

MODULE 5

Brief introduction to conventional primary and secondary batteries;
High energy electrochemical energy systems: Lithium batteries – Primary and secondary, its Chemistry, advantages and applications;
Fuel cells – Polymer membrane fuel cells, Solid-oxide fuel cells- working principles, advantages, applications.
Solar cells – Types – Importance of silicon single crystal, polycrystalline and amorphous silicon solar cells, dye sensitized solar cells - working principles, characteristics and applications;

Introduction

- A galvanic or voltaic cell is a device that generates electrical energy at the expense of decrease of free energy of a cell
- The electrode where oxidation occurs is called **anode** while the electrode where reduction occurs is called **cathode**.
- Voltages generated by such cells have been referred to as **electromotive force (emf)**
- In general, battery is a device that stores chemical energy for later release as electricity
- Also defined as an electrochemical cell or several electrochemical cells connected in series that can be used as a source of direct current at a constant voltage.

Definitions

- **Nominal Voltage** – The reported or reference voltage of the battery, also sometimes thought of as the “normal” voltage of the battery.
- nominal voltage of a primary Li battery = 3V
- **Operating voltage** – The operating voltage of a battery may be slightly higher than the nominal stated voltage
- **Energy Density (Wh/L)** – The nominal battery energy per unit volume, sometimes referred to as the volumetric energy density.
- Specific energy is a characteristic of the battery chemistry and packaging.
- Along with the energy consumption of the vehicle, it determines the battery size required to achieve a given electric range.
- Unit is Watt hour per litre

Definitions

- **Self discharge**– Batteries undergo self-discharging (loosing power) even if not connected or used.
 - Li+ rechargeable batteries have a self-discharge rate typically stated by manufacturers to be 1.5-2% per month.
 - The rate increases with temperature and state of charge.
 - It is due to the chemical reactions that occur even when it is not used
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- ***State of Charge (SOC)(%)*** – An expression of the present battery capacity as a percentage of maximum capacity.
 - SOC is generally calculated using current integration to determine the change in battery capacity over time.

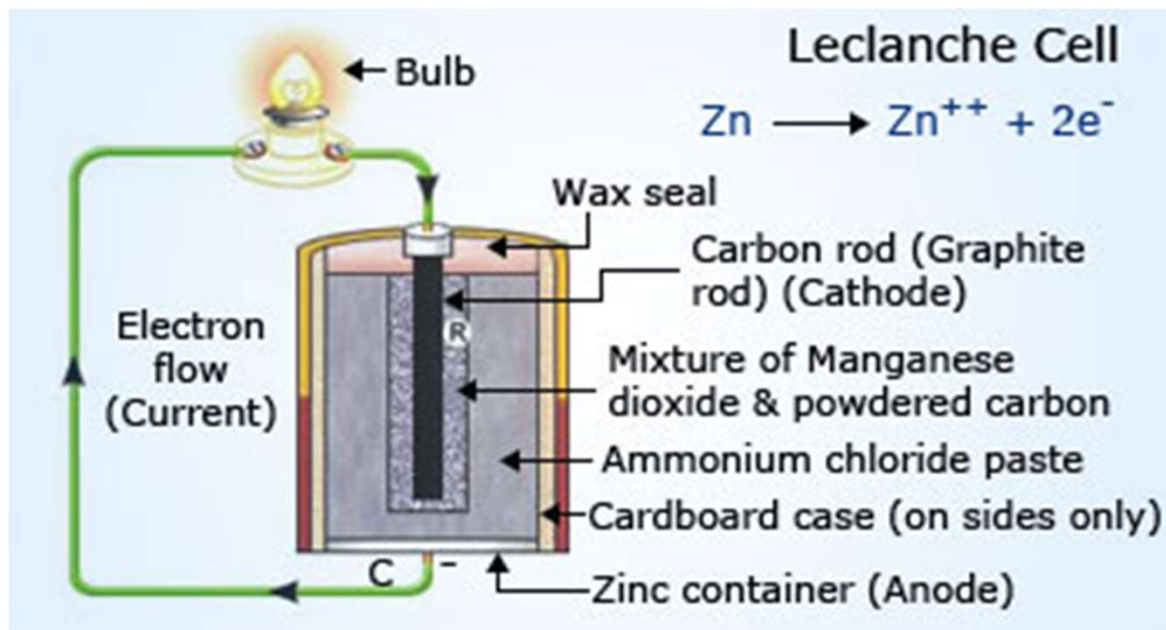
- **Depth of Discharge (DOD) (%)** – The percentage of battery capacity that has been discharged expressed as a percentage of maximum capacity.
 - A discharge to at least 80 % DOD is referred to as a deep discharge
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- ***Capacity or Nominal Capacity (Ah)*** – The coulometric capacity, the total Amp-hours available when the battery is discharged at a certain discharge current from 100 percent state-of-charge.
 - the amount of electric charge that it can deliver at the rated voltage (nominal voltage) and expressed in **amperes per hour (amp/hr)**

- ***Cycle Life (number for a specific DOD)*** – The number of discharge-charge cycles the battery can experience before it fails to meet specific performance criteria.
- The duration of satisfactory performance, measured in years or in number of charge/discharge cycles
- End of life is considered when the battery delivers approximately 80% of the rated ampere-hour capacity
- ***Shelf Life*** – the duration of storage under specified conditions at the end of which a battery still retains the ability to give a specified performance

Battery types

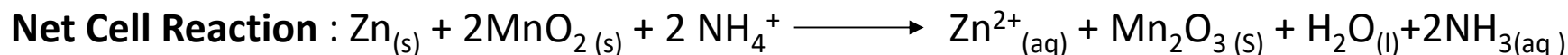
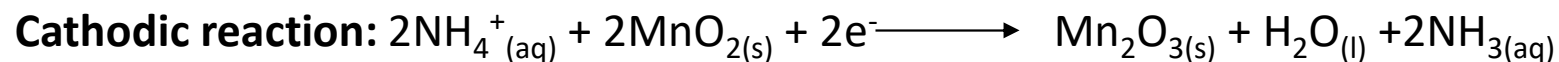
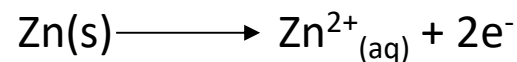
- **Primary battery (cell)** - In which the cell reaction is not reversible. When all the reactants have been converted to product, no more electricity is produced and the battery is dead
- They can give one continuous or intermittent discharge
- Primary batteries cannot be recharged
- E.g. Dry cell or Lechlance cell, Western-Cd cell, Clark Std cell
- Advanced primary cells include alkaline and lithium batteries

Zn-Carbon DRY cell (or) LeCLANCHE Cell

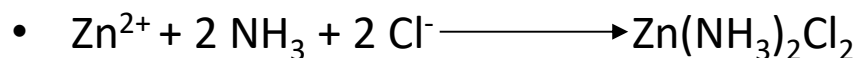
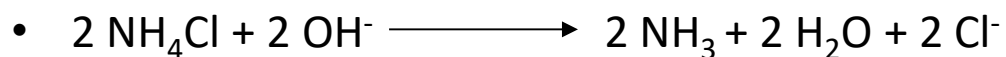


- It consists of a graphite rod (with a metal cap) which acts as cathode
- The cathode is surrounded by thick moist paste of graphite and MnO_2
- The outer layer consists of a paste of $\text{ZnCl}_2 + \text{NH}_4\text{Cl}$
- The entire assembly is placed in a zinc cylinder which acts as an anode

Anodic reaction :



- **Secondary reactions:**



- The ammonia gas produced in the reduction of ammonium, is absorbed by the Zn^{2+} ion by forming the complex $\text{Zn}(\text{NH}_3)_2\text{Cl}_2$

Disadvantages of dry cell

- Dry cells are not re-chargeable
- The voltage of this cell is initially about 1.5 volts, but decreases as energy is taken from the cell. Due to the accumulation of the products on electrodes. It also has a short shelf life and deteriorates rapidly
- Oxidation of the zinc wall eventually causes the contents to leak out, so such batteries should not be left in electric equipment for long periods.
- They are not suitable for high drain applications as they readily polarise and the available capacity falls sharply with increasing discharge rate
- While these batteries have a long history of usefulness, they are declining in application since some of their problems are overcome in ALKALINE BATTERIES.

Alkaline batteries

**HOT IN
SYLLABUS**

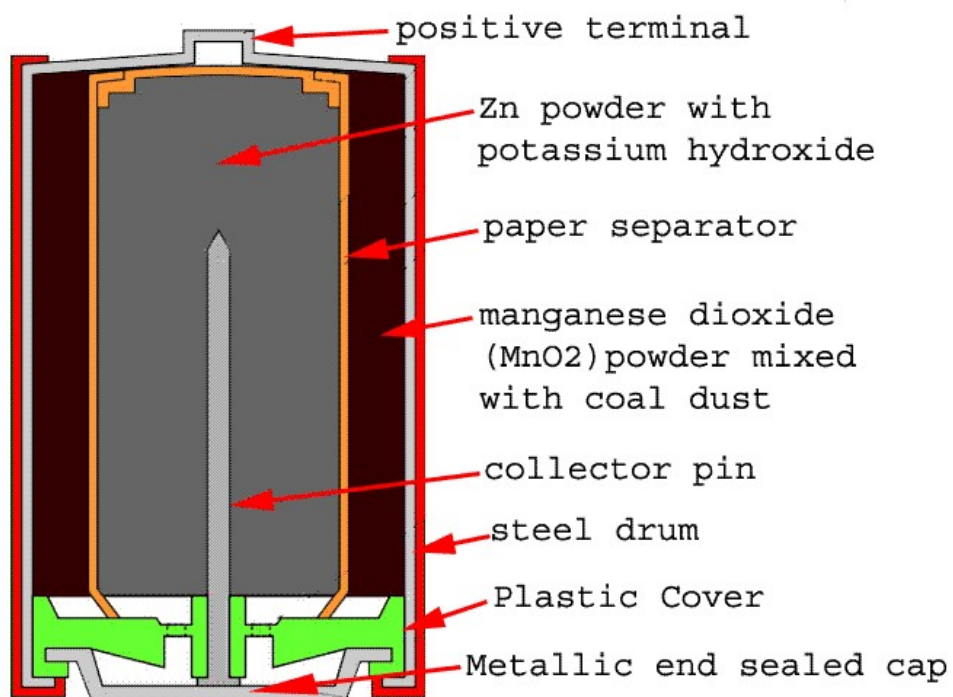
- Alkaline cells are an improved version of dry cell
- Some of the problems with Zn-Carbon primary batteries are avoided by replacing ammonium chloride with potassium hydroxide as the electrolyte.
- The zinc anode does not form the container but it is in the form of a powder, giving a large surface area.
- Zinc in powdered form is mixed with KOH to get a gel.
- Potassium hydroxide is a base or alkaline material, hence the name "alkaline" batteries. The active materials used are the same as in the Leclanche cell – zinc and manganese dioxide.



Construction of an Alkaline battery

Half-cell reactions

- **At the anode:** $\text{Zn}_{(s)} + 2\text{OH}^{-}_{(aq)} \longrightarrow \text{Zn}(\text{OH})_{2(s)} + 2e^{-}$
- **At the cathode:** $2\text{MnO}_{2(s)} + \text{H}_2\text{O}_{(l)} + 2e^{-} \longrightarrow \text{Mn}_2\text{O}_{3(s)} + 2\text{OH}^{-}_{(aq)}$
- **Net Cell Reaction :** $\text{Zn}_{(s)} + \text{MnO}_{2(s)} + 2\text{H}_2\text{O}_{(l)} \longrightarrow \text{Mn}_2\text{O}_{3(s)} + \text{Zn}(\text{OH})_{2(s)}$



Alkaline Battery

Advantages and Uses

1. Zinc does not dissolve as readily in alkaline medium
2. They avoid the use of the zinc-corroding ammonium ions and do not produce any gaseous products.
3. long life because there is no corrosion of Zn and maintains better voltage
4. Used in calculators and watches
5. These cells have much longer shelf life and perform better under drain and in cold weather.

Disadvantages

- Alkaline batteries are bulkier than other lithium batteries which give much higher energy.
- Alkaline batteries have a high internal resistance. This reduces the output.
- Alkaline batteries kept in devices that are not used for a long time, can leak and thus completely ruin the device itself because of the corrosive nature of the leaked material.

Primary Lithium batteries

- Lithium metal is used as an anode material due to its position as the most electropositive metal in the electrochemical series
- It has low density, thus offering the largest amount of electrical energy per unit weight among all solid elements.
- Li cannot be used with the traditional aqueous electrolytes due to the very vigorous corrosive reaction between Li and water with inflammable hydrogen as the product.
- Use of Li as an anode material with MnO_2 , liquid SO_2 (or) thionyl chlorides as the cathode, and hexafluorophosphate dissolved in propylene carbonate as a typical organic electrolyte.
- Li cells are generally properly sealed against contact with air and moisture



Li Cells with liquid or soluble cathode

- The cathodic material are liquids or gases such as SO_2 , SO_2Cl_2 (sulfuryl chloride), SOCl_2 (thionyl chloride) which dissolve in the electrolytic solvent
- E.g. in **Li/ SO_2Cl_2** cell, a Li anode, a carbon cathode and electrolyte (LiAlCl_4 in SO_2Cl_2) are used
- The discharge mechanism is:
- At anode: $2\text{Li} \longrightarrow 2\text{Li}^+ + 2\text{e}^-$
- At cathode: $\text{SO}_2\text{Cl}_2 + 2\text{e}^- \longrightarrow 2\text{Cl}^- + \text{SO}_2$
- Net reaction: $2\text{Li} + \text{SO}_2\text{Cl}_2 \longrightarrow 2\text{LiCl} + \text{SO}_2$

Cell voltage is 3.7 V

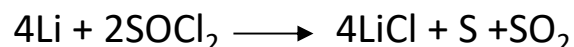
Other soluble cathode Li cells

Li/ $\text{SO}_{2(l)}$: 3V High energy density; best low-temperature performance; long shelf life. High-cost pressurized system, **Military and special industrial needs**



Li/ $\text{SOCl}_{2(l)}$: 3.6V High Energy density; long shelf life. Only low to moderate rate applications. **Memory devices; standby electrical power devices**

The highest energy density of all Lithium type cells have a service life of 15 to 20 years.



Li Cells with solid cathode

- A good example is the Li/ MnO₂ cell
- Li is the anode and a specially prepared heat treated form of MnO₂ as the cathode
- Electrolyte is Li salts in a mixture of propylene carbonate and 1,2-dimethoxy ethane
- The net cell reaction is:
- $n \text{ Li} + \text{MnO}_2 + n e^- \longrightarrow \text{Li}_n \text{MnO}_2$
- Cell voltage is 3V
- High energy density, good low-temperature performance; cost effective.
- Small in size, only low-drain applications, Electrical medical devices; memory circuits

Advantages

- High electron (energy) density
- Long shelf life
- Low self discharge
- Less maintenance
- Can provide very high current
- Used in auto focus cameras

Secondary (or) Rechargeable Batteries

- 1. Lead Acid battery**
- 2. Ni-Cd (NiCad) Battery**

Advanced Secondary (or) Rechargeable Batteries

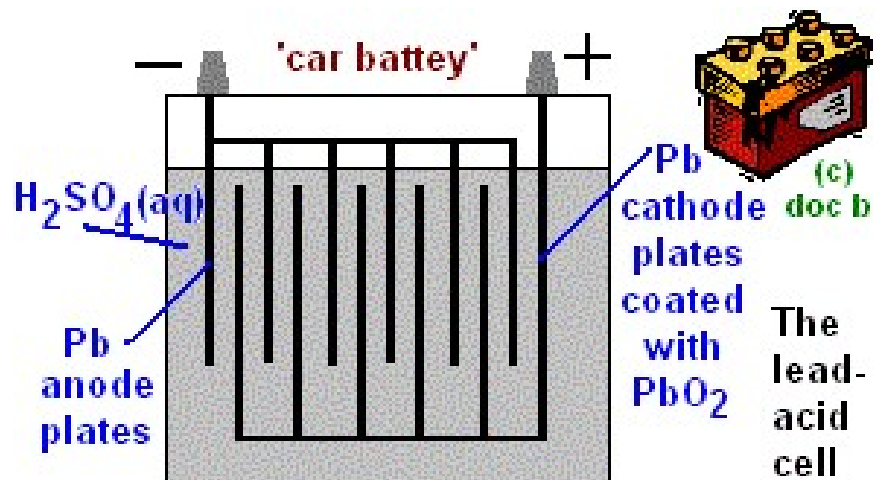
- 1. Lithium ion battery**
- 2. Nickel Metal Hydride Battery**
- 3. Li-ion polymer battery**

Lead Acid battery

- Lead-acid batteries are the oldest type of rechargeable battery, invented in 1859 by French physicist Gaston Planté.
- This acts both as electrochemical cell and electrolytic cell. While discharging it acts as electrochemical (voltaic cell) and on charging it acts as electrolytic cell.
- The maximum emf = 12V (2V cells * 6 = 12 V)



Construction of Lead Acid battery

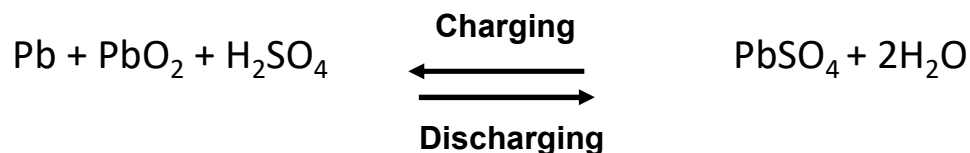


- The anode is a sheet of metallic (sponge) lead immersed in $\text{H}_2\text{SO}_{4(\text{aq})}$. The oxidation reaction is

$$\text{Pb}_{(\text{s})} + \text{SO}_4^{2-}{}_{(\text{aq})} \rightarrow \text{PbSO}_{4(\text{s})} + 2\text{e}^-$$

- The cathode is a sheet of lead dioxide, also immersed in $\text{H}_2\text{SO}_{4(\text{aq})}$. The reduction reaction is

$$\text{PbO}_{2(\text{s})} + 4\text{H}^+{}_{(\text{aq})} + \text{SO}_4^{2-}{}_{(\text{aq})} + 2\text{e}^- \rightarrow \text{PbSO}_{4(\text{s})} + 2\text{H}_2\text{O}_{(\text{l})}$$



Some aspects of Lead Acid battery

- When the storage cell is operating as a voltaic cell it is said to be discharging
- In the discharged state both electrodes turn into lead (II) sulfate (PbSO_4) and the electrolyte loses its dissolved sulfuric acid and becomes primarily water.
- during charging the sulfuric acid concentration rises, and during discharge it falls
- A side reaction which may result from over-charging is the liberation of hydrogen gas at the (-) electrode, resulting from the reduction of $\text{H}^+_{(\text{aq})}$ ions
- In the charged state, each cell contains electrodes of elemental lead (Pb) and lead (IV) dioxide (PbO_2) in an electrolyte of approximately 33.5% (6 Molar) sulfuric acid (H_2SO_4).
- An important disadvantage is that these batteries are very heavy

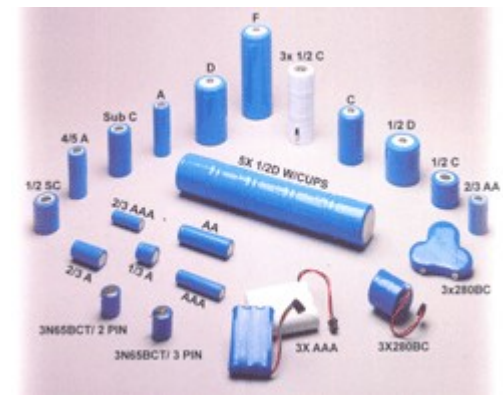
Applications

- For constant power supply for electrical vehicles,
- Gas engine ignition,
- Telephone exchangers,
- Trains,
- Mines,
- Laboratories,
- Hospitals,
- Automobiles and in power stations

Nickel-cadmium battery

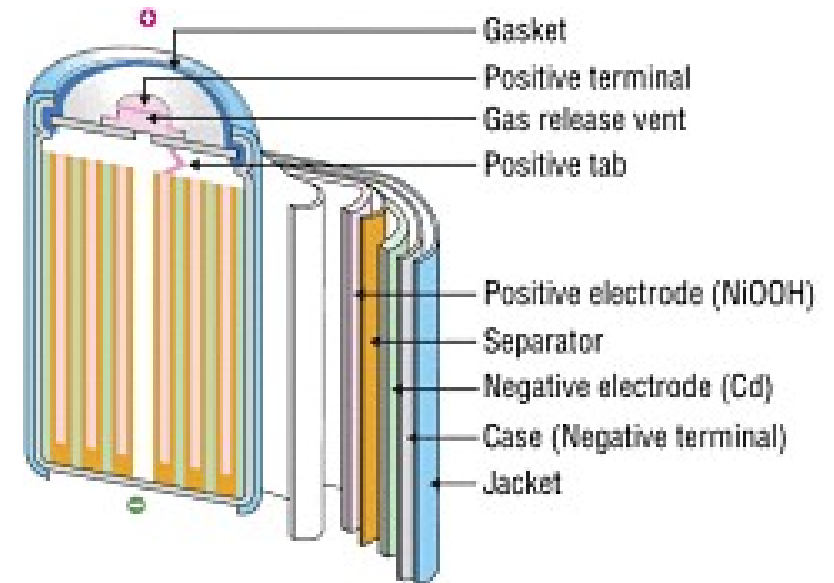


- The nickel-cadmium battery (commonly abbreviated NiCd or Nicad) is a type of rechargeable
- Nickel oxy hydroxide NiO(OH) and metallic cadmium (Cd) are used as electrodes
- Alkaline potassium hydroxide KOH electrolyte.
- A Ni-Cd battery has a terminal voltage during discharge of around 1.2 volts which decreases little until nearly the end of discharge
- Ni-Cd batteries are made in a wide range of sizes and capacities
- The materials are more costly than that of the lead acid battery, and the cells have high self-discharge rates.

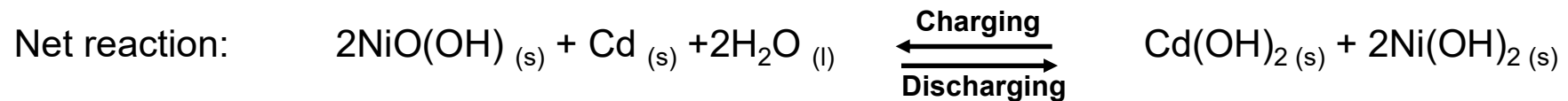
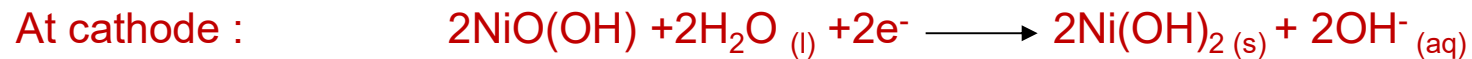
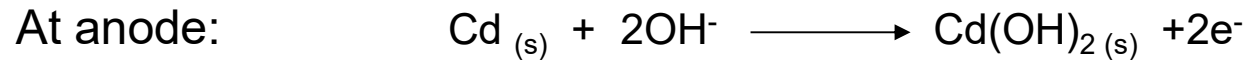


A fully charged Ni-Cd cell contains:

- a nickel(III) oxide-hydroxide positive electrode plate
- a cadmium negative electrode plate
- a separator, and
- an alkaline electrolyte (potassium hydroxide).



Discharging



Advantages

- Constant voltage (1.2V)
- No gaseous products
- Wide temperature range (Up to 70°C)
- Charging process is strongly endothermic-the battery cools during charging. This makes it possible to charge very quickly
- Rapid charge typically 2 hours, but can be as low as 10 to 15 minutes.

Disadvantages

- NiCad batteries are also prone to damage by overcharging.
- Low energy density and self discharge occurs
- Cadmium is toxic and not environment-friendly

Applications

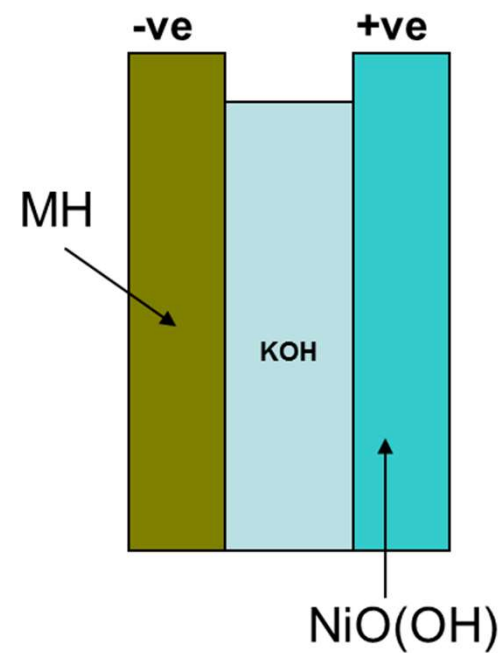
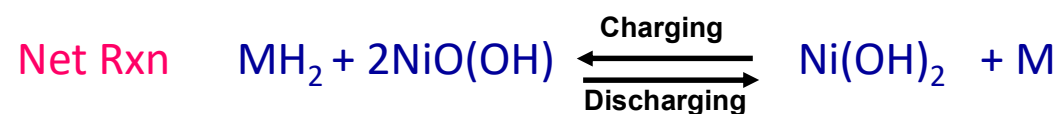
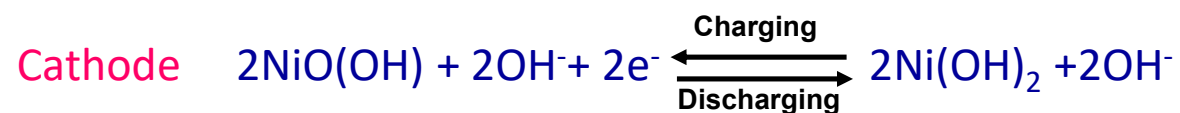
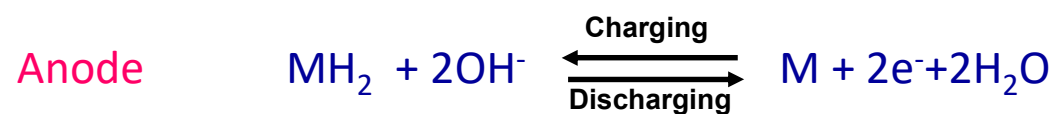
- Motorized equipments
- Power tools
- Transistors
- Electronic calculators
- Commercial and industrial portable products
- Medical instrumentation
- Emergency lighting
- Toys
- Cordless and wireless telephones
- Medical equipment
- Personal care
- Professional lighting
- Radio communication and tracking equipment
- Professional tooling
- Military equipment
- Professional electronic devices

Nickel-Metal hydride (Ni-MH) battery

- They are almost identical to NiCad cells, except that Cd is replaced by a Hydrogen absorbent alloy
- The energy density is more than double that of Lead acid and 40% higher than that of NiCad cells
- Instead of cadmium, hydrogen absorbing alloy is used as the active element at a hydrogen-absorbing negative electrode (anode).
- This electrode is made from a metal hydride (MH, ZrH_2) usually alloys of Lanthanum and rare earths that serve as a solid source of reduced hydrogen that can be oxidized to form protons.
- The components of NiMH batteries include a cathode of Nickel-oxy hydroxide, an anode of Hydrogen absorbing alloys
- Potassium-hydroxide (KOH) electrolyte.
- They are more expensive than Lead-acid and NiCad batteries, but they are considered better for the environment.
- The electrolyte is alkaline potassium hydroxide. Cell voltage is 1.2-1.5 Volts



Electrochemistry of NiMH Battery



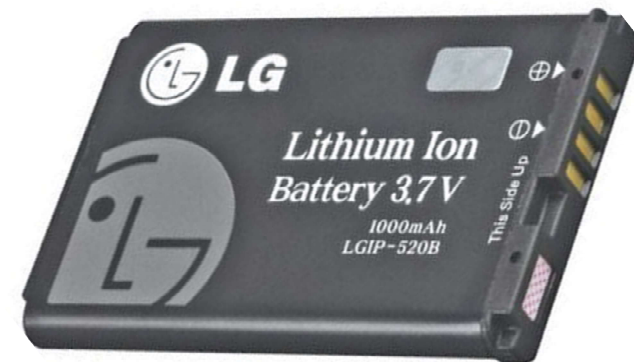
Advantages

- High energy density
- Rapid charge possible in 1 hour
- overcharging can cause deterioration of the battery. Chargers should therefore incorporate a timer to prevent overcharging.
- Because of potential pressure build up due to gassing they usually incorporate a re-sealable vent valve
- Reconditioning is possible.
- Environmentally friendly (No cadmium, mercury or lead)

Applications

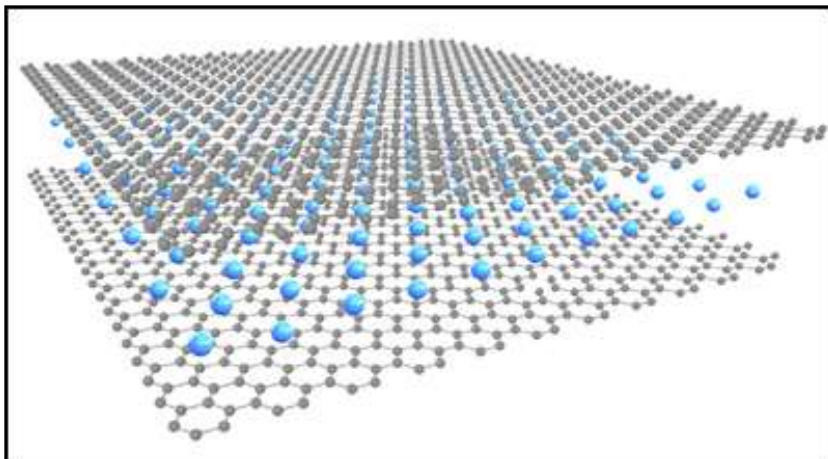
- Low cost consumer applications
- Electric razors
- Cameras
- Mobile phones
- Pagers
- Medical instruments and equipment
- Automotive batteries

Lithium-ion (Li-ion) battery LIB

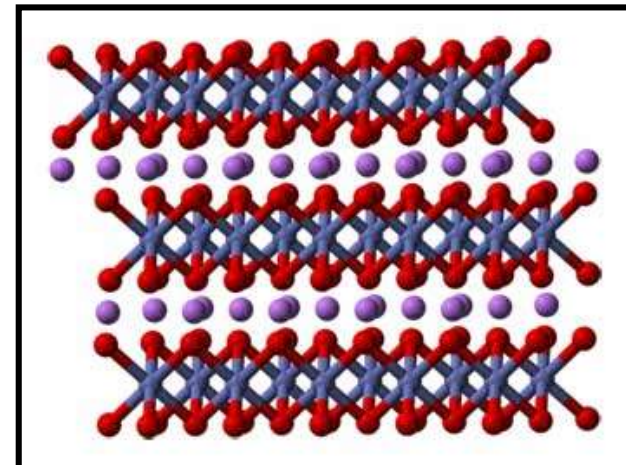


Lithium-ion (Li-ion) battery LIB

- LIB's are one of the most popular types of rechargeable batteries for portable electronics, with a **high energy density and low self-discharge**.
- The essential feature of the Lithium ion battery is that lithium ions move from the negative electrode to the positive electrode during discharge and back when charging
- To facilitate such Li ion movement, LIB's use an intercalated lithium compound as one electrode material
- Lithium-ion batteries thus operate based on what is sometimes called the "rocking chair" or "swing" effect.
- This involves the transfer of Lithium ions back and forth between the two electrodes.

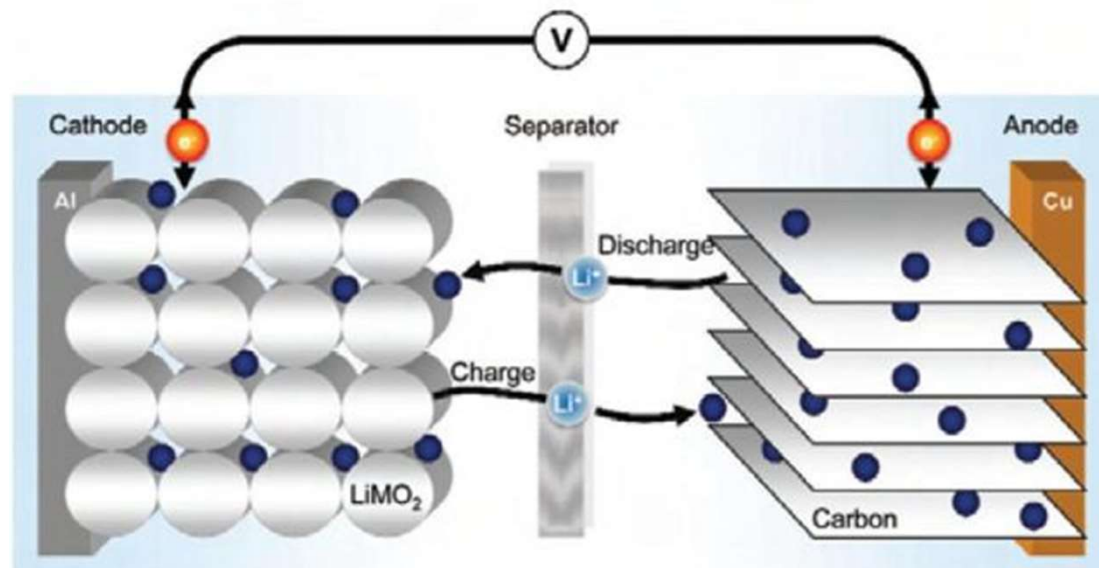


Lithium (blue spheres) intercalated between graphene sheets



Lithium cobalt oxide consists of layers of lithium (show here as purple spheres) that lie between slabs formed by cobalt and oxygen atoms (shown here as connected red and blue spheres).

- The anode of a Lithium-ion battery is composed of Lithium, dissolved as ions, into a carbon based electrode
- The cathode material is made up from Lithium liberating compounds, typically the three electro-active oxide materials, **Lithium Cobalt-oxide LiCoO_2** , **Lithium Manganese-oxide LiMn_2O_4** , and **Lithium Nickel-oxide LiNiO_2**
- Since lithium reacts violently with water, and the cell voltage is so high that water would decompose, a non-aqueous electrolyte must be used.
- A typical electrolyte is LiPF_6 dissolved in an ethylene carbonate and dimethyl carbonate mixture.



Electrode reactions

The positive electrode (cathode) half-reaction in the lithium-doped cobalt oxide substrate is:



The negative electrode (anode) half-reaction for the graphite is:



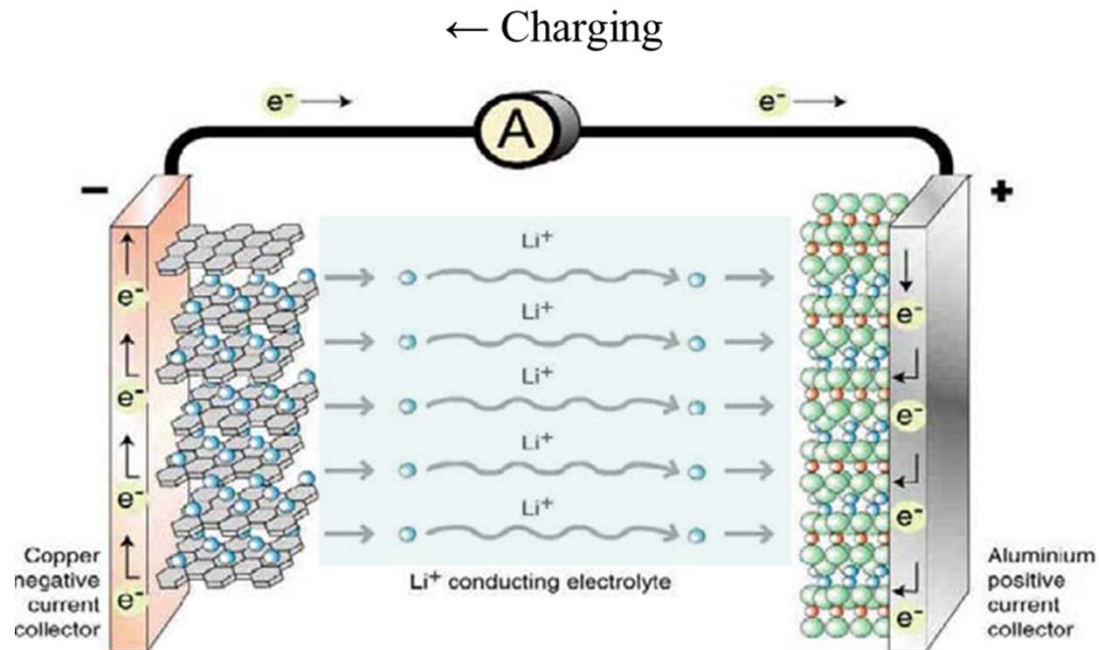
The full reaction (left to right: discharging, right to left: charging) being:



- Anode here is a non-metallic compound, e.g. carbon, which can store and exchange lithium ions.
- A lithium ion-accepting material (Intercalation), for example CoO_2 , is then used as the cathode material, and lithium ions are exchanged back (deintercalation) and forth between the two during discharging and charging. These are called intercalation electrodes.

Lithium-ion Polymer batteries

- Lithium-ion polymer batteries use Lithium-ion electrochemistry in a matrix of ion conductive polymers that eliminate free electrolyte within the cell.
- The electrolyte thus plasticises the polymer, producing a solid electrolyte that is safe and leak resistant.
- A polymer matrix, such as polyvinylidene fluoride (PVdF) or poly(acrylonitrile) (PAN), gelled with conventional salts and solvents, such as LiPF_6 is used as the electrolyte
- These cells have not reached full commercialization and are still a topic of research



Fuel cells

An electrochemical cell in which the energy of a reaction between a fuel (such as hydrogen) and an oxidant (such as oxygen) is converted directly and continuously into electrical energy.

- Fuel cells are different from batteries in requiring a continuous source of fuel and oxygen or air to sustain the chemical reaction
- **They are also known as flow cells**
- Fuel cells consist of an anode, a cathode, and an electrolyte that allows positively charged hydrogen ions (or protons) to move between the two sides of the fuel cell
- **The anode and cathode contain catalysts that cause the fuel to undergo oxidation reactions that generate positively charged hydrogen ions and electrons.**
- The hydrogen ions are drawn through the electrolyte after the reaction.
- **Electrons are drawn from the anode to the cathode through an external circuit, producing direct current electricity.**
- At the cathode, hydrogen ions, electrons, and oxygen react to form water.

Classification :

based on

temperature of

operation

1. Low Temperature fuel cells (< 100°C)

2. **Moderate Temperature fuel cells (100 to 250°C)**

3. High Temperature fuel cell (> 500°C)

4. **Solid Oxide Fuel Cell (SOFC) (1000°C)**

A typical fuel cell consists of :

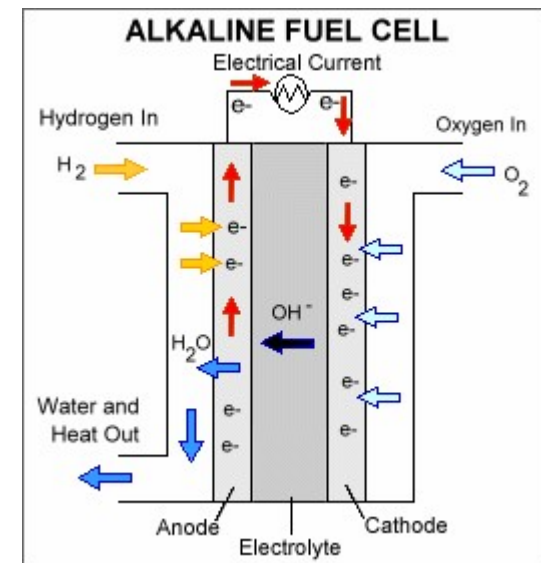
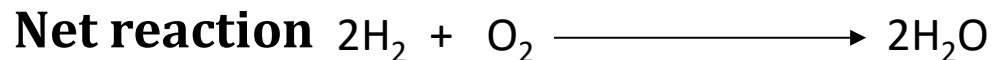
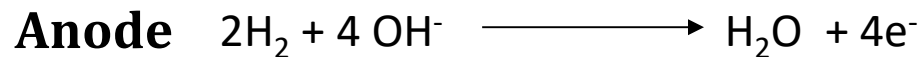
- The electrolyte substance. The electrolyte substance usually defines the type of fuel cell.
- The fuel that is used. The most common fuel is hydrogen.
- The anode catalyst breaks down the fuel into electrons and ions. The anode catalyst is usually made up of very fine platinum powder.
- The cathode catalyst turns the ions into the waste chemicals like water or carbon dioxide. The cathode catalyst is often made up of nickel but it can also be a nanomaterial-based catalyst.
- A typical fuel cell produces a voltage from 0.6 V to 0.7 V

Based on the electrolytes used, fuels cell types are

1. Alkaline fuel cells
2. Phosphoric acid fuel cells
3. Molten carbonate fuel cells
4. Polymer electrolyte membrane fuel cells
5. Solid oxide fuel cells
6. Biochemical fuel cells

Alkaline Fuel Cells (or) H₂- O₂ Fuel Cells

- Also known as the *Bacon fuel cell* after its British inventor, Francis Thomas Bacon
- The cell consists of two porous carbon electrodes impregnated with a suitable catalyst such as Pt, Ag, CoO, etc.
- The space between the two electrodes is filled with a concentrated solution of KOH or NaOH which serves as an electrolyte.
- H₂ gas and O₂ gas are bubbled into the electrolyte through the porous carbon electrodes.
- The overall reaction involves the combination of hydrogen gas and oxygen gas to form water.
- This type of cell provides a potential of about 0.9 V



- Hydrogen (diffused through anode) and oxygen (through cathode) gases are bubbled through the respective compartments.
- Electrode – porous , good conducting, excellent catalyst for the reactions that take place on their surfaces, not deteriorating by the electrolyte heat or electrode reactions.
- Graphite impregnated with finely divided platinum, or alloy of Pd, Ag and Ni serves the purpose if hydrogen is the fuel.
- Electrolyte - aqueous 30-40% KOH or H_2SO_4

Applications:

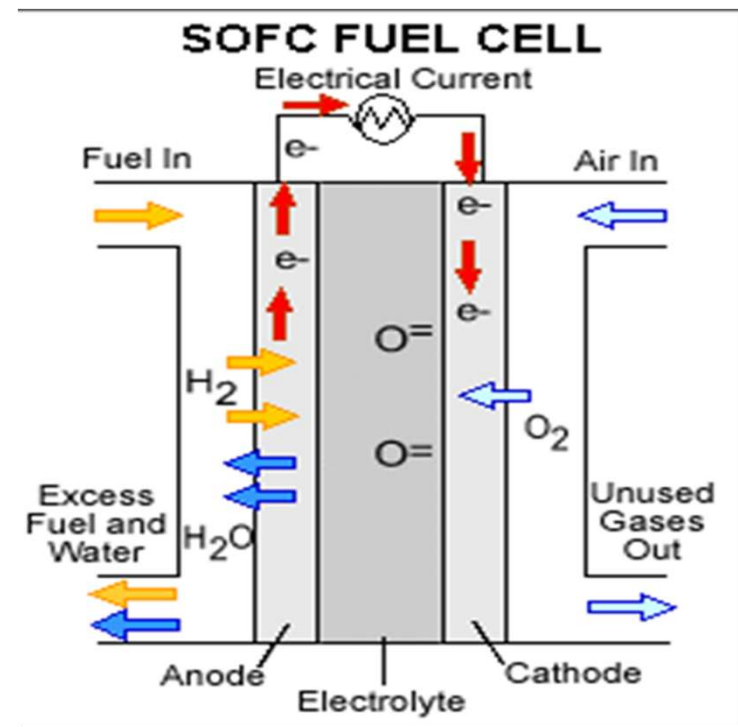
Auxiliary energy source in space vehicles, submarines or other military-vehicles.

Solid oxide fuel cells (SOFC)

- Anode, cathode and electrolyte all made up of ceramic substances
- Anode : porous, to allow the fuel to flow to the electrolyte – Nickel mixed with ceramic material of the electrolyte
- Cathode: Thin porous layer where oxygen reduction occurs
- Popular electrolyte materials include yttria-stabilized zirconia (YSZ), scandia stabilized zirconia (ScSZ) and gadolinium doped ceria (GDC)
- Operate at temperatures as high as 1000°C
- Can be configured as rolled tubes or flat plates

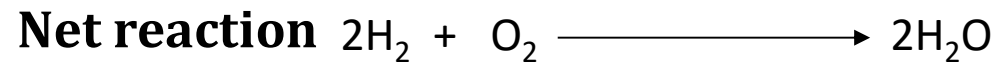
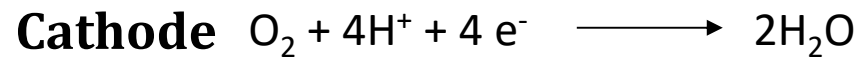
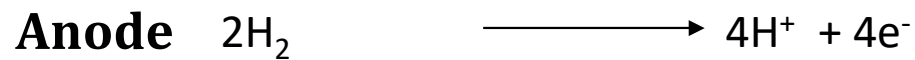
Advantages / Disadvantages

- High efficiency
- Long term stability
- Fuel flexibility
- Low emissions
- High operating temp – longer start up times
- Mechanical / Chemical compatibility issues.



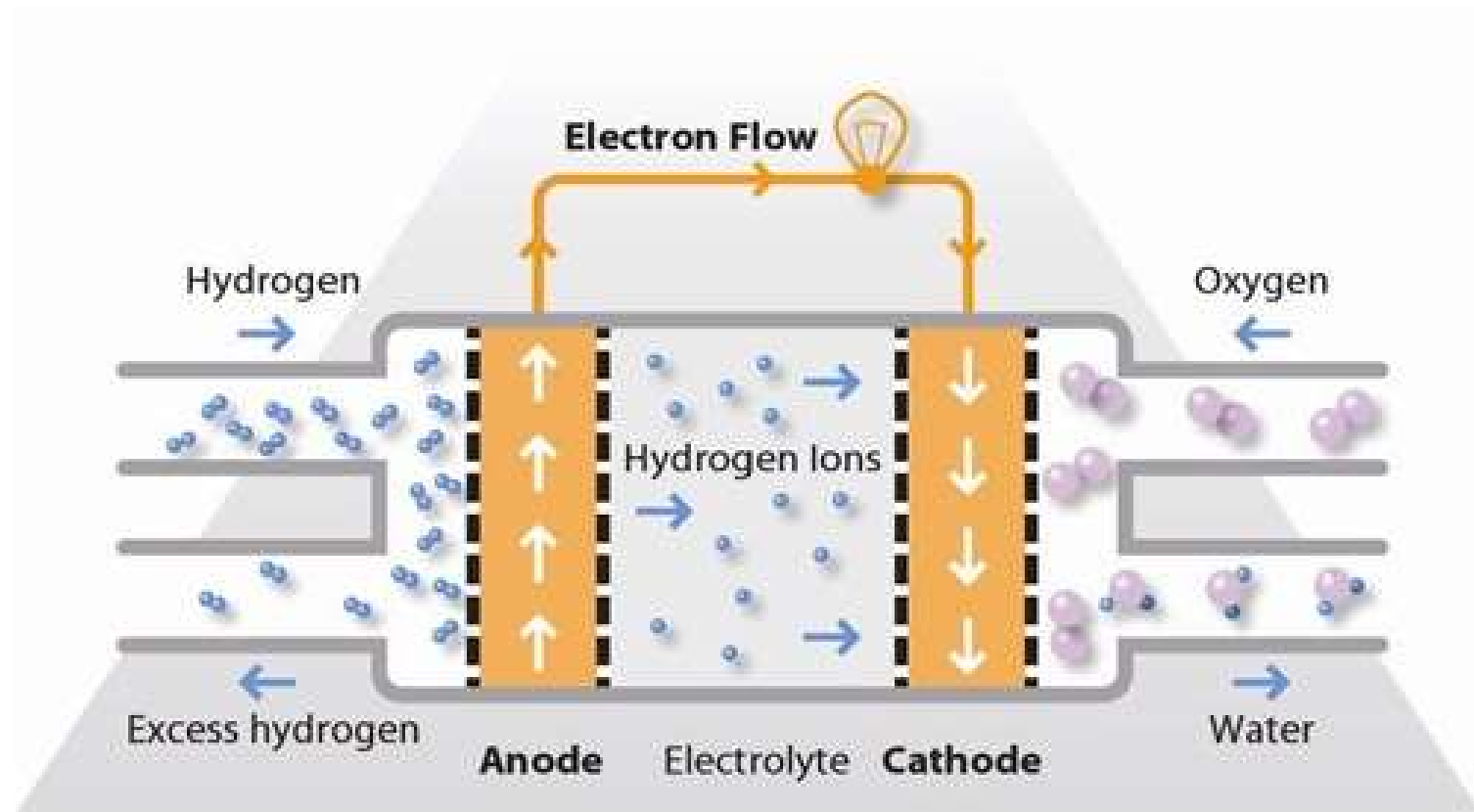
Applications

- Auxiliary power units in vehicles
- Stationary power generation
- By product gases – channeled to turbines to generate more electricity – cogeneration of heat and power and improves overall efficiency



Polymer membrane fuel cells

- The proton exchange membrane fuel cell (PEMFC) uses a water- based, acidic polymer membrane as its electrolyte, with platinum-based electrodes.
- PEMFC cells operate at relatively low temperatures (below 100 degrees Celsius)
- PEMFC cells are currently the leading technology for light duty vehicles and materials handling vehicles, and to a lesser extent for stationary and other applications.
- The PEMFC fuel cell is also sometimes called a polymer electrolyte membrane fuel cell (also PEMFC)



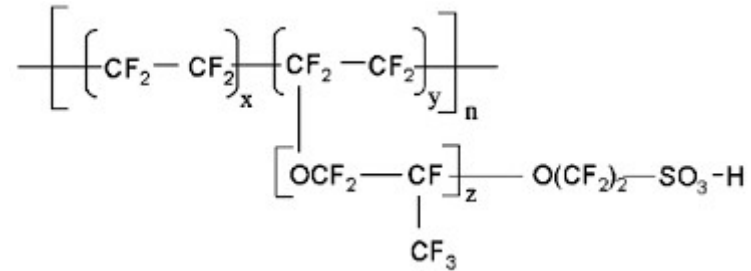
To function, the membrane must

- conduct hydrogen ions (protons) but not electrons as this would in effect "short circuit" the fuel cell.
- also not allow either gas to pass to the other side of the cell, a problem known as gas crossover
- be resistant to the reducing environment at the cathode as well as the harsh oxidative environment at the anode.

WORKING

- Hydrogen fuel is processed at the anode where electrons are separated from protons on the surface of a platinum-based catalyst.
- The protons pass through the membrane to the cathode side of the cell while the electrons travel in an external circuit, generating the electrical output of the cell.
- On the cathode side, another precious metal electrode combines the protons and electrons with oxygen to produce water, which is expelled as the only waste product; oxygen can be provided in a purified form, or extracted at the electrode directly from the air.

The most commonly used membrane is Nafion which is a sulfonated tetrafluoroethylene based fluoropolymer-copolymer



Alternatives to Nafion include

- 1) PVDF (Poly Vinylidene Fluoride),
- 2) heterocyclic polymers such as PBI (Polybenzimidazole)
- 3) sulfonated aromatic hydrocarbons (SAPs).

Solar cells

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is the creation of voltage and electric current in a material upon exposure to light

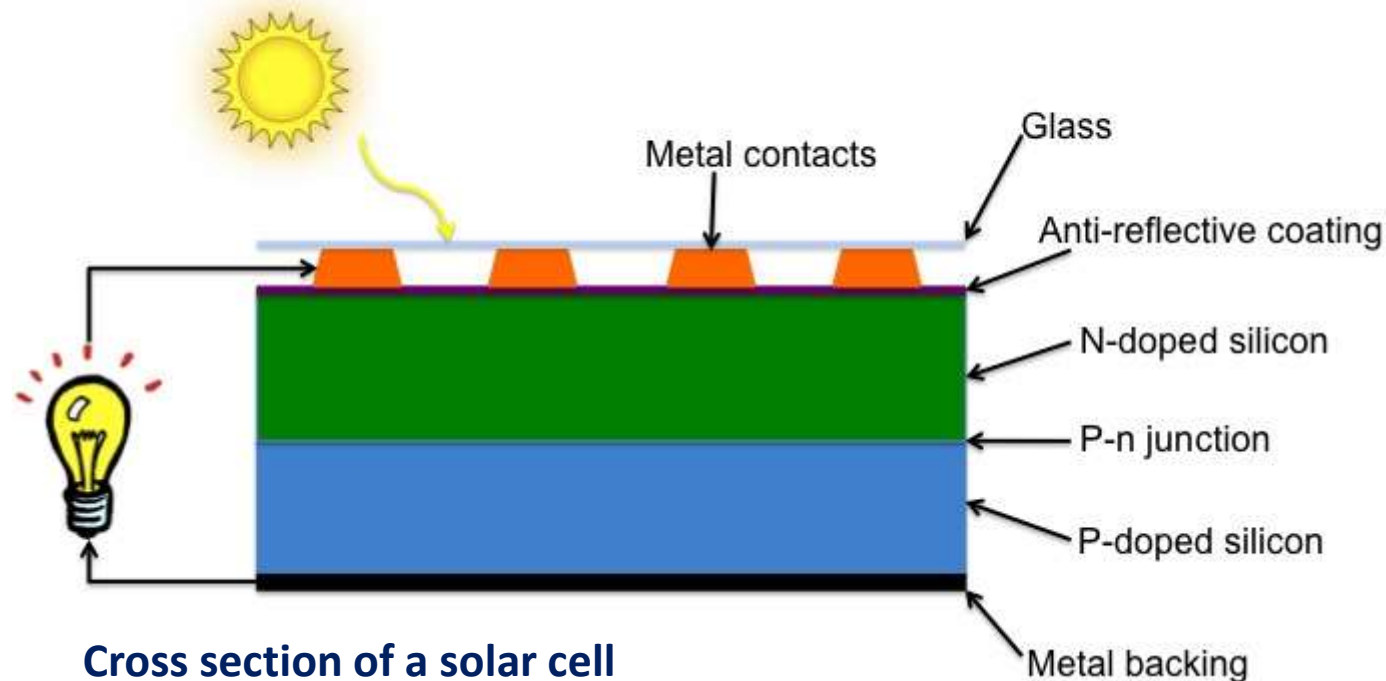
The operation of a photovoltaic (PV) cell requires three basic attributes:

1. The absorption of light, generating electron-hole pairs
2. The separation of charge carriers of opposite types.
3. The separate extraction of those carriers to an external circuit.



How Do Silicon Solar Cells Work?

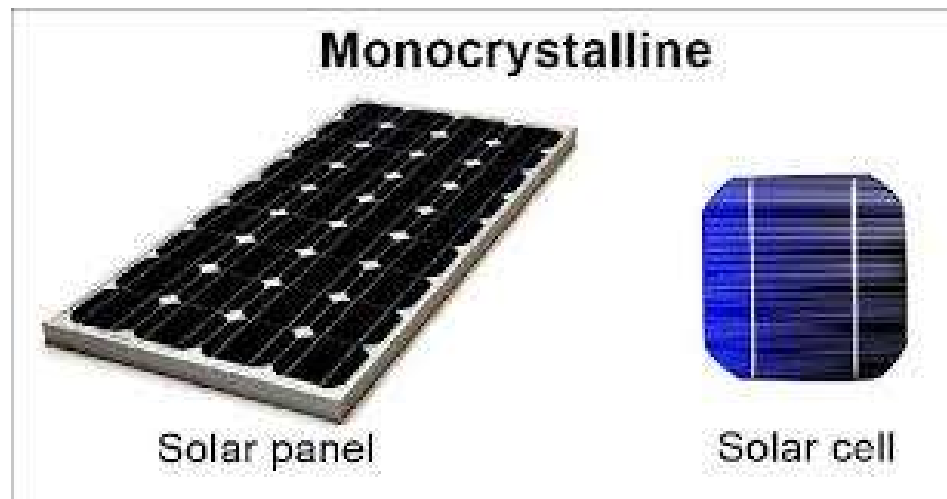
- Pure crystalline silicon is a poor conductor of electricity as it is a semiconductor material at its core.
- When trivalent impurities like boron or gallium are doped, it results in p-type Si material
- When pentavalent impurities like Phosphorous or arsenic are doped, we get n-type Si
- In a solar cell, the layers are positioned next to each other and that way an electric field is created.
- When the sunlight hits the solar cell, the energy stimulates electrons that leave holes behind.
- These migrate to the electrodes in the cell because of the presence of the electric field. In this way, electricity is generated.



Types of Silicon Solar Cells

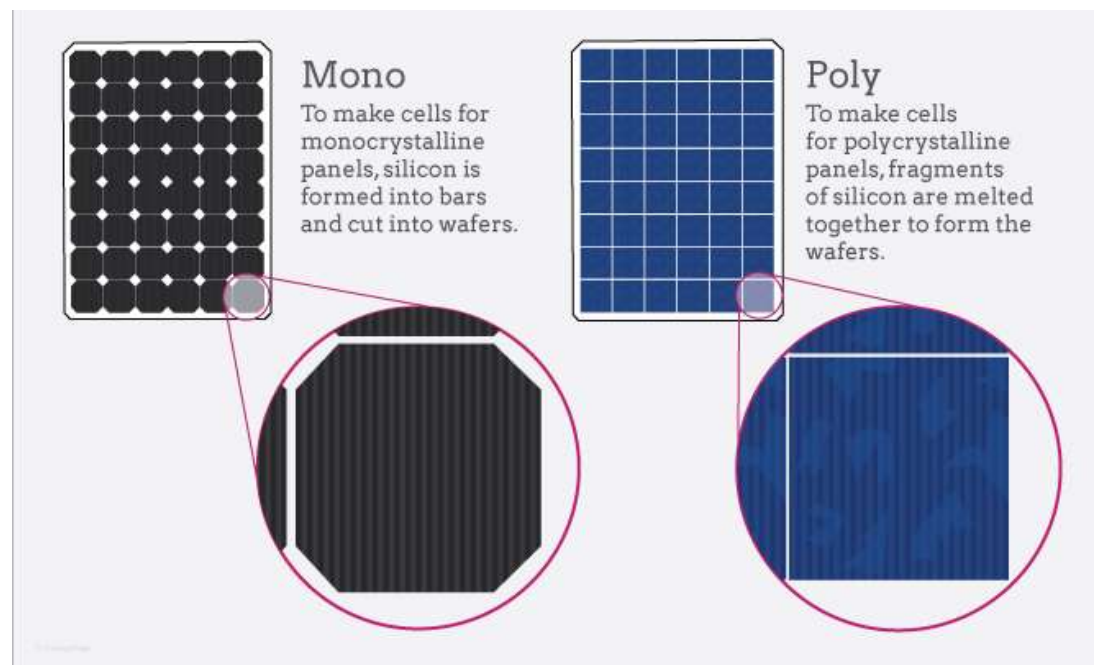
Monocrystalline Solar Cells

- Monocrystalline solar cells, also called "single crystalline" cells are identified by their dark black colour.
- Monocrystalline solar cells are made from a very pure type of silicon, which makes them the most efficient material for converting sunlight into electricity.
- In addition, monocrystalline solar cells are also the most space-efficient.
- Another advantage of monocrystalline cells is that they last the longest of all types - many manufacturers offer warranties of up to 25 years on these types of photovoltaic systems.
- Monocrystalline cells are the most expensive option, mostly because the four sided cutting process results in wasting a lot of silicon, sometimes more than half.
- The cheaper alternatives for consumers would be polycrystalline cells.



Polycrystalline Solar Cells

- Polycrystalline solar cells, also known as polysilicon and multi-silicon cells, were the first solar cells presented to the industry, in the beginning of the 1980s.
- Polycrystalline cells do not undergo the cutting process used for monocrystalline cells. Instead, the silicon is melted and poured into a square mould, hence the square shape of polycrystalline.
- This makes polycrystalline solar cells much more affordable, as hardly any silicon is wasted during the manufacturing process.
- On the minus side, they are less efficient and require more space than single crystalline cells, due to the fact that the purity level is lower in polycrystalline cells.
- Another disadvantage is that polycrystalline has lower heat tolerance than monocrystalline, meaning that they are unable to function as efficiently in high temperatures.



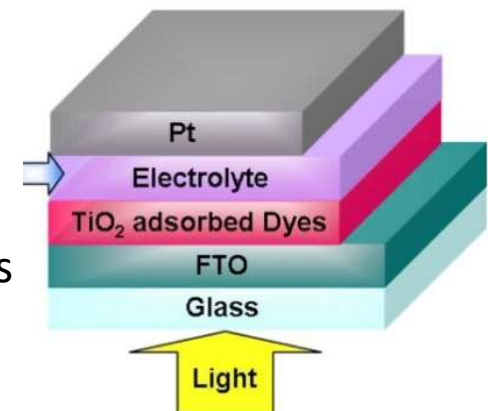
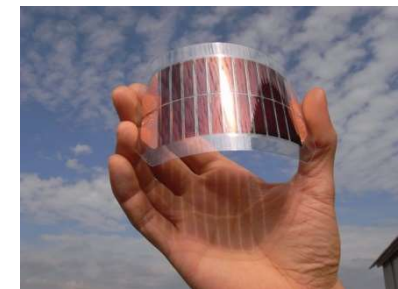
Amorphous Solar Cells

- The silicon is not structured or crystalline.
- In the past, amorphous solar cells were used for smaller-scale applications, such as pocket calculators, because their power output was relatively low.
- Amorphous silicon solar panels are a powerful and emerging line of photovoltaic systems that differ from crystalline silicon cells in terms of their output, structure, and manufacture.
- The material costs are reduced since amorphous silicon only requires about 1% of the silicon that would have been used to produce a crystalline-silicon based solar cell.
- The development process of amorphous silicon solar panels has made them more flexible and lightweight, which makes the transportation and installation of the panels less risky.
- A flexible thin-film module renders amorphous solar cells suitable even for curved surfaces.
- One of the drawbacks is the lower efficiency rate of amorphous thin-film solar cells. However, the technology is new, and efficiency rates are thought to increase with technological breakthroughs in the near future.

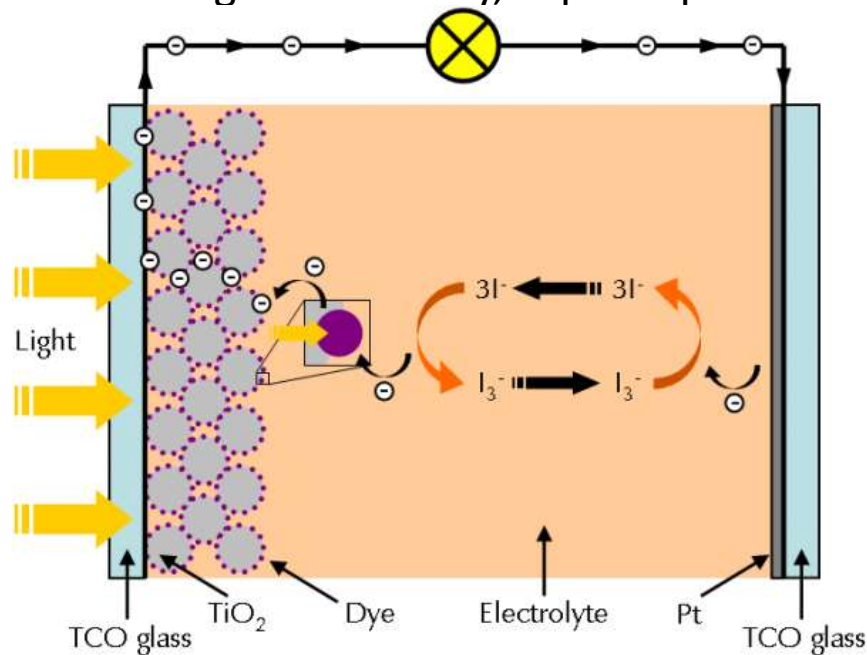


Dye sensitized solar cells

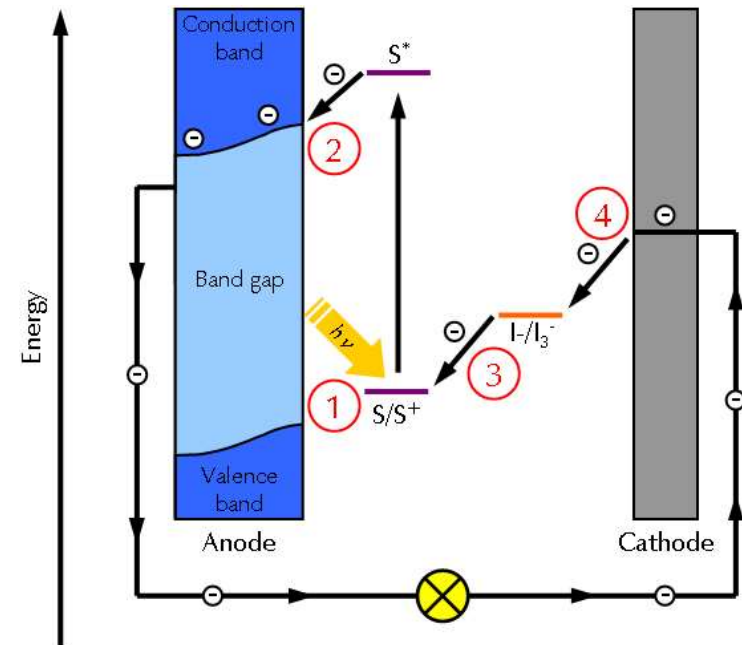
- This new class of advanced solar cell can be likened to artificial photosynthesis due to the way in which it mimics nature's absorption of light energy.
- Manufacturing of DSCs is simple, mostly low cost, and incorporate environmentally friendly materials. They have a good efficiency (about 10-14 %) even under low flux of sunlight.
- The anode of a DSC consists of a glass plate which is coated with a transparent conductive oxide (TCO) film. Indium tin oxide (ITO) or fluorine doped tin oxide are most widely used. A thin layer of titanium dioxide (TiO_2) is applied on the film. The semiconductor exhibits a high surface area because of its high porosity.
- The anode is soaked with a dye solution which bonds to the TiO_2 . In some laboratory cells plain fruit juice which contain pigments can be used. These pigments are able to convert light energy into electrical energy.
- The cathode of a DSC is a glass plate with a thin Pt film which serves as a catalyst. An iodide/triiodide solution is used as the electrolyte.
- Both electrodes are pressed together and sealed so that the cell does not leak. An external load can be powered when light shines on the anode of the dye solar cell.



- The dye is the photoactive material of DSSC, and can produce electricity once it is sensitized by light
- The dye catches photons of incoming light (sunlight and ambient artificial light) and uses their energy to excite electrons, behaving like chlorophyll in photosynthesis
- The dye injects this excited electron into the Titanium Dioxide (a white pigment commonly found in white paint)
- The electron is conducted away by nanocrystalline titanium dioxide (a nano-scale crystallized form of the titanium dioxide).
- A chemical electrolyte in the cell then closes the circuit so that the electrons are returned back to the dye
- It is the movement of these electrons that creates energy which can be harvested into a rechargeable battery, super capacitor or another electrical device.



The set up



The energy level diagram

The DSSC has a number of attractive features;

- it is simple to make using conventional roll-printing techniques,
- is semi-flexible and semi-transparent which offers a variety of uses not applicable to glass-based systems, and
- most of the materials used are low-cost.

Disadvantages

- The major disadvantage to the DSSC design is the use of the liquid electrolyte, which has temperature stability problems
- Another disadvantage is that costly ruthenium (dye), platinum (catalyst) and conducting glass or plastic (contact) are needed to produce a DSSC.
- A third major drawback is that the electrolyte solution contains volatile organic compounds (or VOC's), solvents which must be carefully sealed as they are hazardous to human health and the environment