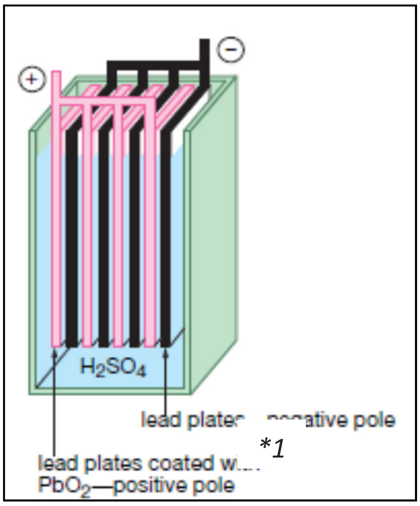
CHEMISTRY

Galvanic Cells Research

Lead-Acid Cell



The lead-acid cell, which is also known as the lead accumulator makes up the rechargeable storage batteries commonly used today as car batteries. It was invented by the French physician, Gaston Plantè in 1859. It is a galvanic cell which is made up of a porous lead plate and a lead sheet coated with lead(IV) oxide (PbO_2). Sulfuric acid with a concentration of about 6 mol/L acts as the electrolyte in both cells. The lead plates are closely placed together to enable the cell to generate high electric currents and are separated by a thin, perforated plastic film. A picture of what a lead-acid cell looks like is shown on the right.

When the cell delivers electric current, both the lead plates become covered with insoluble lead sulfate and then the concentration of the sulfuric acid decreases. Each cell supplies about 2 V and 6 cells can produce about 12 V (the typical car battery). The overall redox reaction is:

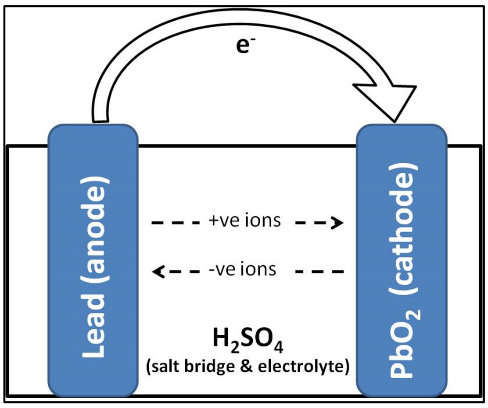
$$PbO_2(s) + Pb(s) + 4H^+(aq) + 2SO_4^{2-}(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$$

The oxidation reaction occurs in the lead plate (the anode) as shown in the equation:

$$Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2e^-$$

At the same time, the reduction reaction occurs in the plate coated with lead oxide (the cathode) and this half-reaction can be written as:

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



The electrodes where the reactions occur, the electron flow and the migration of ions are demonstrated in a schematic diagram on the left.

A lead-acid battery can be recharged by an application of external current and this can be done indefinitely. During this recharge, the redox reactions which occur are reversed.

Further information on the lead-acid cell in relation to its cost and practicality as well as social and environmental impact is shown in the table below.

Cost and practicality	• It is expensive but long lasting. • It is a durable and reliable battery which can last for many years and can be easily recharged in an indefinite number of times. • It is capable of being charged and discharged many times. • It requires at least 6 hours to be recharged. Also, it is important to avoid recharging quickly as rapid reactions can form H2 gas, which can cause an explosion. This rapid recharging can also damage the battery. • They operate in a wide range of temperatures. • It can supply high surges of current in short periods, but because it is bulky and heavy, it produces a low power. This also limits the portability of the battery. • There are many factors which shortens the life of the battery. These include internal short circuiting and release of gases which can result to loss of electrolyte. • As the battery ages, the lead plates begin to corrode which affects the capacity of the battery.

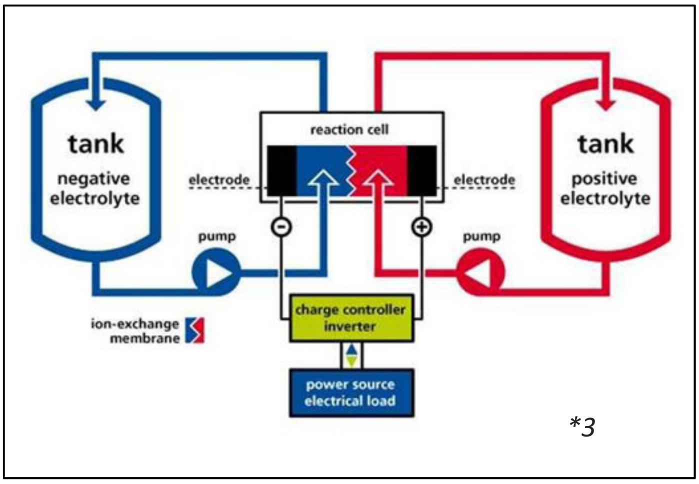
Impact on society	• It is the most commonly used battery for motor vehicles which allows for improvement of transport and travel.
	• It is a very useful storage battery for:
	    • Use in remote locations
	    • Emergency lighting for large business/offices/companies
	    • Large back-up power supplies
	• They can also be used as batteries in submarines.

Environmental Impact	• It can negatively impact on the environment as it contains lead, which is toxic to many organisms in the environment (e.g. plants and animals). • Long-term exposure to the lead content can cause brain damage and hearing impairment. • There is explosive hydrogen generated when recharging. • Improper disposal can also be hazardous to the environment. • The electrolyte is acidic which can cause severe damage if spilled. • Due to the weight of the battery and the corrosive lead plates, it contributes to waste pollution. • It is a recyclable battery, which can be considered as an advantage as this can reduce the use of new resources and batteries for cars.

Vanadium Redox Cell

The vanadium redox cell was invented by Professor Maria Skylla-Kazacos and her research team at the University of New South Wales (UNSW) in 1985. This cell makes up the rechargeable vanadium redox flow battery and each cell generates approximately 1.26 volts. This is a useful battery as it stores charge in its electrolytes and draws this stored energy converting it into electrical energy.

It is a cell which involves two half-reactions involving vanadium in several different oxidation states. Both electrodes in the half-cells are contain solid graphite and porous. The electrolytes within these half-cells consist of vanadium ions with oxidation states +2 and +1 (in the anode) and the vanadium ions with oxidation states +4 and +5 (in the cathode). These are stored in tanks separated by a porous (ion-exchange as shown in the diagram) membrane. These electrolytes in the compartments are pumped through a battery stack and into a cell unit (reaction cell) where the chemical energy stored in the vanadium solutions is becomes electrical energy.



A schematic diagram of the structure of this cell can be seen on the left. As shown in this diagram the blue tank contains the negative electrolyte which is the vanadium solutions with valencies +2 and +1 while the red tank contains the positive electrolyte which is the solutions with valencies +4 and +5.

The reaction occurs when the solution of VSO4, where vanadium has a valency of +2, flows through the anode compartment where the vanadium ion oxidises into a V3+ and releases electrons to the external circuit. The oxidation half-equation is:

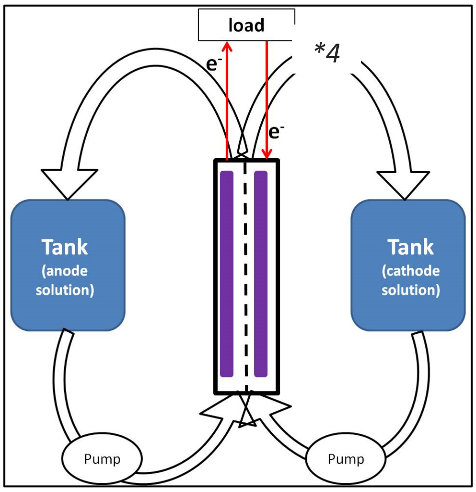
$V2+(aq) \rightarrow V3+(aq) + e-$

At the same time, a solution of (VO2)2SO4, where vanadium has a valency of +5, flows through the cathode compartment and becomes reduced to VO2+. The reduction half-equation for this reaction is:

$VO2+(aq) + e- + 2H+ \rightarrow VO2+(aq) + H2O$

During the battery operation, the sulfate ions migrate through the porous membrane to preserve the electrical neutrality of the whole cell.

When the cell is generates electricity, the reactant solutions are being recirculated until the concentrations of the vanadium solutions drop considerably and allow the transfer of electrons (from the anode to the cathode). This is shown in the diagram on the right. Also, the positive vanadium ions move from the anode to the cathode while the negative vanadium ions move from the cathode to the anode. It can then be recharged by replacing the solutions with fresh ones or by passing an electric current through it and reversing the flows of the solutions. During this recharge, the half-reactions are reversed.



Further information on the lead-acid cell in relation to its cost and practicality as well as social and environmental impact is shown in the table below.

Cost and practicality	• Initially, it has a high cost but can be produced relatively cheaply. • It is a rechargeable battery which can store very large amounts of energy. • It can be recharged at a low voltage but generate a high voltage. • It can be quickly and easily recharged and capacity of the charge can be easily increased. • It can be stored completely discharged for long periods and its ability as a battery is not affected. • The vanadium solutions are present in both compartments which allows for less contamination and longer life of the battery. • The operation of the battery is complicated because of the tanks and different vanadium ions solutions.

Impact on society	• It has a significant impact on society in regards with storing and generating electrical energy. These include:
	  ◦ Electrochemical storage of solar energy
	  ◦ Storage of wind energy collected by wind generators in low wind areas
	  ◦ Assist power stations in generating electricity
	  ◦ Assist electrical generators with large surges in demand
	  ◦ Used as an emergency back-up battery system.
	• It can also be used as a durable power source for electric vehicles.
	• It can act as a replacement for lead-acid storage batteries which are used to power up diesel engines.
	• The development of this battery has also led to the adoption of military electronics as it can be stored for a long period of time with little maintenance.

Environmental impact	• The vanadium solutions are not hazardous to the environment and are reusable. • There is little explosive hydrogen generated in recharging. • It doesn't need to be disposed. • Its use and development is more energy efficient than most batteries as the reactions involved in the cells are reversible. • It is known to have the lowest ecological footprint as it does not use any toxic heavy metals, for example, cadmium and lead.

Comparison and Evaluation

Chemistry:

The lead-acid cell and the vanadium redox cell both have similarities and differences in terms of their chemistry. One similarity is that both chemical reactions within the cells can be reversed which allows both to be recharged easily. This is beneficial as their ability to be recharged allows for long-term use and other functions. On the other hand, their difference is that lead-acid cell consists of metal electrodes (lead) while vanadium redox cell contains porous and graphite.

Another difference is between their redox reactions. The reactions which occur within the lead-acid cell involve the formation of lead-oxide. This is different to the reactions in the vanadium redox cells since no new substances are formed during the reaction, only changes in valencies.

In relation to reactions within the cells, the vanadium redox cell has a much more complex system with its different oxidation states of vanadium solutions compared to the lead-acid cell's lead plates. Therefore, the lead-acid cell can be produced easier and quicker.

Cost and Practicality:

In terms of their cost, lead-acid batteries are more likely to be less expensive to manufacture and to purchase than vanadium redox flow batteries. This is because lead can be recycled and is more commonly used in society. The operation of lead-acid cell is simpler than the vanadium redox cell which makes it easier to make, therefore making its production cheaper. However, the lead-acid cell is bulky and heavy, which does not make it suitable for use in small and portable appliances. This also applies to the vanadium redox cell since it is still in prototype stage of its developments.

According to the research, both are reliable and durable batteries as they can both be recharged many times. However, it is evident that the vanadium redox cell is more suitable for long-term use. This is because the battery is not affected if it is discharged and stored for long periods of time. In contrast to this, the lead plates in the lead-acid cell can corrode over time which then affects the ability of the battery. There are also setbacks with recharging the lead-acid cell which include long periods of recharge and rapid recharging can permanently damage the battery. On the contrary, recharging vanadium redox flow batteries is very simple as it involves only an application of electricity or the replacement of its electrolyte. Therefore, it is clear that vanadium redox cell is suitable for long-term use.

Vanadium redox flow batteries only contain vanadium solutions as electrolytes. This is a technical benefit as this prevents contamination between the two half-cells, allowing for longer battery life. This is different with lead-acid batteries since the lead electrodes can corrode which significantly shorten the life of the battery.

Lead-acid cells can supply high surges of current, but is very bulky while vanadium redox cells store large amount of energy but its system is complex. This proves that both batteries are useful in different but have shortcomings in relation to their design. However, it may be better to increase manufacture of vanadium redox flow batteries as its use has many potential benefits for the future.

Impact on Society:

Both batteries have significant impacts on society. Today, lead-acid batteries are widely used as batteries for cars while vanadium redox flow batteries are used as storage batteries. The use of lead-acid cells in car batteries has improved the capability of people to move around and travel long distances. Both are used as emergency back-up power supplies which is beneficial, especially for businesses and offices that require electricity at all times of the day.

These batteries are also essential to people living in remote area since lead-acid batteries can be used as storage batteries in very remote locations while vanadium redox flow batteries can be used as storage for solar and wind energy in remote areas. Vanadium redox flow batteries also assist large power stations in generating electricity and assist generators with large surges of electricity in demand. This has then allowed for power stations and businesses meeting market and customer needs and on a larger scale, increase economic activity.

According to the research, vanadium redox flow batteries can potentially be used as replacement for lead-acid batteries for use in car engines and can be used for batteries in electric vehicles. The development of this battery has also led to developments of other electronic developments proving that it has a greater impact on society and technology than lead-acid batteries. It is also evident that vanadium redox flow batteries can assist in other developments that can be beneficial in the future. Therefore, it is seen that vanadium redox flow batteries have impacted significantly on society, much more than lead-acid batteries have.

Environmental Impact:

In relation to the production of lead-acid batteries and vanadium redox flow batteries, it is evident that vanadium redox flow batteries are more ecologically sustainable to use. This is because the lead-acid cell contains toxic lead that is hazardous for living organisms and the environment when disposed while the vanadium solutions in the vanadium redox cell do not harm the environment at all. Vanadium redox flow batteries do not need to be disposed. The lead-acid cells also contain sulfuric acid which can damage the environment if spilled while vanadium redox cells contain no acidic electrolytes.

Also, the vanadium solutions in the vanadium redox cells are fully reusable in contrast to the lead plates in the lead-acid cell. Parts of these lead plates must be recycled while some are thrown away because of corrosion, which also contributes to waste pollution. On the other hand, because it is a recyclable battery, it allows for reduced production of new components for car batteries and reduced use of new resources. Exposure to lead in the lead-acid cells after their disposal can also be harmful to humans as it can cause brain damage and diseases. The vanadium redox flow batteries, on the other hand, have no severe impacts when exposed to human beings.

The operation of vanadium redox flow batteries is also more energy efficient than the lead-acid batteries. Also, the use of lead-acid batteries in cars contributes to air pollution and the production of greenhouse gases.

Even though both are very useful and durable batteries, the production of lead-acid cells should be reduced as it has severe environmental effects when disposed while vanadium redox flow batteries are harmless to the environment.