Online Radio & Electronics Course

Reading 16

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ELECTRIC CELLS & BATTERIES

PREFACE

There are many different types of batteries today. The basic principles for all of them is the same as the ones I will cover here. This is a broad overview of the subject, which will more than cover what you will need to know for the exam. In fact there is much material here that you do not need to know. However, without the preliminary overview I would just have to give you the bare facts and say "remember this", not a pleasant way of learning, at least I don't think so.

It might seem a bit strange, but lets start off our discussion about batteries by starting with corrosion. The two topics are related chemically and knowledge of corrosion is useful particularly when it comes to antennas.

CORROSION

Corrosion is a chemical reaction. Corrosion involves removal of metallic electrons from metals and the formation of more stable compounds such as iron oxide (rust), in which the free electrons are usually less numerous. In nature, only rather chemically inactive metals such as gold and platinum are found in pure or nearly pure form; most others are mined as ores that must be refined to obtain the metal. Corrosion simply reverses the refining process, returning the metal to its natural state. Corrosion compounds form on the surface of a solid material. If the compounds are hard and impenetrable, and if they adhere well to the parent material, the progress of corrosion is arrested. If the compound is loose and porous, however, corrosion may proceed swiftly and continuously.

Aluminium is a good example. When aluminium corrodes it becomes covered with aluminium oxide. Aluminium oxide adheres well to aluminium and prevents further corrosion. This makes aluminium an excellent choice for antennas. An added bonus is its light weight and strength.

HOW THINGS CORRODE

If two different metals are placed together in a solution (electrolyte), one metal will give up ions to the solution more readily than the other. This difference in behaviour will bring about a difference in electrical voltage between the two metals. If the metals are in electrical contact with each other, electrons will flow between them and they will corrode; this is the principle of the galvanic cell or battery. Though useful in a battery, this reaction causes problems in a structure. For example, steel bolts in an aluminium framework may, in the presence of rain or fog, form multiple **galvanic** cells at the point of contact between the two metals, corroding the aluminium.

Note: an electrolyte is any liquid that conducts electricity.

With corrosion, the electric cell effect of dissimilar metals in the presence of an electrolyte is undesirable. However, it is exactly what we desire in an electric cell.

Although the term battery, in strict usage, designates an assembly of two or more voltaic **cells** capable of such energy conversion, it is commonly applied to a single **cell** of this kind.

THE VOLTAIC CELL

When two different electrodes are immersed in an electrolyte the chemical reaction which takes place results in a separation of charges. The arrangement required to convert chemical energy into electrical energy is called the voltaic cell.

The charged conductors are the electrodes, serving as the connection of the cell to an external circuit. The potential difference resulting from the separated charges enables the cell to function as the source of applied voltage.

Electrons from the negative terminal of the cell flow through the external circuit and return to the positive terminal. The chemical action in the cell continuously separates charges to maintain the terminal voltage that produces the current in the circuit.

AN EXPERIMENT

If you have a voltmeter with a low DC volts scale you can easily demonstrate the action of a voltaic cell. All you need is two different conductors and some type of electrolyte. I have had great success using a lemon or an orange. Just take the lemon and push two electrodes into it. I have used different nails, paper clips, almost anything will work. Place your voltmeter across the conductors and you will measure a potential difference, usually a significant fraction of a volt.

SEPARATION OF CHARGES

When metals dissolve in an electrolyte, the chemical action of forming the solution causes separation or dissociation of the molecules, which results in charged ions.

Figure 1 shows a zinc electrode immersed in ammonium chloride (sal-ammoniac) solution as an electrolyte.

Where the zinc electrode contacts the solution, molecules of zinc dissolve to form a different compound, which is zinc ammonium chloride. This chemical reaction requires zinc ions. Each zinc ion in the solution

Figure 1.

Negative Zinc Electrode

Postive Zinc Ions

Zn++

Ammonium Chloride - electrolyte
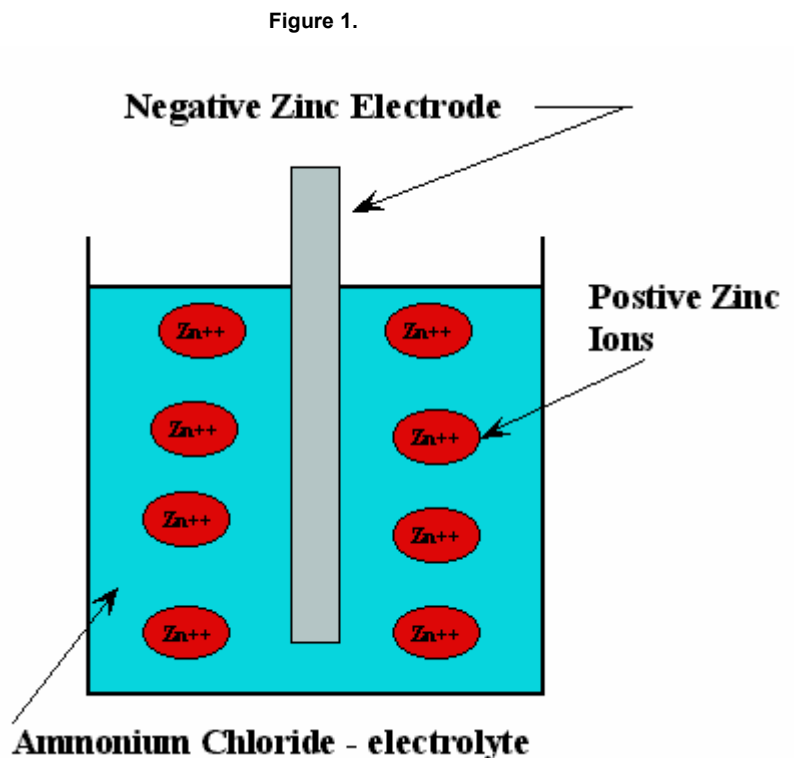
is positive, with a deficiency of two electrons. For every molecule of zinc dissolved in the solution there are 2 excess electrons on the zinc electrode. As a result the entire zinc electrode has excess electrons that make it negative with respect to the solution. If we added another electrode, other than zinc to the solution, the result is a voltaic cell with a potential difference between the electrodes.

When the cell is connected to an external circuit current flows from the negative electrode through the circuit and back to the positive electrode. This current tends to neutralise the charges generated by the cell. The chemical reaction will increase, and the cell works harder to maintain the separation of charges on the electrodes. With a negative zinc electrode as shown above, as more electrons are lost through the external circuit, more ions can be formed by zinc dissolving in the electrolyte.

One of the first practical batteries developed used zinc and copper electrodes immersed in ammonium chloride. These early cells were assembled using glass jars. To obtain the required output voltage the cells (jars) would be connected in series. These banks of cells connected together were called a voltaic pile; we call it a battery today. Something for which I am pleased as whenever I hear or read the term voltaic pile I think of a haemorrhoid with a potential difference.

PRIMARY CELLS

In a primary cell, the chemical action of forming the solution is not reversible. For instance zinc can dissolve in ammonium chloride, but the process cannot be reversed to form the zinc electrode from the solution.

SECONDARY CELLS

In secondary cells the chemical action occurring in the electrolyte can be reversed. The electrodes can dissolve in the solution when the cell provides current to the external circuit. In this case the cell is discharging. When an external voltage is applied to the cell to make current flow in the reverse direction, the metal comes out of the solution and is deposited back on to the electrodes, recharging the cell.

Since a secondary cell can be recharged it is also called a storage cell.

The carbon-zinc dry cell is a modern day version of the LeClanche cell – see figure 2.

We will look at this cell with a view to understanding how most cells work in general. You do need to know a couple of things specific to other cells and these will be covered in this reading.

The LeClanche cell is a zinc-carbon cell. The carbon rod in the centre is the positive electrode and the zinc case is not only the negative electrode but also the housing for the entire cell. The electrolyte in the cell is ammonium chloride. The cell is a primary cell in that it cannot be recharged. The Eveready Red, is a modern zinc-carbon cell.

As the cell discharges the zinc electrode becomes dissolved in the ammonium chloride electrolyte. The electrolyte is in the form of a paste. The cell is completely discharged when the electrolyte is converted to zinc ammonium chloride, which usually corresponds with the zinc in the zinc case almost being depleted. I say almost as the cell is usually designed for the electrolyte to wear out first. Early carbon-zinc cells would often leak
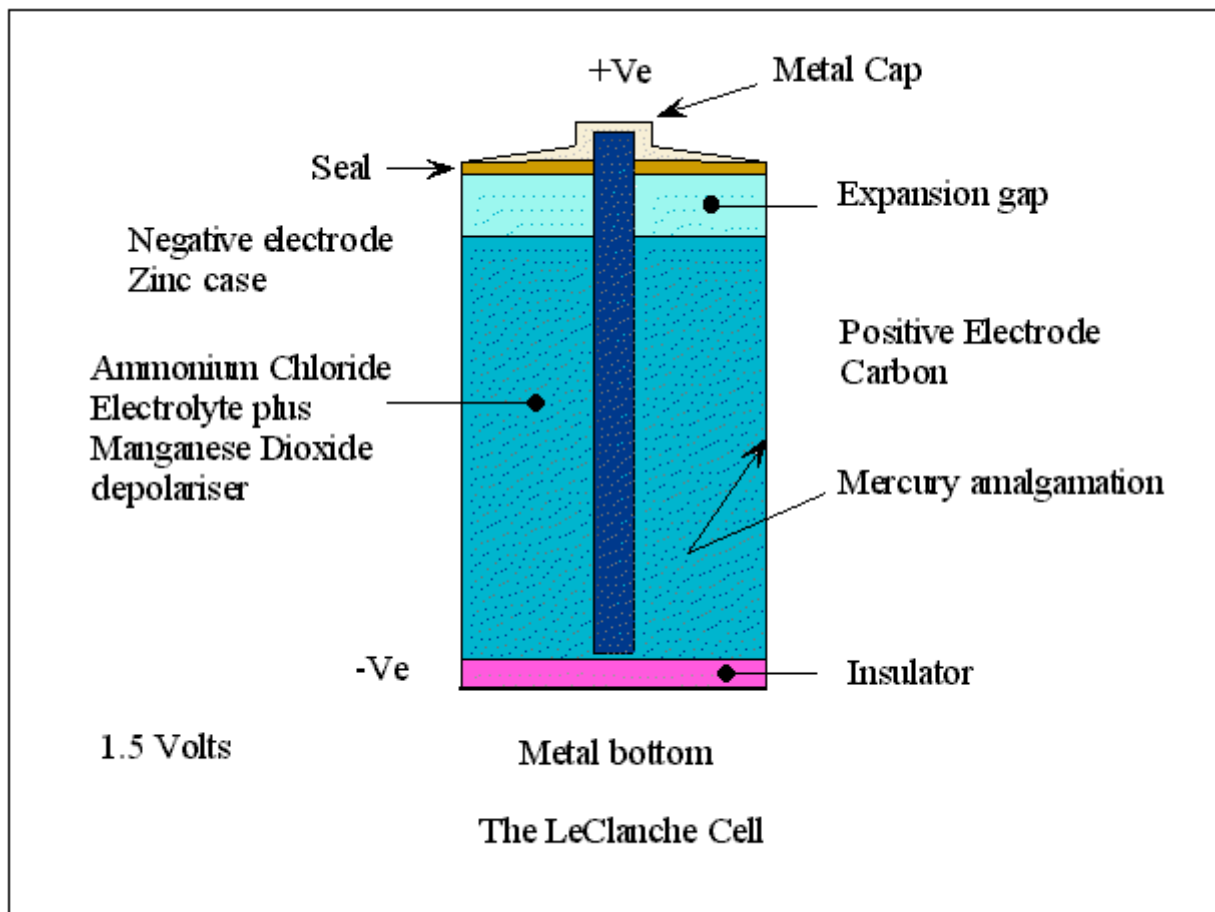
Figure 2.

electrolyte into equipment when they were discharged, as the zinc case would get holes in it.

POLARISATION

Now, if you're old enough, do you remember when the zinc-carbon battery would no longer work, it could be heated by placing it in an oven for a few minutes and it would come to life again, for a while anyway.

Well, one of the problems with the zinc-carbon cell is that as the chemical reaction takes place to charge both of the electrodes, hydrogen gas forms around the carbon rod in the form of small bubbles. This build up of hydrogen gas around the carbon rod will begin to insulate the carbon rod from the electrolyte. Since the surface area of the carbon rod in contact with the electrolyte is reduced, the terminal voltage of the cell will drop dramatically and the cell(s) will no longer operate the equipment. This unwanted buildup of hydrogen gas (and other gases in other cells) is called polarisation.

Placing the dry cell in the oven would drive the hydrogen gas from the carbon rod bringing it back to life for a while.

A chemical called manganese dioxide is mixed in with the electrolyte. Manganese dioxide absorbs the hydrogen gas and prevents the gas from building up on the carbon rod. Manganese dioxide is rich in oxygen and this oxygen combines with the hydrogen to form water. Manganese dioxide in the zinc-carbon cell is called the depolariser, as removing hydrogen from the carbon rod is called depolarisation.

LOCAL ACTION

If the zinc electrode (the case) contains impurities, small voltaic cells are formed which do not contribute to the output voltage of the cell. Also, these unwanted cells caused by impurities in the zinc, consume chemicals and dissolve the zinc. This is called local action. To minimise local action, the zinc electrode is generally coated with mercury by a process called amalgamation.

ALKALINE CELL

The carbon-zinc cell is now largely being superseded by the alkaline cell, which has better discharge characteristics and will retain more capacity at low temperatures. The alkaline cell typically has an ampere-hour capacity of about twice that of the carbon-zinc cell. Its nominal voltage is also 1.5 V.

The negative electrode is manganese dioxide and the positive zinc. The electrolyte is potassium hydroxide, or sodium hydroxide. High conductivity (low resistance) of the electrolyte results in higher current ratings than the carbon-zinc cell. The alkaline cell is supposed to be a primary cell. However, I have been charging them for years after finding out by experiment it could be done. I charge these cells at 50mA constant current overnight. I place them inside a plastic garbage bin in case they do explode, but have never had a misadventure with one yet. I have found that over the last couple of years chargers have become available to recharge them! I guess they just did not want the public to know about it!

These are the copper top and energizer type batteries.

LEAD-ACID STORAGE BATTERY

The most widely used high-capacity rechargeable battery is the lead-acid type. In automotive service, the battery is usually expected to discharge partially at a very high rate, and then to be recharged promptly while the alternator is also carrying the electrical load. If the conventional car battery is allowed to discharge fully from its nominal 2 V per cell to 1.75 V per cell, fewer than 50 charge and discharge cycles may be expected, with reduced storage capacity.

The typical lead-acid car battery consists of 6 cells connected in series. Many car batteries can actually be physically sliced into 6 individual cells.

The plates in a lead-acid battery are lead peroxide for the positive and spongy lead for the negative. The electrolyte is dilute sulphuric acid.

SULPHATION

As a lead-acid cell discharges, lead sulphate is deposited onto the plates. This is commonly referred to as sulphation. Lead sulphate is a white powder often seen on the outside of old batteries or on the terminals. If lead-acid batteries are allowed to remain discharged for very long the plates will be covered in lead sulphate and the capacity of the battery greatly reduced as the lead sulphate insulates the plates from having contact with the electrolyte. (Sulphation has appeared in AOCP exams).

For amateur radio use lead-acid batteries make a very cheap alternative to an expensive power supply. They are cheap to buy and can be trickle charged with an inexpensive or homemade charger.

Lead-acid batteries are also available with gelled electrolyte. Commonly called gel cells, these may be mounted in any position if sealed, but some vented types are position sensitive.

Lead-acid batteries with liquid electrolyte usually fall into one of three classes:
1. Conventional, with filling holes and vents to permit the addition of distilled water lost from evaporation or during high-rate charge or discharge;
2. Maintenance-free, from which gas may escape but water cannot be added;
3. Sealed.

SPECIFIC GRAVITY

Specific gravity is the weight of a substance compared to the weight of water. A hydrometer can be used to draw some electrolyte from a lead-acid cell into a reservoir tube and a weighted float can be used to measure the specific gravity of the electrolyte. This reading gives a very good indication of the state of charge of a cell. In a fully charged cell the specific gravity is in the vicinity of 1.280 (which means the density of the electrolyte is 1.280 times that of water). When the specific gravity is down to about 1.150 the cell is fully discharged. As you can imagine, when a lead-acid cell discharges, its electrolyte becomes weaker in sulphuric acid and approaches water.

As a lead-acid cell discharges, the specific gravity or density of its electrolyte decreases (it turns more towards water).

WARNING

Lead-acid cells produce hydrogen and oxygen when being charged, these are highly flammable gases in combination with air. The bubbles in a liquid electrolyte are hydrogen. The oxygen remains mostly locked in the cell due to other chemical reactions. It is the combination of liberated hydrogen with air with is hazardous.

I have seen a telephone exchange levelled to the ground by the ignition of hydrogen gas from the charging cells.

Neither hydrogen nor oxygen is flammable independently, but they are flammable when found in combination with other substances. Pure hydrogen will not burn by itself nor will oxygen. A spark in a container of hydrogen won't cause an explosion. Likewise, a spark in a container of pure oxygen may only form a bit of ozone. But when oxygen and hydrogen are combined, a vigorous reaction takes place when the mixture is ignited.

It is dangerous to allow salt water to get into lead acid cells – though its is a bit hard to stop this in a sinking boat. Salt water in combination with sulfuric acid releases huge amounts of chlorine gas, a very heavy green gas which if inhaled causes severe burning of the respiratory system.

Another warning. If a lead-acid cell is short circuited, enormous current will be drawn from the battery. It will overheat in seconds and explode spraying sulphuric acid everywhere. It happens in car accidents.

NICKEL-CADMIUM BATTERY (NiCd)

The most common type of smaller rechargeable battery is the nickel-cadmium (NiCd), with a nominal voltage of 1.2 - 1.25 V per cell.

The NiCd cell has a positive electrode made from Nickel and a Cadmium negative electrode. The electrolyte is potassium hydroxide.

Carefully used, these are capable of 500 or more charge and discharge cycles. For best life, the NiCd battery must not be fully discharged. Where there is more than one cell in the battery, the most discharged cell may suffer polarity reversal, resulting in a short circuit, or seal rupture. All storage batteries have discharge limits, and NiCd types should not be discharged to less than 1.0 V per cell.

Nickel cadmium cells are not limited to "D" cells and smaller sizes. They also are available in larger varieties ranging to mammoth 1000 Ah units having carrying handles on the sides and caps on the top for adding water, similar to lead-acid types. These large cells are sold to the aircraft industry for jet engine starting, and to the railroads for starting locomotive diesel engines. They also are used extensively for uninterruptible power supplies. Although expensive, they have very long life. Surplus cells are often available through surplus electronics dealers, and these cells often have close to their full rated capacity.

Advantages for the amateur radio in these vented-cell batteries lie in the availability of high discharge current to the point of full discharge. Also, cell reversal is not the problem that it is in the sealed cell, since water lost through gas evolution can easily be replaced. Simply remove the cap and add distilled water. By the way, tap water should never be added to either nickel cadmium or lead-acid cells, since dissolved minerals in the water can hasten self-discharge and interfere with the electrochemical process.

NiCd batteries must be charged with a constant current source. A constant current source is one where the current through the cell does not change as the battery is charged. The rule of thumb is $1/10^{th}$ the milliamp hour rating. So if a NiCd battery is rated at 500 mA/hours, then it should be charged for about 15 hours at 50mA constant current if it is fully discharged. If the NiCd is only 1/3 discharged then it should be charged for 5 hours.

CELLS IN SERIES AND PARALLEL

Cells can be connected in series, positive to negative etc, to increase the output voltage. This method is common to all batteries. The small 9 volt transistor battery is 6 cells connected in series. The 6V lantern battery has 4 completely separate cells inside the case. If you get the opportunity I suggest you break an old one open and have a look. It isn't messy, and you will find what looks like 4 oversized 'D' cells inside.

1.5 volts

6 volts
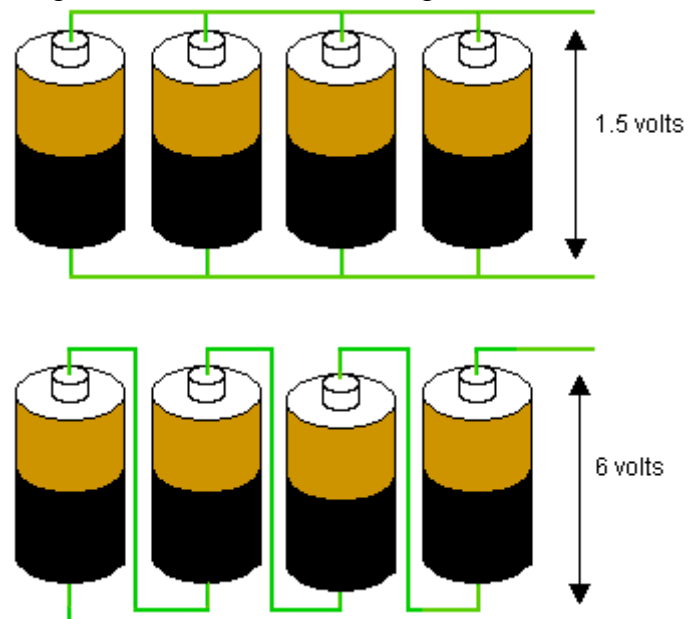
It is not common for batteries or cells to be connected in parallel though it can be done to increase the current capacity. The batteries must be identical. A more desirable way to get greater capacity is to use a bigger battery to begin with.   **Figure 3.**

It is very rare indeed to have batteries connected in a combination of series-parallel. This would only be done in specialist applications and is not recommended.

TESTING BATTERIES

The best way to test a lead-acid cell is by measuring the specific gravity of the electrolyte as already discussed. Smaller batteries and cells must be tested on load. This means the equipment in which the battery is installed should be turned on and then the terminal voltage of the cell or battery measured.

A fully discharged battery will still show its correct terminal voltage if it is not under load. It is important you understand this and the reasons why. As a battery ages its internal resistance increases. A new battery will have an internal resistance, which is a small fraction of an ohm. The electrolyte between the plates forms part of the total circuit. If the battery is supplying 1 A and the internal resistance of the battery is 0.1 ohms then a mere 0.1 volts will be dropped across the internal resistance, which is insignificant. As the battery discharges the internal resistance will increase. However, no voltage is lost across the internal resistance unless the battery or cell is placed on load. The load should be the nominal load that the battery is expected to deliver.

If you would like to do some additional study there are many good sites on the Internet about batteries. We have covered much more than you need to know for examination purposes here. A couple of good sites are: http://www.sanyo.com and http://www.duracell.com

ELECTROLYTIC CORROSION

The use of dissimilar metals in engineering (say when building an antenna) is likely to cause considerable trouble due to electrolytic corrosion. Every metal has its own electro-potential, and unless metals of similar potential are used the difference will cause corrosion at the point of contact even when dry. When moisture is present this effect will be even more severe.

If, for any reason, dissimilar metals must be used then considerable care should be taken to exclude moisture, the corrosive effects of which will vary with atmospheric pollution.

Metals can be arranged in what is called the electrochemical series, as follows:

Magnesium   Anodic
Aluminium
Duralumin   ↑
Zinc
Cadmium
Iron
Chromium iron alloys
Chromium nickel iron alloys
Soft solder tin-lead alloys
Tin
_____

Lead
Nickel
Brasses
Bronzes
Nickel copper alloys   ↓
Copper
Silver Solders
Silver
Gold
Platinum   Cathodic

Table 1 – Electrochemical series for metals.

Metals from within the same group of table 1 above may be used together with little corrosion, but metals used from across the groups will suffer greatly from the voltaic corrosion effects. Also, since the above groups are arranged in order, the greater the spacing in the list, the greater will be the effect.

The metals of the lower group in table 1 will corrode those in the upper portion. For example, brass or copper screws in aluminium will corrode the aluminium considerably, whereas with cadmium plated brass or copper screws there will be much less corrosion of the aluminium.

End of Reading 16.
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