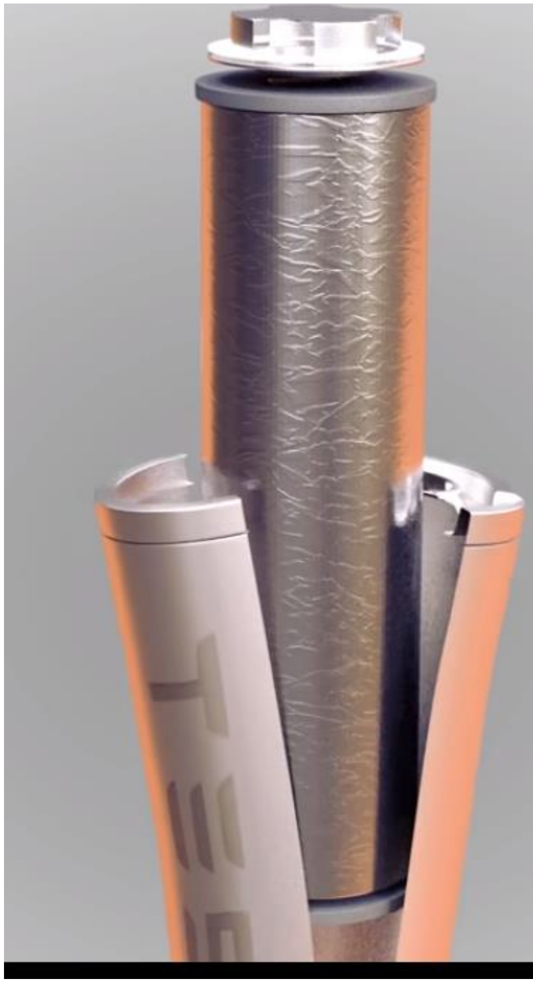
- Lithium-ion batteries have the highest **charge density** of any comparable system. This means they can give you a ton of energy without being very heavy.

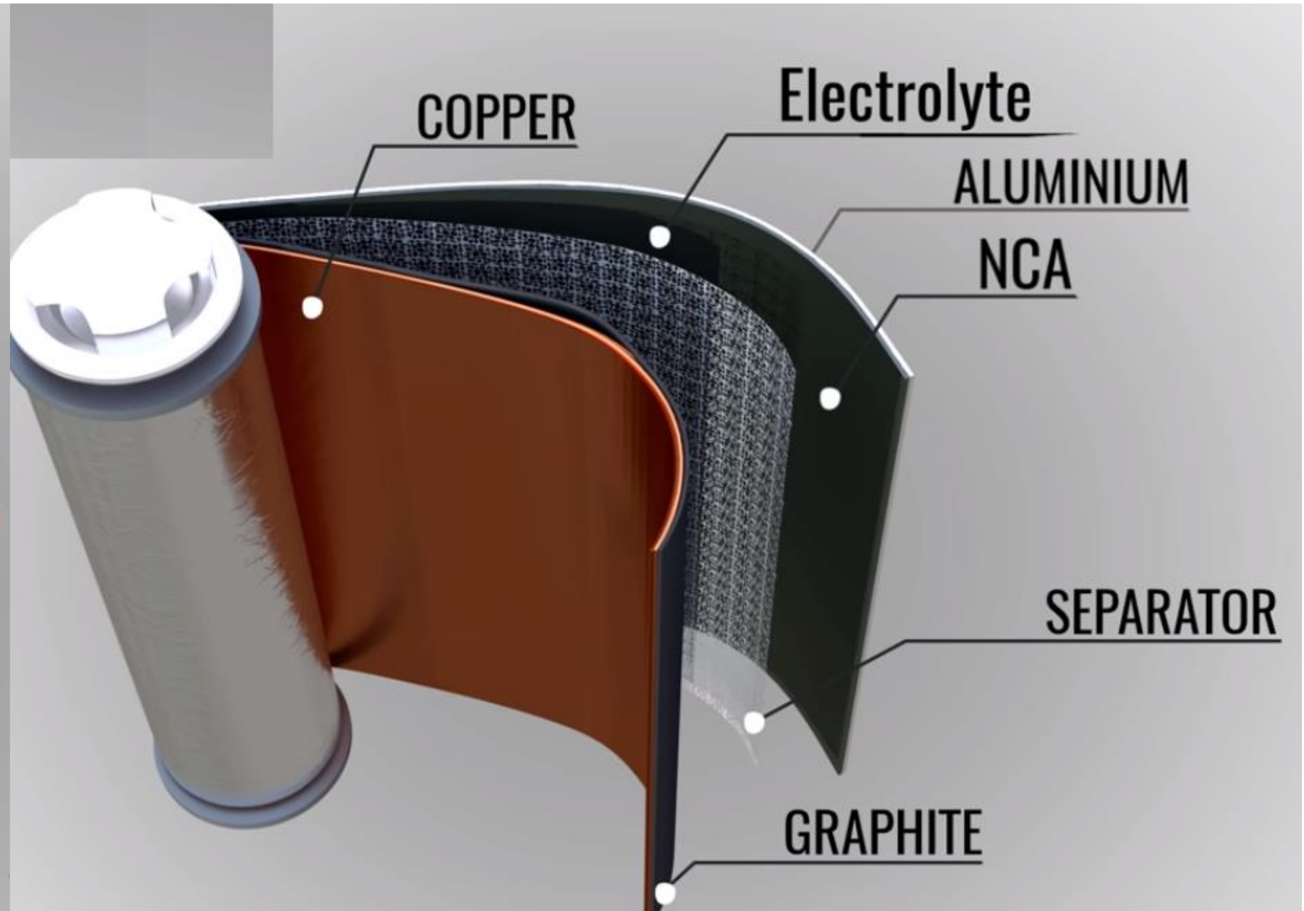
- This is for two reasons. First, lithium is the most **electropositive** element. Electropositivity is a measure of how easily an element can donate electrons to produce positive ions. In other words, it's a measure of how easily an element can produce energy. Lithium loses electrons very easily. This means it can easily produce a lot of energy.

- Lithium is also the **lightest** of all metals. Intercalation materials are used as electrodes in lithium-ion batteries instead of actual lithium metal. Still, these batteries weigh much less than other types of batteries that use metals like lead or nickel.

Activity Series of Metals		
Most reactive	lithium	Li
↓	rubidium	Rb
	potassium	K
	barium	Ba
	strontium	Sr
	calcium	Ca
	sodium	Na
	magnesium	Mg
	beryllium	Be
	aluminum	Al
	manganese	Mn
	zinc	Zn
	cadmium	Cd
	iron	Fe
	cobalt	Co
	nickel	Ni
	tin	Sn
	lead	Pb
	(hydrogen)	(H_2)
	copper	Cu
	mercury	Hg
	silver	Ag
	palladium	Pd
	platinum	Pt
Least reactive	gold	Au

Activity Series of Non-Metals		
Most reactive	fluorine	F
↓	chlorine	Cl
	oxygen	O
	bromine	Br
	iodine	I
	sulfur	S
Least reactive	(red) phosphorus	P

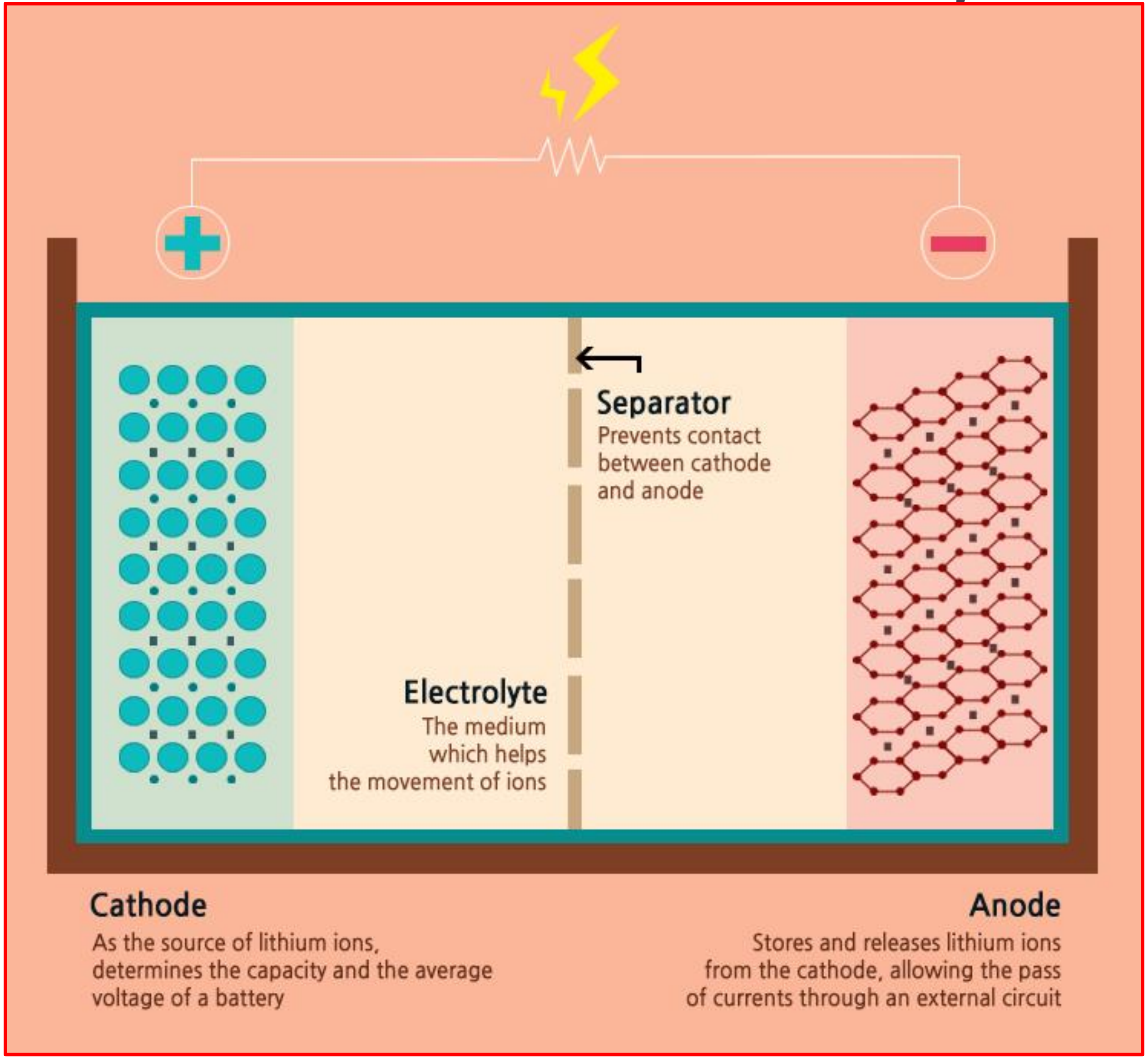


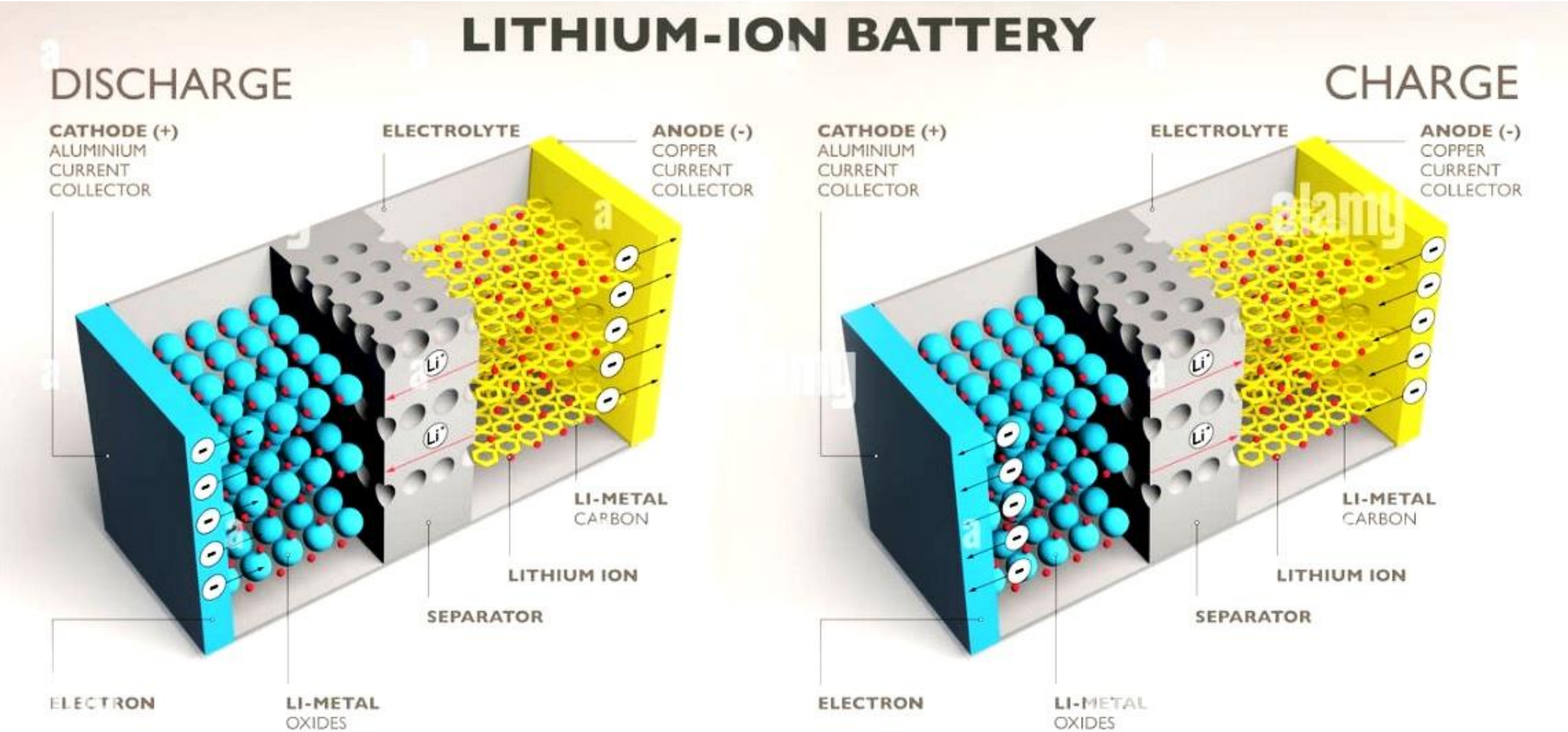


NCA: **lithium nickel cobalt aluminium oxides** $LiNi_xCo_yAl_zO_2$

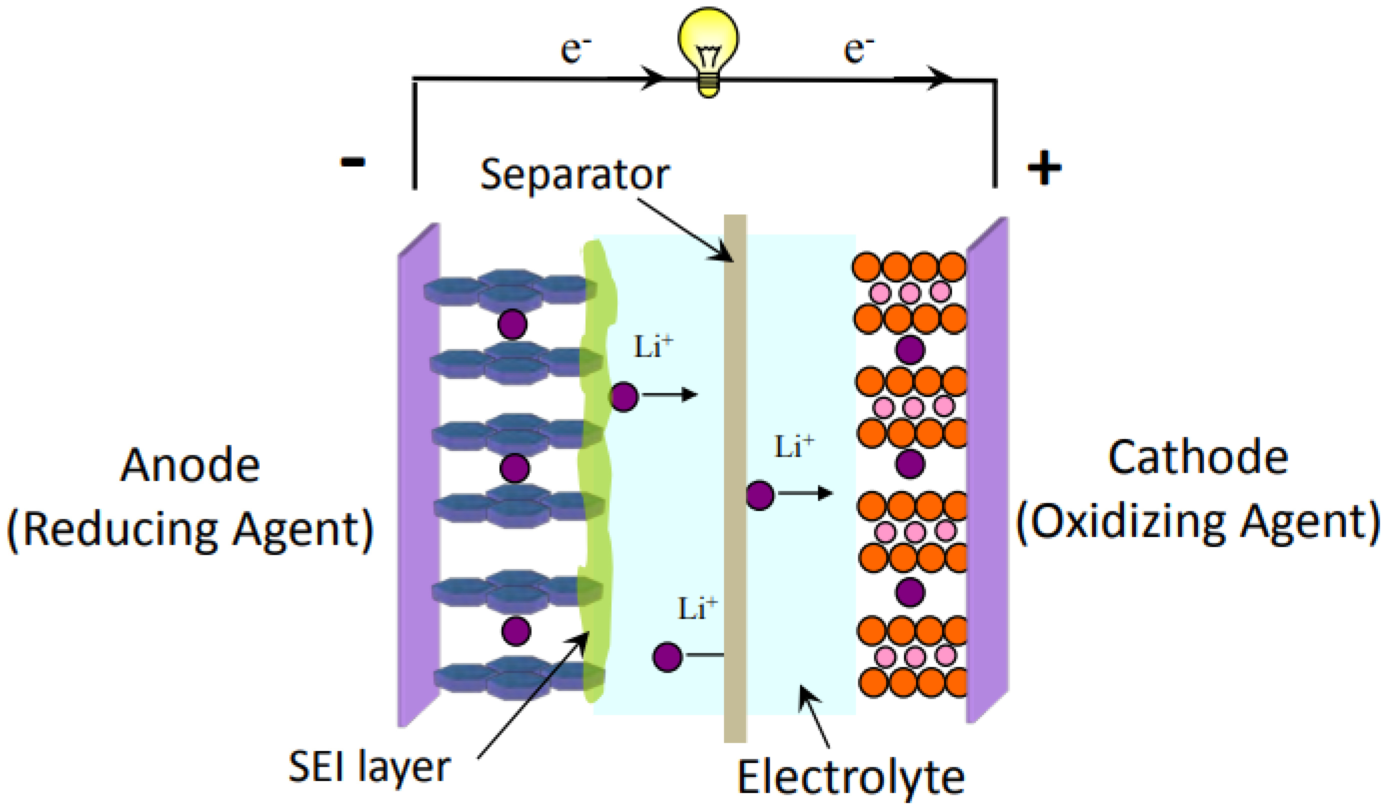
Components of lithium ion battery

1. Cathode
2. Anode
3. Electrolyte
4. Separator




LITHIUM-ION BATTERY
DISCHARGE
CHARGE
CATHODE (+)
ALUMINIUM
CURRENT
COLLECTOR
ELECTROLYTE
ANODE (-)
COPPER
CURRENT
COLLECTOR
LI-METAL
CARBON
LITHIUM ION
SEPARATOR
ELECTRON
LI-METAL
OXIDES
CATHODE (+)
ALUMINIUM
CURRENT
COLLECTOR
ELECTROLYTE
ANODE (-)
COPPER
CURRENT
COLLECTOR
LI-METAL
CARBON
LITHIUM ION
SEPARATOR
ELECTRON
LI-METAL
OXIDES

Typical Lithium Ion Battery (LIB) Cell



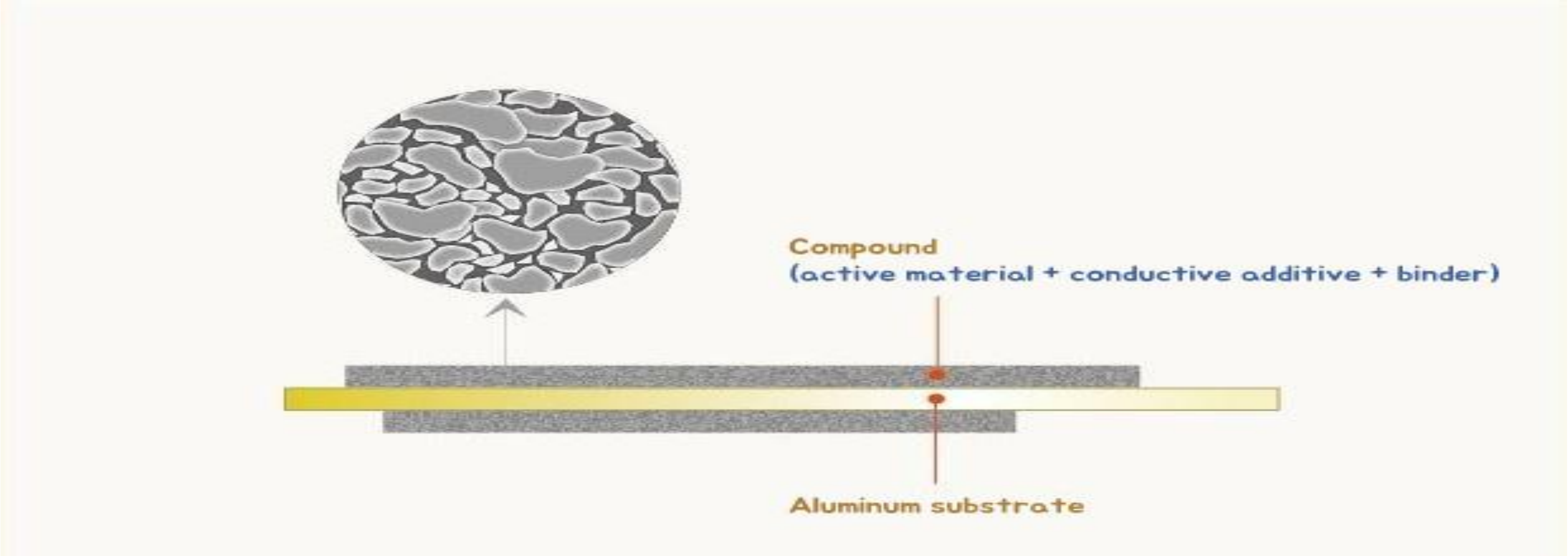
A passivation layer called the solid electrolyte interphase (SEI) is formed on electrode surfaces from decomposition products of electrolytes. The SEI allows Li^+ transport and blocks electrons in order to prevent further electrolyte decomposition and ensure continued electrochemical reactions

Cathode:

- A Lithium-ion battery generates electricity through chemical reactions of lithium. This is why lithium is inserted into the battery and that space for lithium is called "cathode".

- However, since lithium is unstable in the element form, the combination of lithium and oxygen, lithium oxide is used for cathode.

- The material that intervenes the electrode reaction of the actual battery just like lithium oxide is called "active material" i.e., in the cathode of a Li-ion battery, lithium oxide is used as an active material



If we take a closer look at the cathode, we will find a thin aluminum foil used to hold the frame of the cathode coated with a compound made up of active material, conductive additive and binder.

The active material contains lithium ions, the conductive additive is added to increase conductivity; and the binder acts as an adhesive which helps the active material and the conductive additive to settle well on the aluminum substrate.

Anode

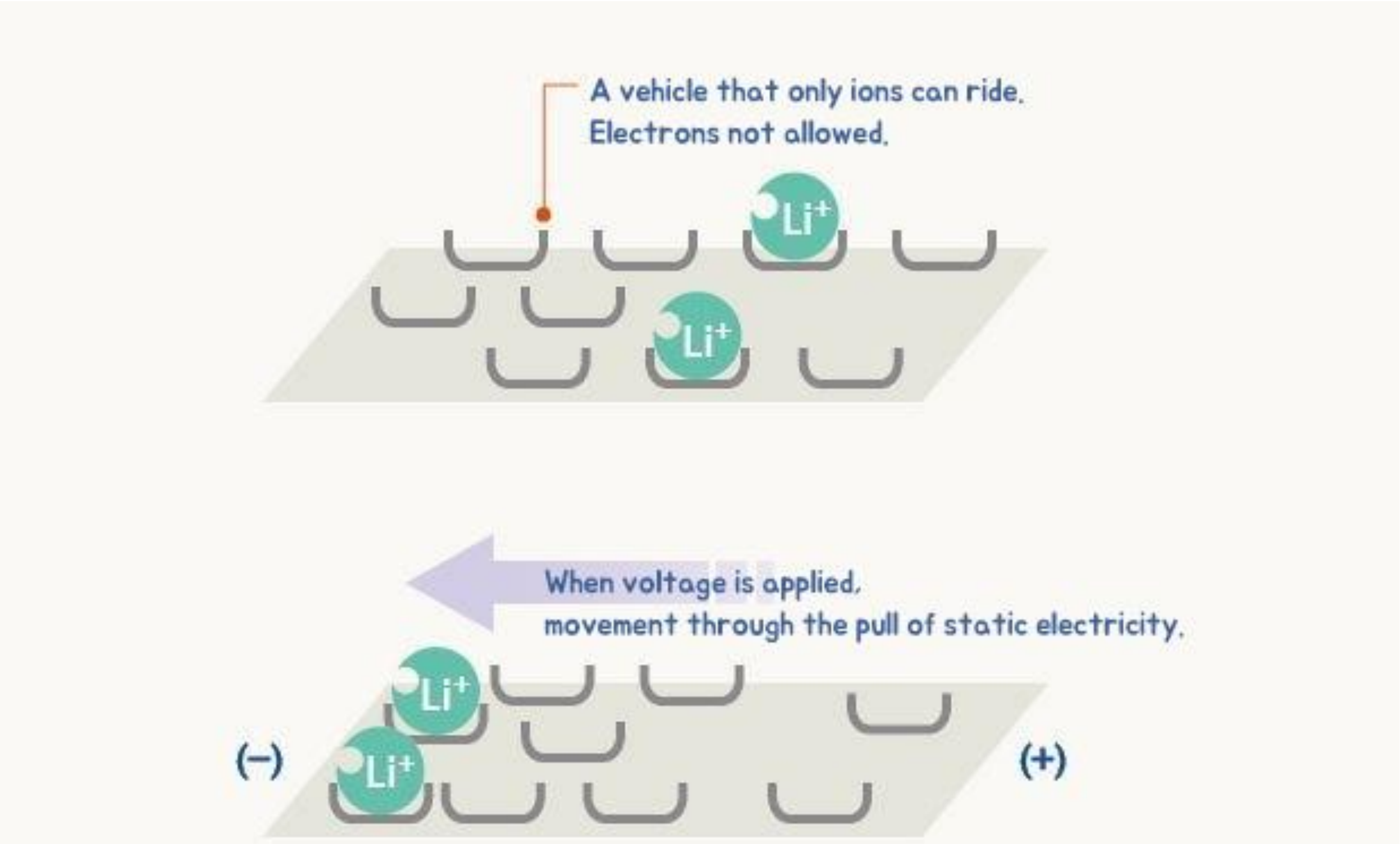
- Anode substrate is also coated with active material. The anode's active material performs the role of enabling electric current to flow through the external circuit while allowing reversible absorption/emission of lithium ions released from the cathode.

- When the battery is being charged, lithium ions are stored in the anode and not the cathode. At this point, when the conducting wire connects the cathode to the anode (discharge state), lithium ions naturally flow back to the cathode through the electrolyte, and the electrons (e^-) separated from lithium ions move along the wire generating electricity.

- For anode graphite which has a stable structure is used, and the anode substrate is coated with active material, conductive additive and a binder.

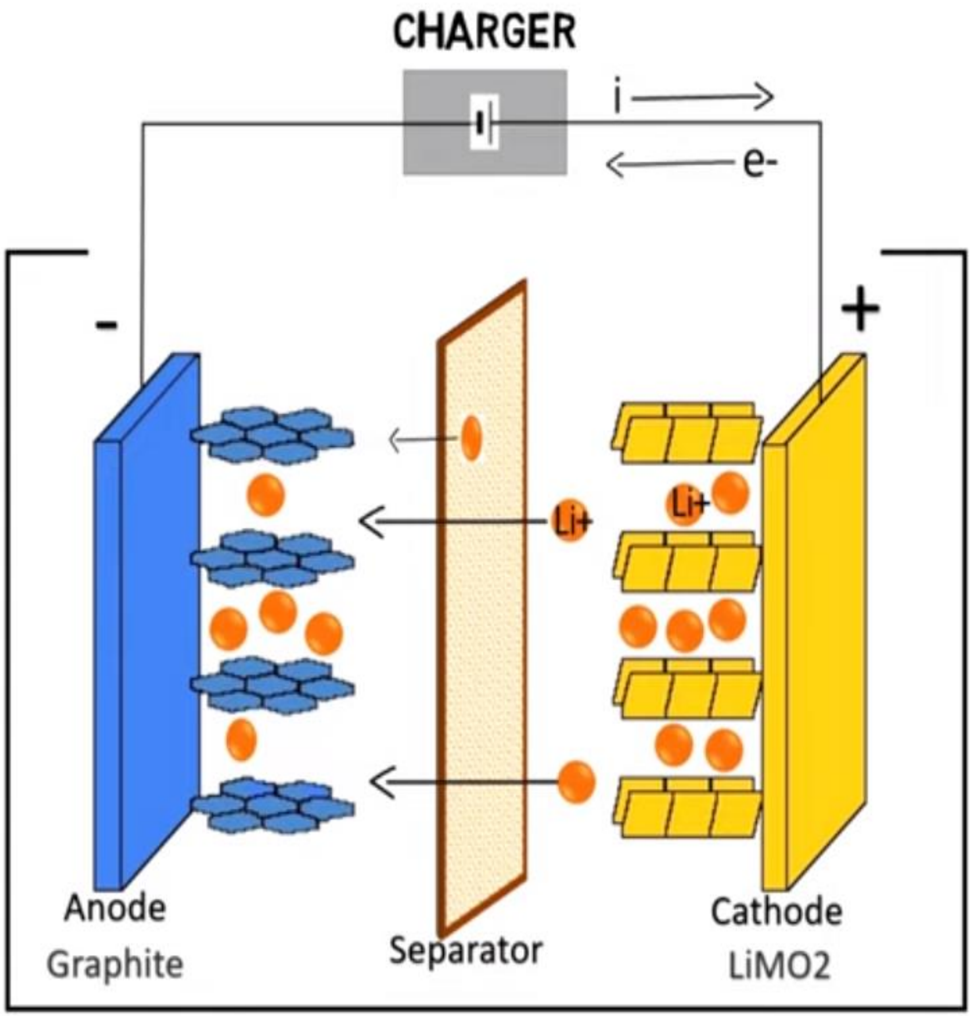
Electrolyte:

- "Electrolyte" allows the movement of ions only.
- It serves as the medium that enables the movement of only lithium ions between the cathode and anode but restrict the movement of electrons.
- For the electrolyte, materials with high ionic conductivity are mainly used so that lithium ions move back and forth easily.
- Liquid electrolytes in lithium-ion batteries consist of lithium salts, such as $LiPF_6$, $LiBF_4$ or $LiClO_4$ in an organic solvent, such as ethylene carbonate, dimethyl carbonate, and diethyl carbonate.


A vehicle that only ions can ride.
Electrons not allowed.
Li+
Li+
When voltage is applied,
movement through the pull of static electricity.
Li+
Li+
(−)
(+)

Separator:

- The separator functions as a physical barrier keeping cathode and anode apart.
- It prevents the direct flow of electrons and carefully lets only the ions pass through the internal microscopic hole.
- Commercialized separators we have today are synthetic resin such as polyethylene (PE) and polypropylene (PP).



AT CATHODE

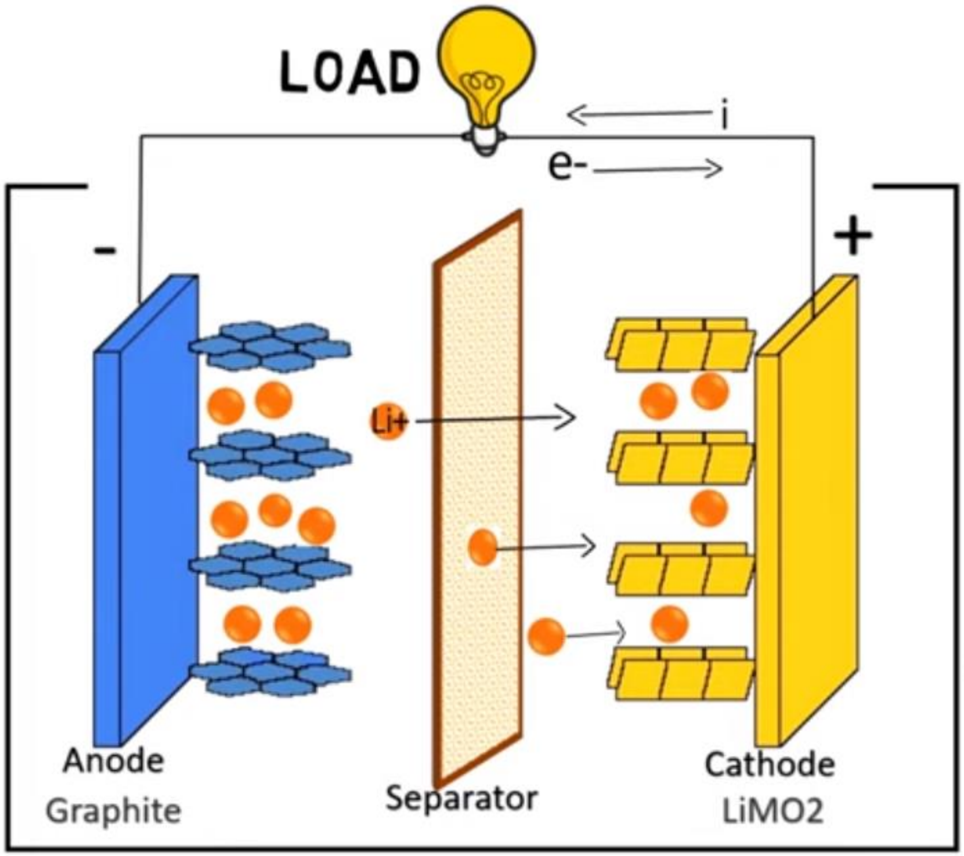
$$LiMO_2 \rightarrow Li^+ + MO_2 + e^-$$

AT ANODE

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

CELL REACTION:

$$LiMO_2 + C_6 \rightarrow MO_2 + LiC_6$$



AT CATHODE

$$MO_2 + Li^+ + e^- \rightarrow LiMO_2$$

AT ANODE

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

CELL REACTION

$$MO_2 + LiC_6 \rightarrow LiMO_2 + C_6$$

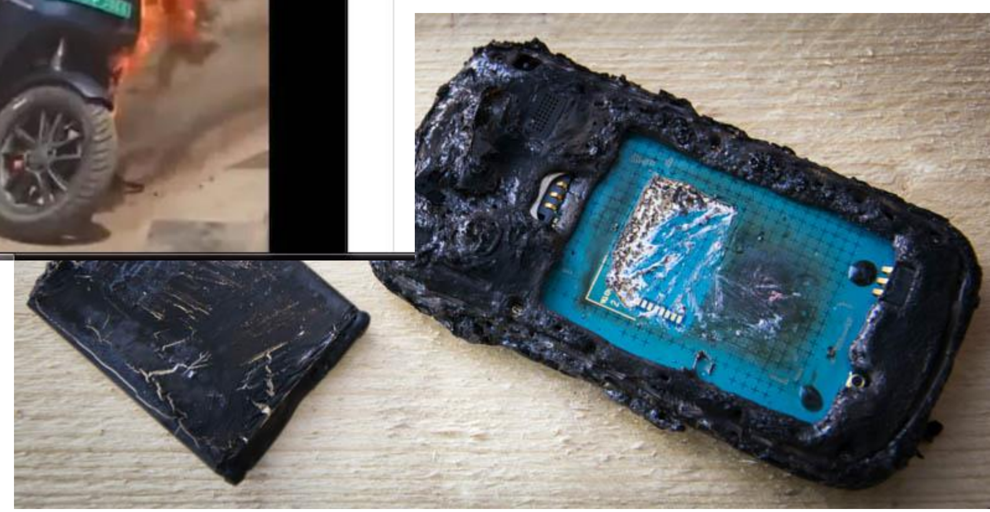
Lithium-Ion batteries have a nominal voltage of **3.7 volts per cell**

Battery failure

Ola electric scooter catches fire in Pune, company says probe underway

Ola Electric said it is investigating the incident in Pune wherein its S1 scooter caught fire.

Pankaj Khelkar
Pune
March 27, 2022 UPDATED: March 27, 2022 12:00 IST



ENERGY DENSITY VS. POWER DENSITY

The two most common concepts associated with batteries are energy density and power density.
Energy density is measured in watt-hours per kilogram (Wh/kg) and is the amount of energy the battery can store with respect to its mass.

Power density is measured in watts per kilogram (W/kg) and is the amount of power that can be generated by the battery with respect to its mass.

To draw a clearer picture, think of draining a pool. Energy density is similar to the size of the pool, while power density is comparable to draining the pool as quickly as possible.

The difference between lithium and lithium-ion batteries:

- The difference between lithium and lithium-ion batteries is that one is not rechargeable (primary cell) and the other can be recharged (secondary cell).

- Lithium batteries have a shelf life up to four times longer than lithium-ion batteries and are also much cheaper and easier to make.

- Lithium-ion batteries is the best choice for the electronics we use every day such as cell phone, digital camera , laptop etc. Conversely, the items we rely on to hold their charge for extended periods of time(upto 15 years) are best powered using Lithium batteries . For example medical pacemaker , smoke alarm etc.

- Lithium-ion batteries have been known to catch fire and explode, a feature not seen from Lithium batteries.

Lithium batteries are primary batteries that have metallic lithium as an anode. These types of batteries are also referred to as lithium-metal batteries.

Advantages of Li-ion batteries:

▪**Eco-friendly:**
Lithium-ion batteries contain relatively low levels of toxic heavy metals found in other types of batteries, such as lead-acid and nickel-cadmium (NiCd) batteries

•**Lightweight and compact:**
Electrodes commonly used in lithium-ion batteries, lithium and carbon, are lightweight on their own, making for much smaller and lighter batteries than their older counterparts such as lead-acid batteries.

•**High energy density:**
Lithium is a highly reactive element with the ability to release and store large amounts of energy, allowing Li-ion batteries to pack a high energy capacity in a small size.

•**Low Maintenance**
Lithium-ion batteries also have no memory effect, which would cause batteries to perform at a lower capacity after repeated partial discharge and charge cycles hence requires no maintenance.

•**Low self-discharge:**
One issue with many rechargeable batteries is the self discharge rate. Lithium ion cells is that their rate of self-discharge is much lower than that of other rechargeable cells such as Ni-Cd and NiMH forms. It is typically around 5% in the first 4 hours after being charged but then falls to a figure of around 1 or 2% per month.

Solid-state Battery

- Solid-state batteries are quite similar to that of lithium-ion batteries.
- The only difference is that a solid-state battery consists of a solid electrolyte in place of a liquid electrolyte. Materials such as glass, ceramic, etc., can be used for this purpose.

Construction of Solid-State Battery

A solid-state battery makes use of solid electrodes as well as solid electrolytes.

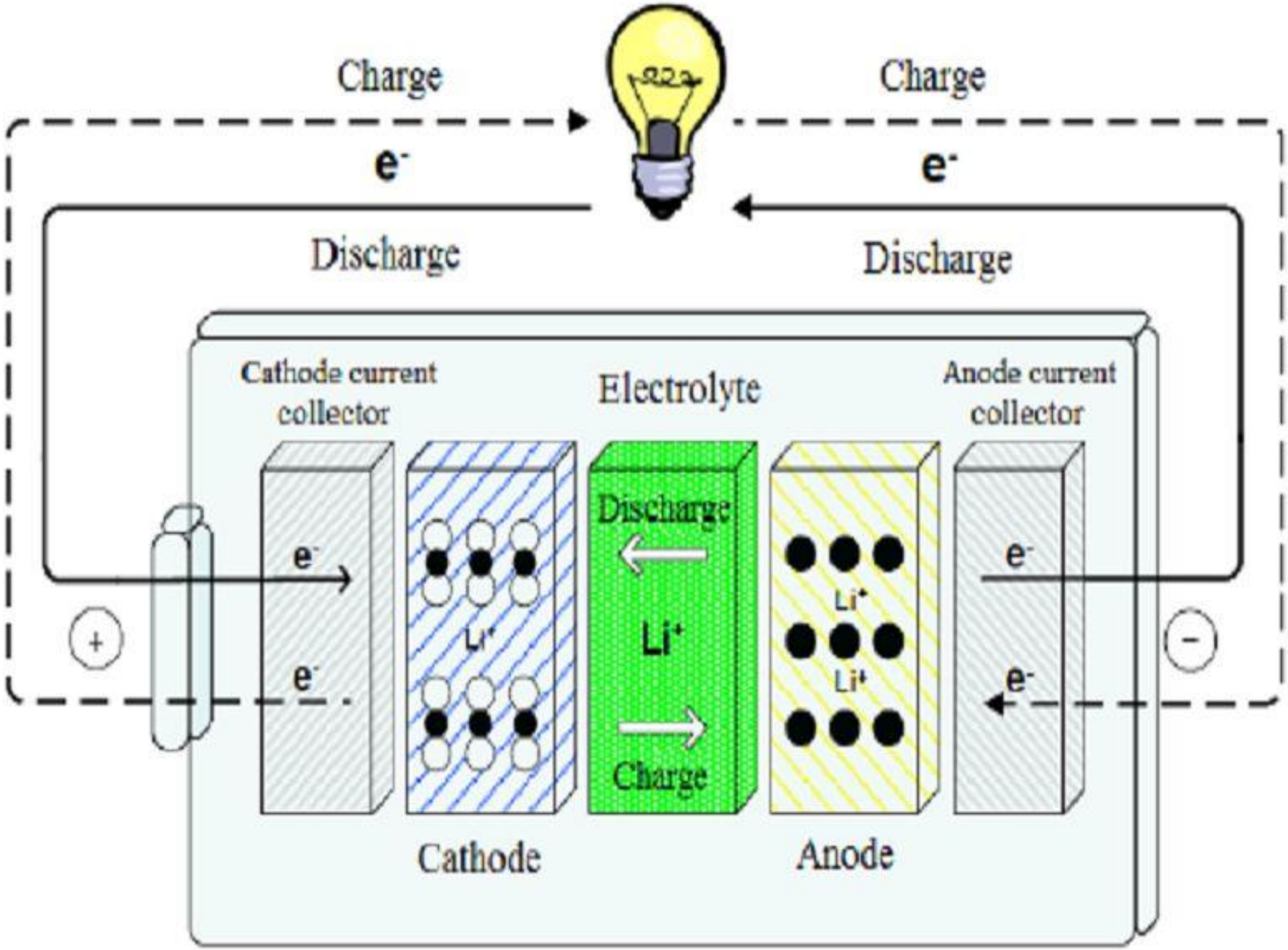
The solid electrolytes include oxides, sulfides, phosphates, polyethers, polyesters, nitrile-based, polysiloxane, polyurethane, etc.

The performance of the battery depends on the type of electrolyte used.

Ceramics are suitable for rigid battery systems due to their high elastic moduli, while low elastic moduli of polymers make them fit for flexible devices.

Working of Solid-State Battery

- The working of a solid-state battery is quite similar to that of a lithium-ion battery.
- The anode and cathode of the battery are made up of electrically conductive materials.
- An electrolyte is present between the two electrodes that contain the charged ion particles.
- The lithium ions move through the electrolyte between the electrodes. This movement of charged particles in a particular direction produces current.
- When the ions move from the cathode to the anode, i.e., from the positive electrode to the negative electrode, it is said to be charging.
- Similarly, the movement of ions in the reverse direction, i.e., from the anode to the cathode discharges the battery and supplies the current to the load.


Charge
Charge
e-
e-
Discharge
Discharge
Cathode current collector
Electrolyte
Anode current collector
e-
e-
Li+
Discharge
Li+
Charge
Li+
Li+
e-
e-
+
−
Cathode
Anode

Advantages of Solid-State Battery

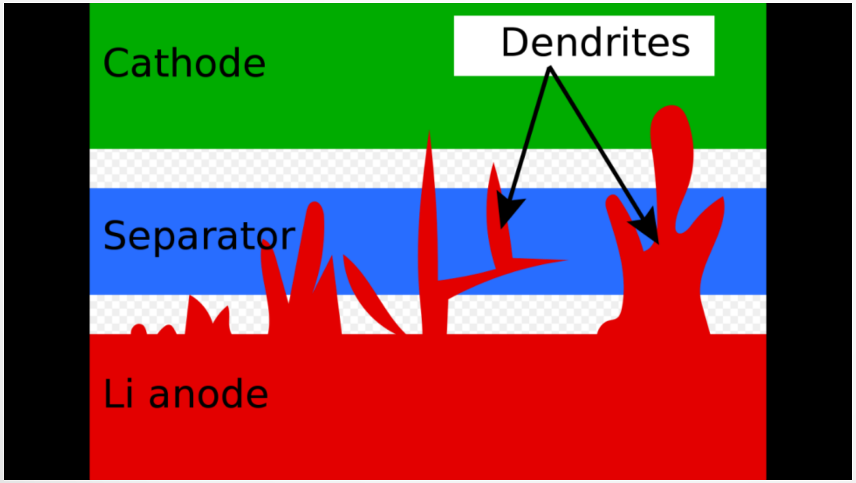
1. Solid-state batteries are capable of delivering 2.5 times more energy density as compared to lithium-ion batteries.
2. Solid-state batteries are comparatively more durable and safe.
3. The solid electrolyte used in solid-state batteries is non-flammable, hence they are less prone to catch fire.
4. Solid-state batteries are comparatively less expensive and compact in nature.
5. The greater electrochemical stability of solid-state batteries make them more reliable.
6. Solid-state batteries are comparatively lighter in weight.
7. The recharge rate of solid-state batteries is 4-6 times more than regular batteries.
8. A solid-state battery does not contain any volatile element.

9. Stable solid electrolyte interphase was found to be the most effective strategy for inhibiting dendrite growth and increasing cycling performance

Dendrites(tree like crystals) penetrate the separator between the anode and the cathode causing short circuits. This causes overheating, which may result in fires or explosions from thermal runaway

Dendrites commonly form during electrodeposition, during charge and discharge.

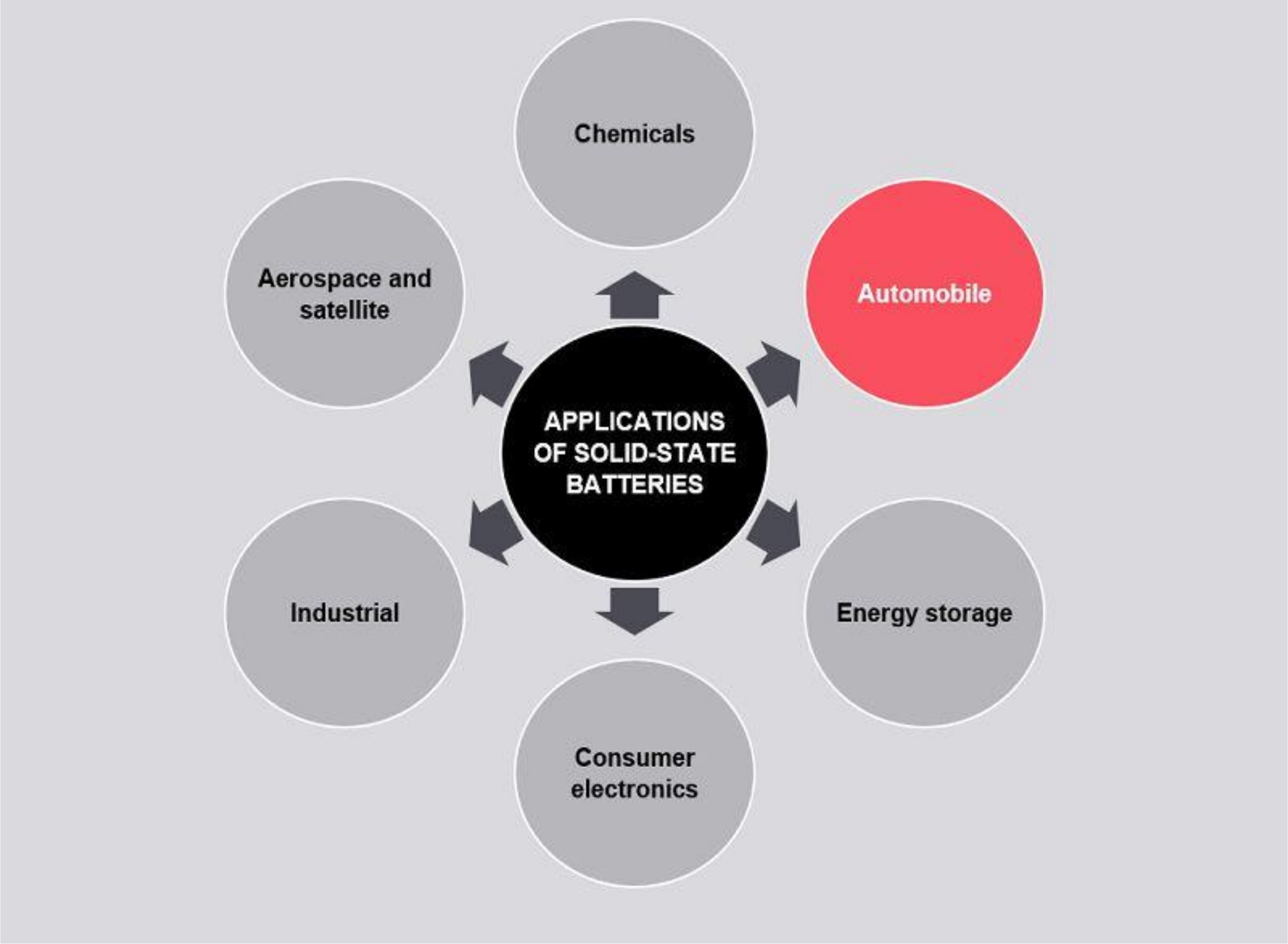
The component of Li dendrites was confirmed as Li_xC_y, Li_2O, and $Li_xC_yO_z$



Disadvantages of Solid-State Battery

1. The mass production and manufacturing of solid-state batteries are quite complex.

2. Research regarding solid-state batteries is still in progress and the perfect material for the electrolyte with an ideal ionic conductivity is yet to be found.


Chemicals
Aerospace and satellite
Automobile
APPLICATIONS OF SOLID-STATE BATTERIES
Industrial
Energy storage
Consumer electronics

Uses of Solid-State Battery

1. Solid-state batteries are extensively used in medical devices such as pacemakers, defibrillators, etc.
2. Automobile industry employs solid-state batteries at a large scale to power various electric vehicles.
3. Solid-state batteries have a variety of applications in the manufacturing and production industries.
4. Aerospace and satellites generally use solid-state batteries to power various gadgets and devices because they are light in weight and are non-flammable.

Fuel Cell

Introduction:

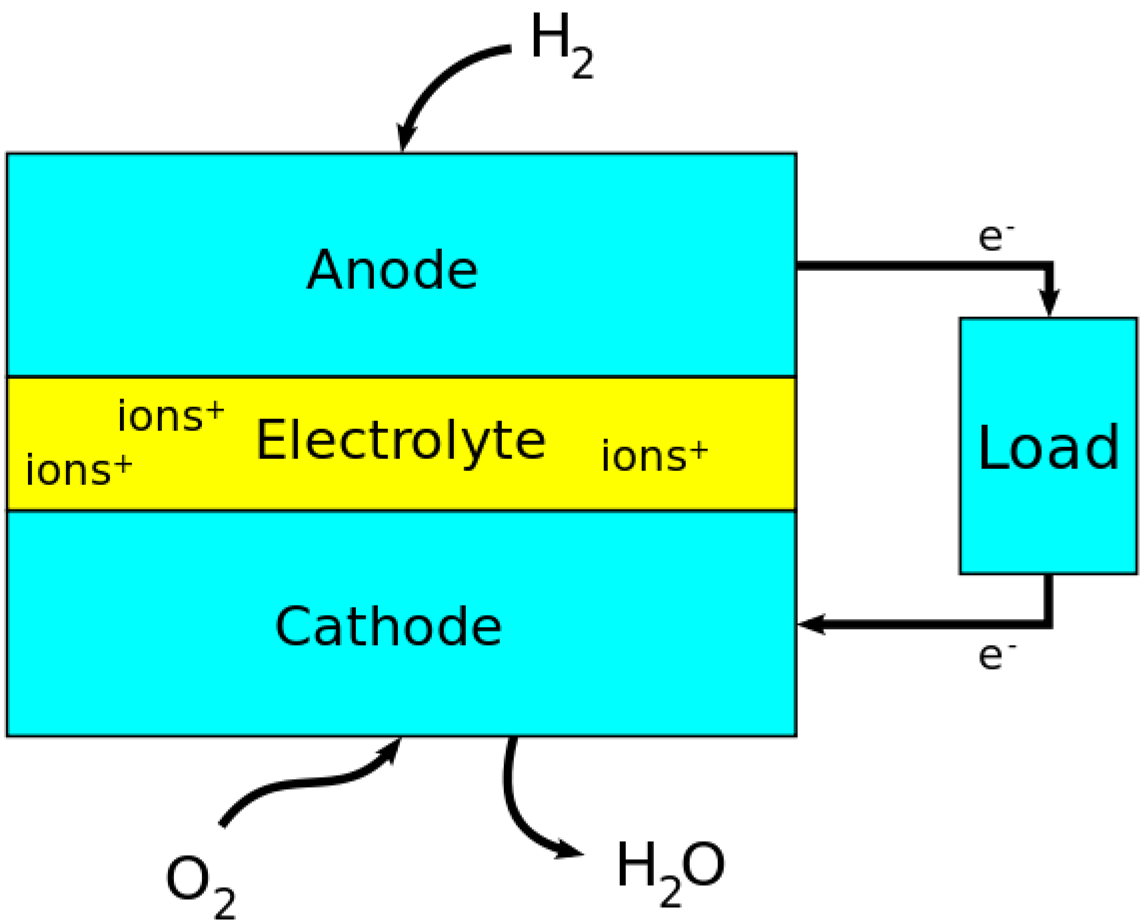
- Fuel cell is a galvanic cell that converts chemical energy of fuel into electrical energy
- A fuel cell consist of two electrodes and an electrolyte
- Efficiency of fuel cell is 100%
- The fuel and oxidants are supplied continuously during the operation of the cell.

Components

- Fuels:
  Gaseous: H_2, CH_4, NH_2NH_2, NH_3,CO etc
  Liquid: CH_3OH, C_2H_5OH etc
- Oxidant: O_2(usually from air), H_2O_2, HNO_3
- Electrolyte: KOH, H_3PO_4, salt carbonates etc
- The anode catalyst, usually fine platinum powder
- The cathode catalyst, usually nickel
- Gas diffusion layers that are designed to resist oxidization

Design features in a fuel cell include:

- The electrolyte substance, which usually defines the type of fuel cell, and can be made from a number of substances like potassium hydroxide, salt carbonates, and phosphoric acid.
- The fuel that is used. The most common fuel is hydrogen.
- The anode catalyst, usually fine platinum powder, breaks down the fuel into electrons and ions.
- The cathode catalyst, often nickel, converts ions into waste chemicals, with water being the most common type of waste.
- Gas diffusion layers that are designed to resist oxidization.

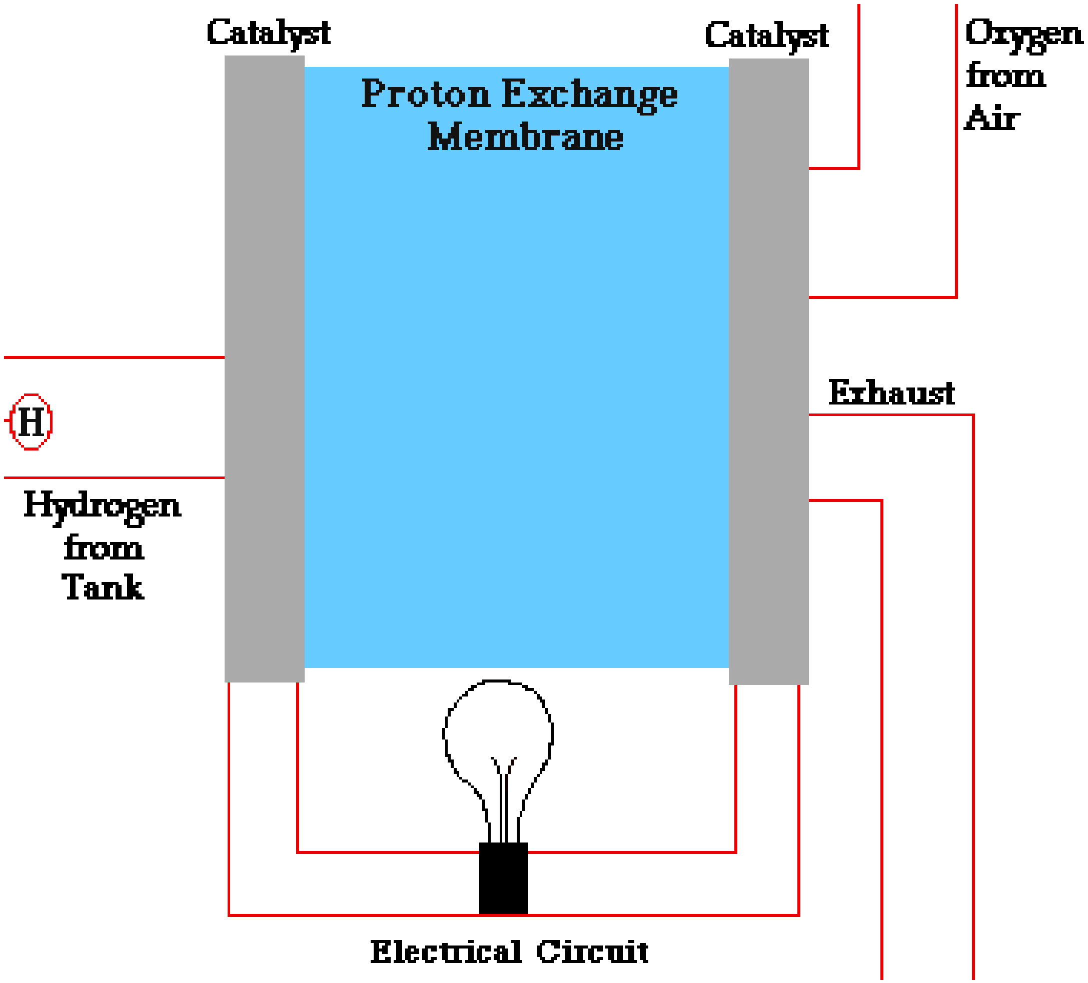

H2
Anode
e-
ions+
Electrolyte
ions+
ions+
Load
Cathode
e-
O2
H2O

- There are many types of fuel cells, but they all consist of an anode, a cathode, and an electrolyte that allows ions, often positively charged hydrogen ions (protons), to move between the two sides of the fuel cell.
- At the anode a catalyst causes the fuel to undergo oxidation reactions that generate ions (often positively charged hydrogen ions) and electrons.

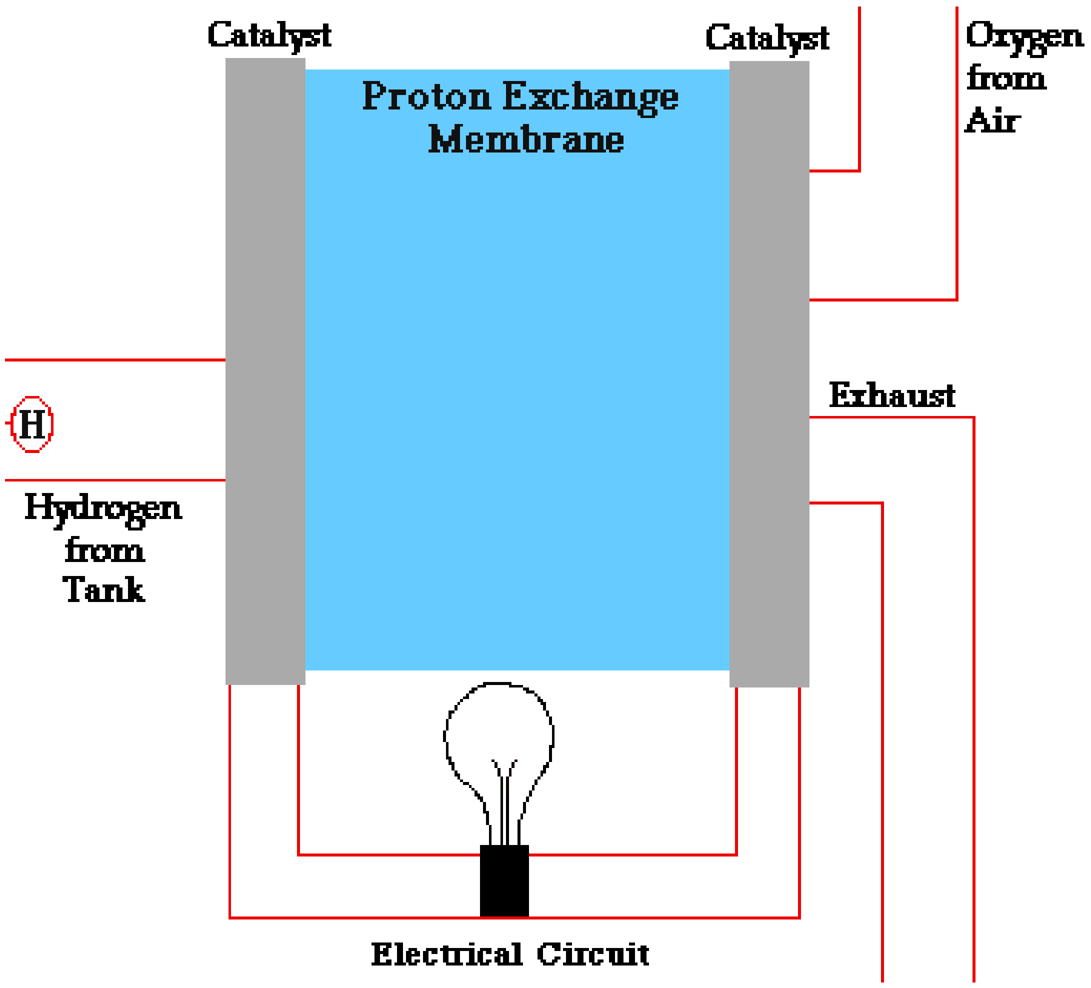
- The ions move from the anode to the cathode through the electrolyte. At the same time, electrons flow from the anode to the cathode through an external circuit, producing direct current electricity.

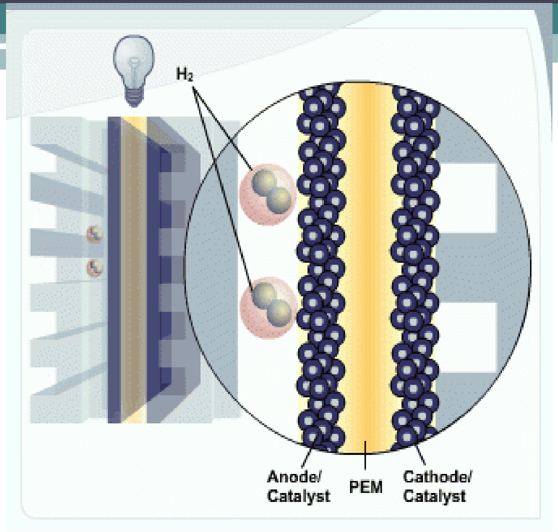
- At the cathode, another catalyst causes ions, electrons, and oxygen to react, forming water and possibly other products

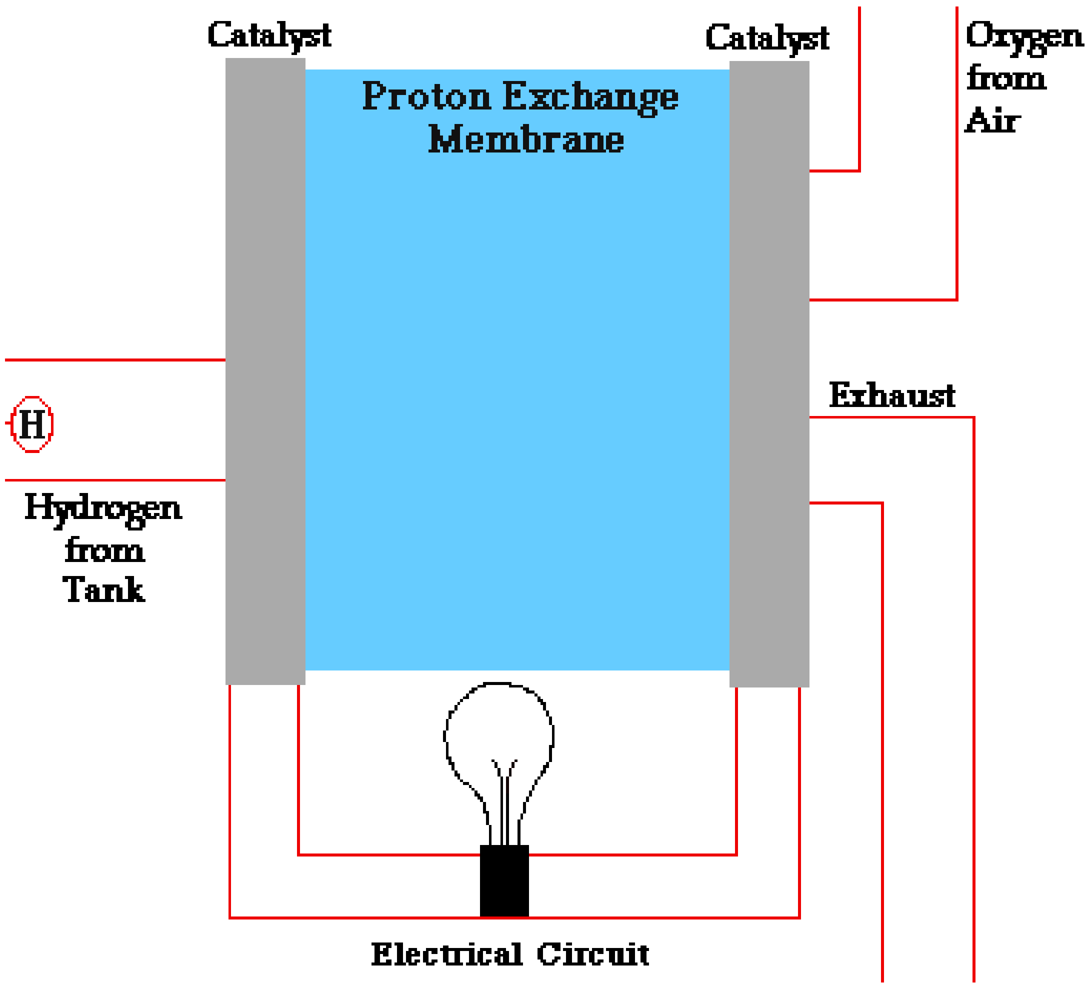
Working Principle

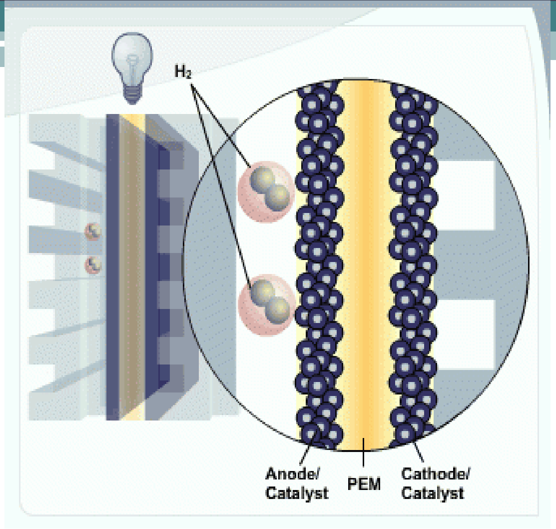


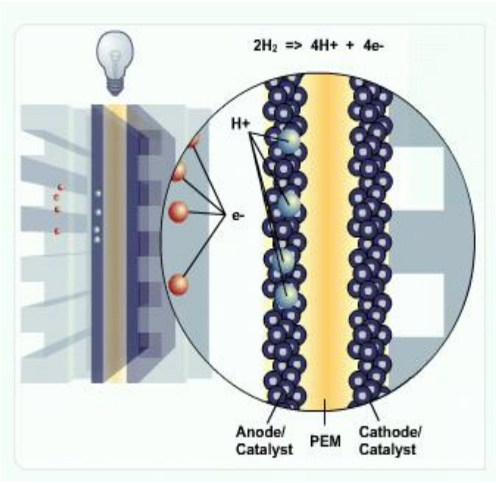
Catalyst
Catalyst
Oxygen from Air
Proton Exchange Membrane
H
Hydrogen from Tank
Exhaust
Electrical Circuit

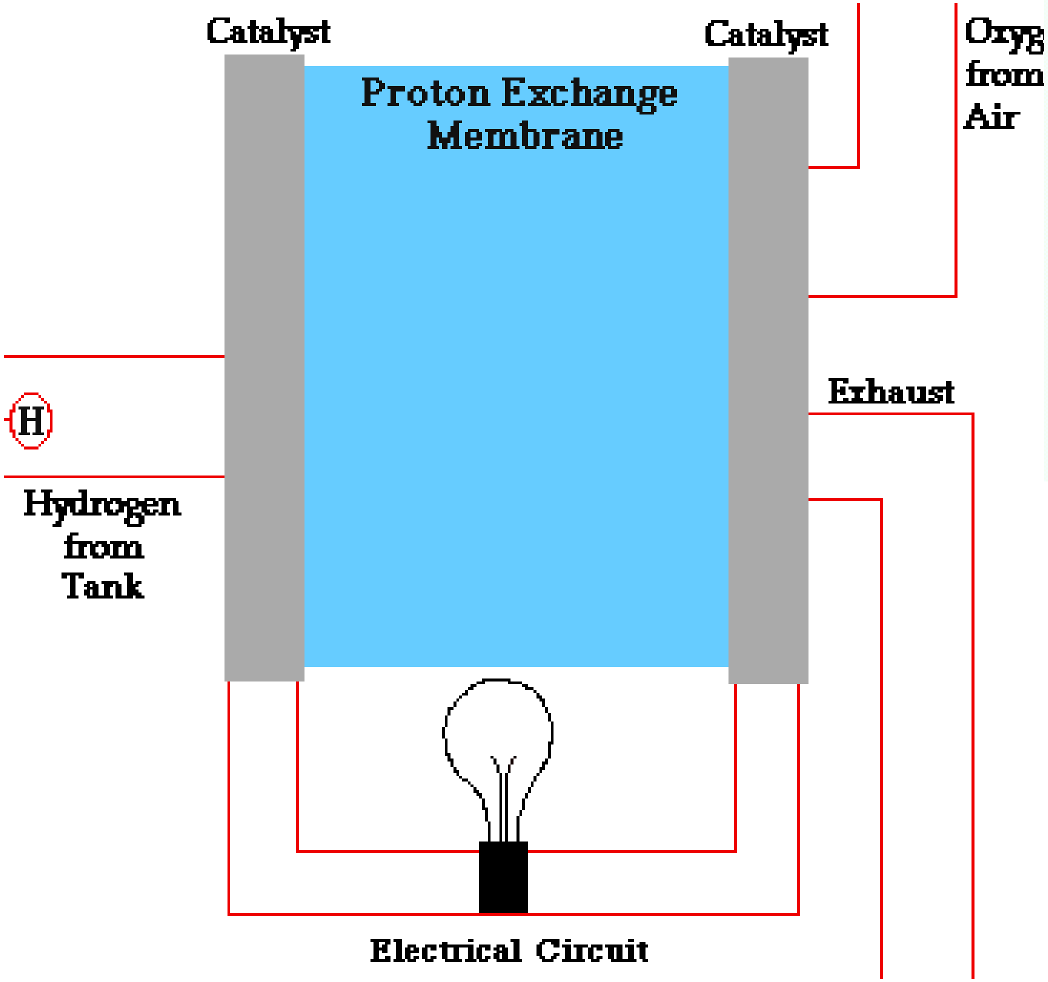

Catalyst
Catalyst
Proton Exchange Membrane
Oxygen from Air
H
Hydrogen from Tank
Exhaust
Electrical Circuit

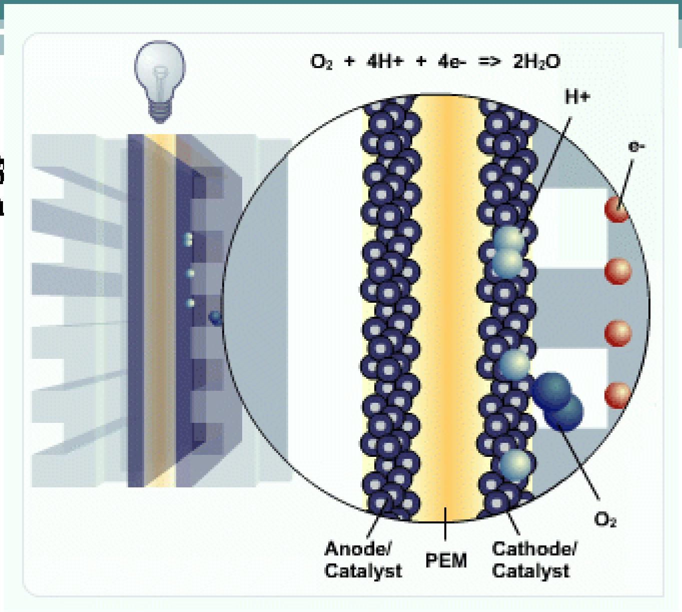

H₂
Anode/ Catalyst
PEM
Cathode/ Catalyst

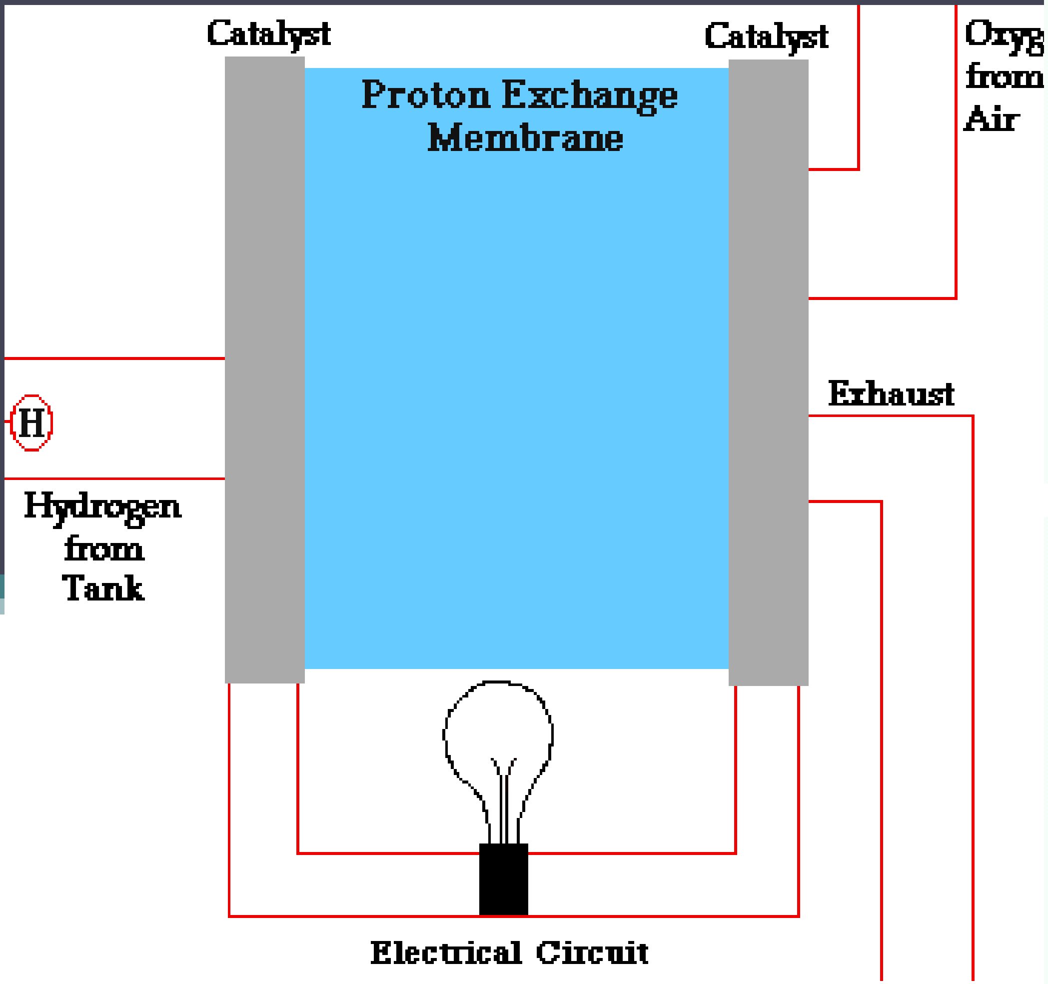

Catalyst
Catalyst
Proton Exchange Membrane
Oxygen from Air
H
Hydrogen from Tank
Exhaust
Electrical Circuit

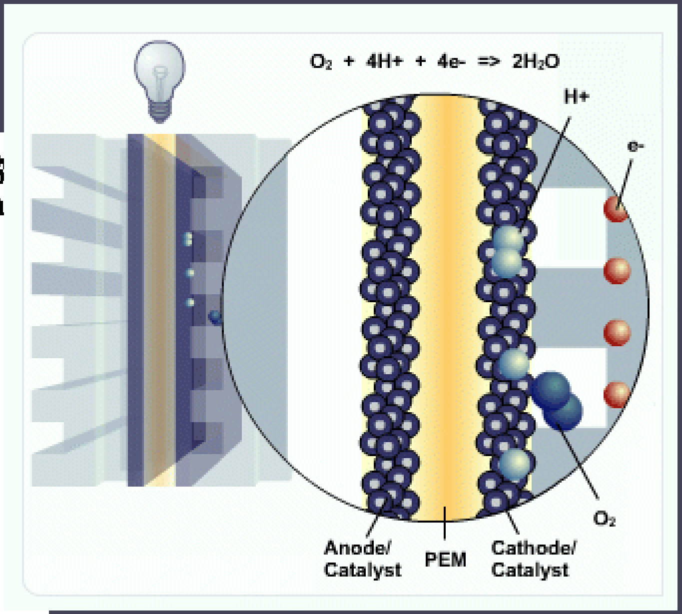

H_2
Anode/ Catalyst
PEM
Cathode/ Catalyst

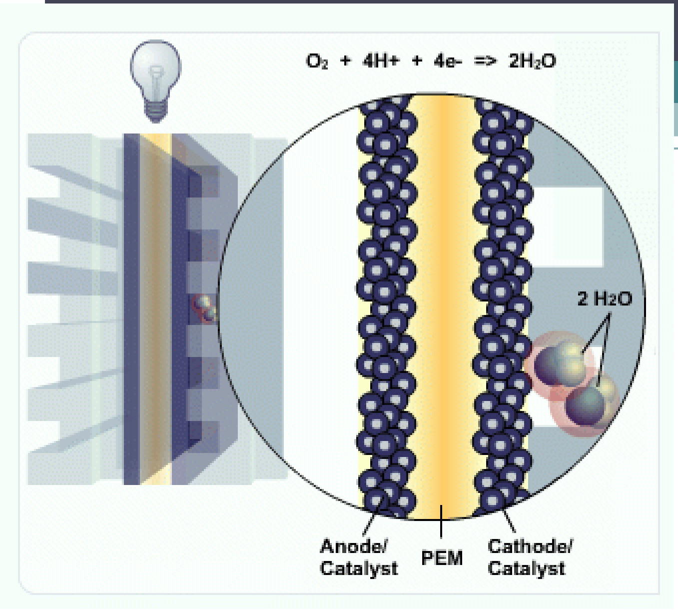

$2H_2$ => 4H+ + 4e-
H+
e-
Anode/ Catalyst
PEM
Cathode/ Catalyst


Catalyst
Catalyst
Proton Exchange Membrane
Oxyg from Air
Exhaust
H
Hydrogen from Tank
Electrical Circuit

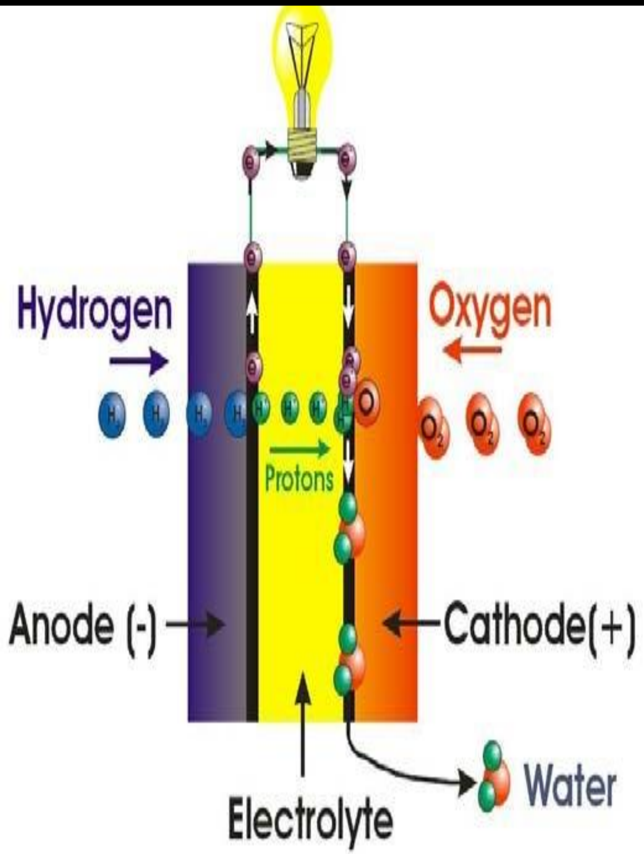

O2 + 4H+ + 4e- => 2H2O
H+
e-
O2
Anode/ Catalyst
PEM
Cathode/ Catalyst


Catalyst
Catalyst
Oxygen from Air
Proton Exchange Membrane
H
Hydrogen from Tank
Exhaust
Electrical Circuit


O_2 + 4H+ + 4e- => $2H_2O$
H+
e-
O_2
Anode/ Catalyst
PEM
Cathode/ Catalyst


O_2 + 4H+ + 4e- => $2H_2O$
2 H_2O
Anode/ Catalyst
PEM
Cathode/ Catalyst

Chemical Reactions Involved



Anode reaction:

$H_2 \rightarrow 2H^+ + 2e^-$

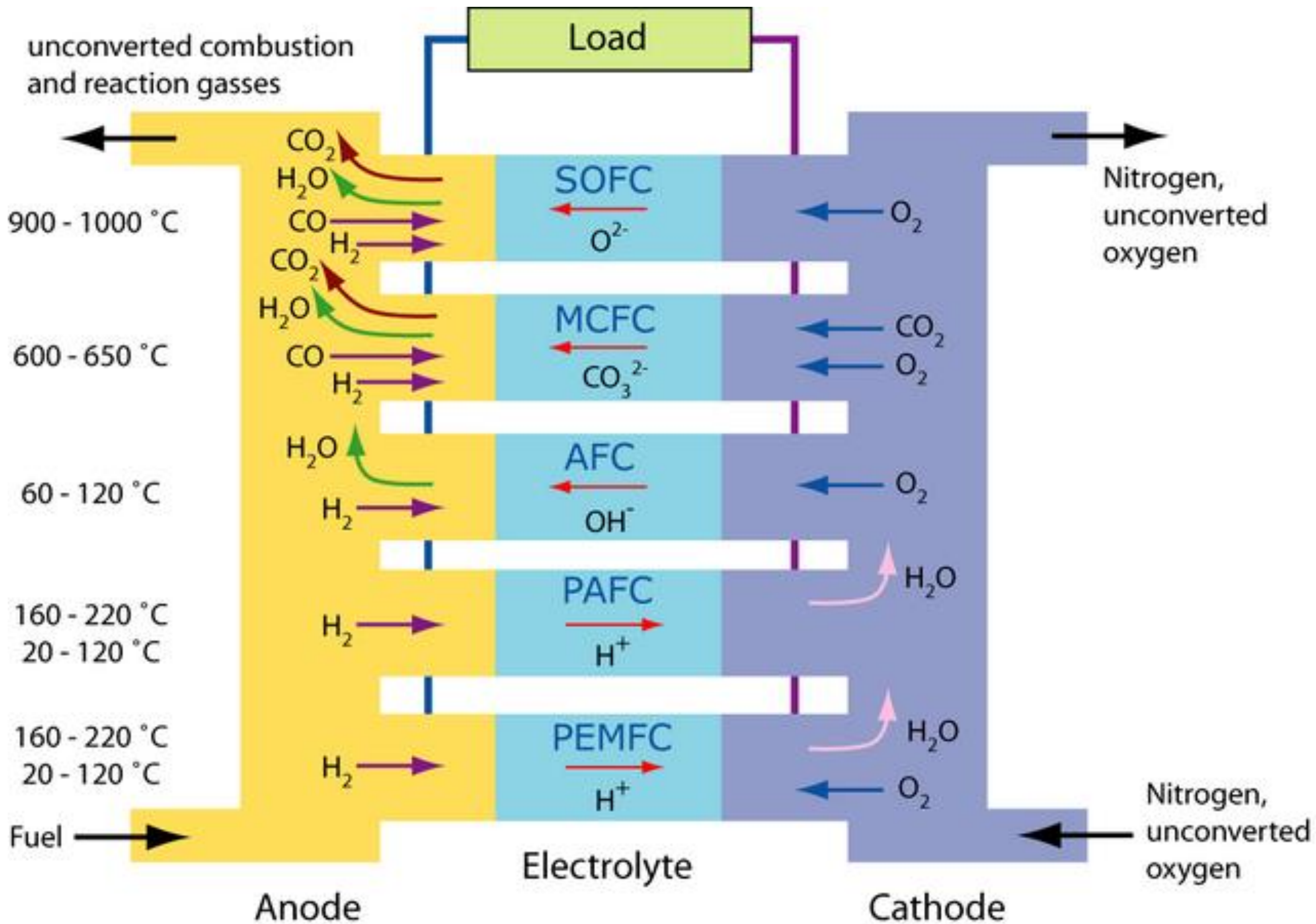
Cathode reaction:

$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

Cell reaction:

$2H_2 + O_2 \rightarrow 2H_2O$

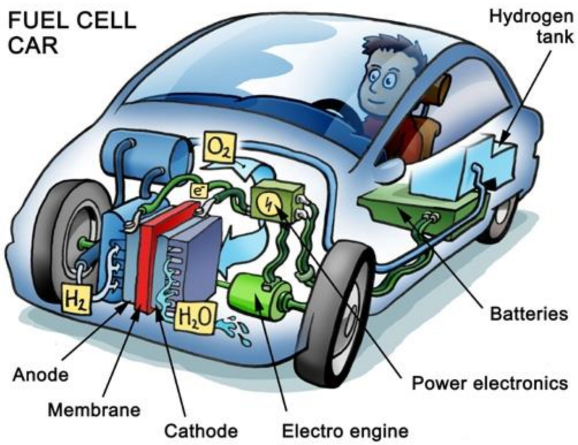
Types of fuel cell




APPLICATION

- **Power**

- **Automobiles**



- **Spacecrafts**

- High level of energy efficiency.
- Zero emissions.
- Better fuel economy.
- Reduce the risk of chemical exposure
- The maintenance of fuel cells is simple since there are few moving parts in the system
- Most fuel cells operate silently.

Disadvantages

- One must regulate the temperature of a hydrogen fuel cell to maximize its use
- The cost to store hydrogen is expensive enough that it is prohibitive for most people
- It costs more to transport hydrogen than it does most other fuels.
- It is not currently a complete renewable energy resource
- Constant supply of fuel is required

Thank You