Learning resource

Demonstrate knowledge of electromotive force (EMF) production

Level 2 | Credits 3

Te Pūkenga

Contents

Introduction

This study guide contains information on electromotive force (EMF) production, which is essential knowledge for all careers in the electrical and electronic industries. After working through this material you should have a thorough knowledge of electromotive force (EMF) production and electrochemistry.

This study guide will provide you with the information you need to know, as well as some activities to test your knowledge along the way. The activities are optional, but they will help you retain the information that you have read and will be useful when you decide to complete the assessment

Learning objectives and outcomes

At the end of this study guide you should know and be able to:

- Describe the different methods of EMF production including how it is achieved and the voltage produced
- Identify a common device that uses each method of EMF production
- Describe the construction and operation of a primary cell and lead acid battery, with the help of sketches
- Define battery capacity in terms of current and time
- Describe characteristics and typical application of cells
- Understand how to safely charge lead-acid batteries
- Describe situations when electrical energy can create a chemical effect
- Describe electrochemical corrosion and methods of reducing corrosion

Part 1: Production of an electromotive force

Electromotive Force (EMF) is the electrical force which causes electrons to flow in a conductor, so it is defined as “the force which causes current flow in electric circuits”.

EMF is a form of energy and to produce it, some other form of energy must be converted into electrical energy. Common examples of this are:

- Chemical.
  - Cells and batteries – which convert chemical energy into electrical energy.
- Magnetic.
  - Generators – which convert mechanical energy into electrical energy by means of electromagnetic induction.
- Friction.
  - Static electricity – where friction between certain materials produces electrical energy.
- Piezo-electric.
  - Piezo-electric cells – which convert mechanical energy into electrical energy by means of pressure on crystals.
- Photo-electric.
  - Photo-electric cells – which convert light energy into electrical energy.
- Thermocouple.
  - Thermocouples – which convert heat energy into electrical energy.

Cells and batteries

Cells are devices that convert chemical energy into electricity. Cells produce an EMF by chemical reactions between two different metal electrodes which are placed in an electrolyte.

The EMF produced varies depending on the materials used for the Anode, Cathode and Electrolyte. Depending on the cell type, an output voltage in the range of 1.2V - 5V per cell can be achieved.

The chemical reactions cause a transfer of electrons from one electrode to the other so that one electrode becomes positively charged, and the other becomes negatively charged. This will cause current to flow if a circuit is connected to the electrodes.

An EMF will be produced by a cell as long as the chemical action between the electrodes and the electrolyte continues. When the chemical action no longer produces an EMF, the cell is considered to be discharged.

One single cell is not actually a battery, like an AA cell (battery), but people generally (incorrectly) refer to them as a battery.

A battery is two or more electrochemical cells electrically connected together so that their voltages accumulate.

Primary cells - such as common flashlight “batteries” are used once and replaced. The chemical reaction that supplies the emf in them is irreversible. A typical carbon-zink primary cell produces around 1.5V.

Secondary cells - use reversible chemical reactions (for example, lead acid car batteries) and can be recharged and reused. Lead acid cells usually produce around 2V.

By reversing the flow of electricity i.e. forcing current in, rather than taking it out, the chemical reaction is reversed to restore the charge of the cell. This action “repairs” the active material that has been depleted.

Secondary cells/ batteries are also known as rechargeable batteries, storage batteries or accumulators.

Generators and alternators

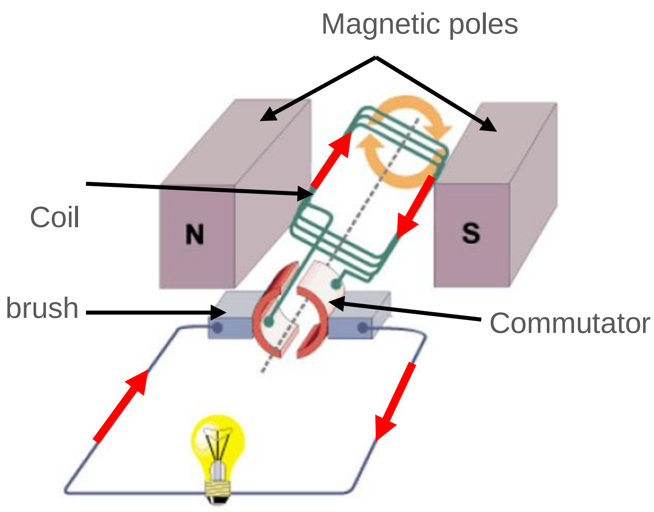
Mechanical energy is converted into electrical energy in generators because an EMF is produced in a conductor when it is moved across a magnetic field. This process is called electromagnetic induction.

In a simple AC generator, the rotating part is called the armature (or the rotor) and it consists of a coil of wire connected to the external circuit by means of slip rings and brushes.

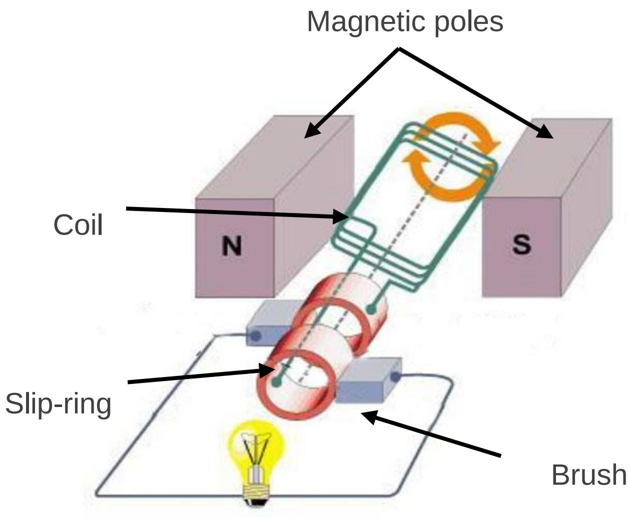
The armature is driven by some mechanical means so that it rotates in the magnetic field created either by permanent magnets or by electromagnets.

An alternator is a generator which produces alternating current (AC) and industry they are usually designed to produce either 230V single phase or 400V 3 phase. Electricity supply companies used generators that produce up to 16.5 kV.

The construction and operation of generators and alternators is covered in more detail in Unit Standard 25072.



DC generator



AC generator

Static electricity

The study of current flow in electric circuits normally relates to the movement of electrons caused by a voltage source, but static electricity refers to the effect that electrons can have when they remain stationary.

Static electric charges (electrostatic charges) are often produced by friction between materials and can build up on insulating materials because insulating materials do not allow electron movement to occur within them.

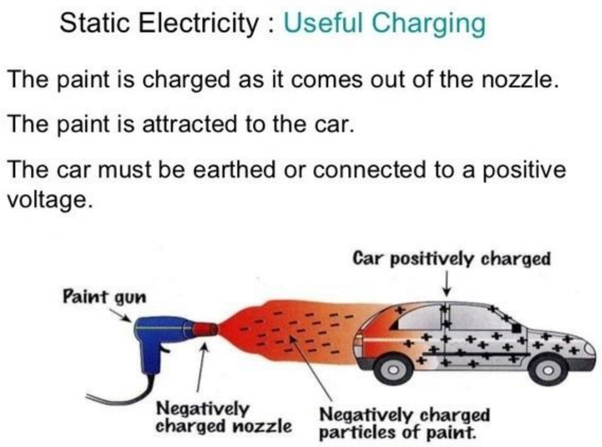
If electrostatic charges build up to high enough strength, they can cause a discharge in the form of a spark or cause a mild electric shock as a charge of up to 50000V can be generated. This principle is used in Van de Graaff generators to produce high voltages.

Lightning is an extreme example of electrostatic charges building up due to friction between clouds and air, until they cause a high voltage discharge as a (very intense!) spark.

Walking across a carpet or sliding across a car seat can produce a charge on a person which will cause a mild shock when discharged by touching a door handle or other metal object.

When petrol tankers deliver fuel to in-ground tanks they must first connect an earthing strap to earth the tanker and discharge any electrostatic build up. This is to prevent sparking which could cause an explosion.

In the automotive industry electrostatic charges are used in the spray painting of cars. The car body is at one polarity and the paint at the opposite. This causes the paint to be attracted to the car body and causes the paint to enter small openings to give a complete coating.



Air filtration machines called electrostatic precipitators, or electrostatic air cleaners are filter machines that use electrostatic charges to attract and remove particles like dust and smoke out of air or other gasses flowing through them.

They are very efficient and effective in situations like the Huntley coal powered power station, removing the unburnt carbon from the exhaust stacks.

Photo-electric cells

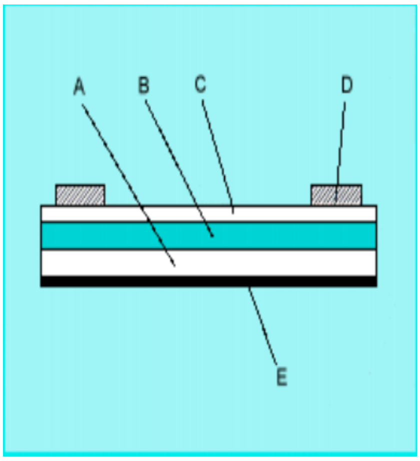
Light energy can be converted into electrical energy because some materials will produce an EMF when light falls on them.

One of these materials is selenium, and one type of photo-electric cell consists of a layer of selenium deposited on a metal base and covered by a very thin, transparent gold film.

Light passing through the gold film releases free electrons from the selenium to give the gold film a negative potential, and the metal base plate a positive potential.

This EMF is very small, only about 0.4 volts, but because the EMF is proportional to the amount of light falling on the photocell, these are used in light measuring devices such as light meters in cameras, lux level meters for measuring lighting levels in buildings and for counting objects on production lines when they break a light beam.

A	**Metal Plate (e.g. Brass)**
B	**Selenium layer**
C	**Transparent Gold film (leaf)**
D	**Collector ring**
E	**Base**



Solar Cells - are a type of photo cell, they are more often referred to as photo-voltaic cells. Photo-voltaic cells are made of P and N type silicon semiconductor material and they convert sunlight into electrical energy.

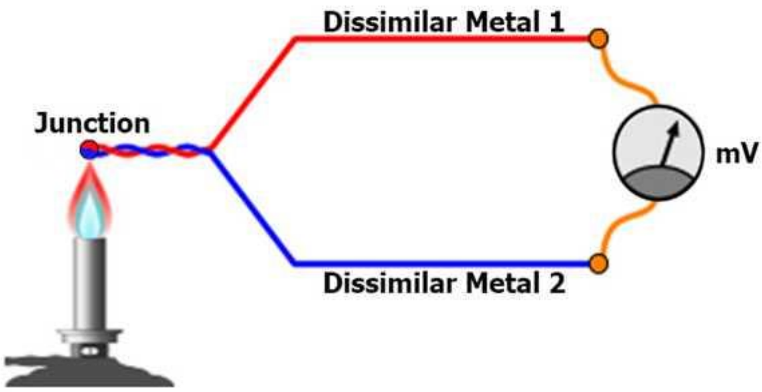
Photo voltaic cells produce about 0.4 – 0.6 volts each, but when made with a very large surface area and combined into panels of multiple cells connected together, they can produce enough current to be used for running loads, battery charging and are becoming very popular for both domestic and industrial installations.

Thermocouples

A thermocouple consists of a welded junction between two different metal wires. When the junction is heated, electrons move away from the heat in one of the metals, and towards the heat in the other metal. This produces a very small EMF in the range of -7mV to 80mV across the ends of the thermocouple. As the EMF produced is proportional to the heat applied, thermocouples are used for temperature measurement in industrial control processes.

Two types are:

- Copper-constantan which can be used up to 300ºC and at that temperature produces about 20mV (0.02V).
- Iron-constantan which can be used up to 800ºC and produces about 40mV (0.04V) at that temperature - (constantan is an alloy of copper and nickel).



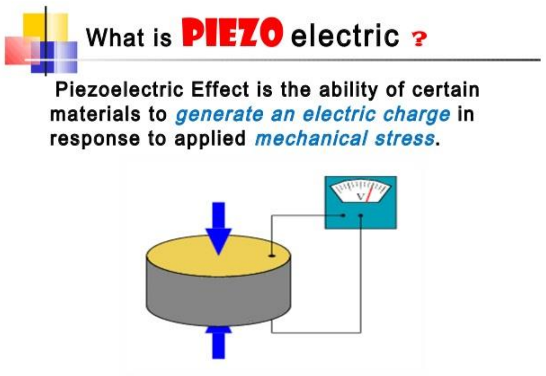
Piezo-electric cells

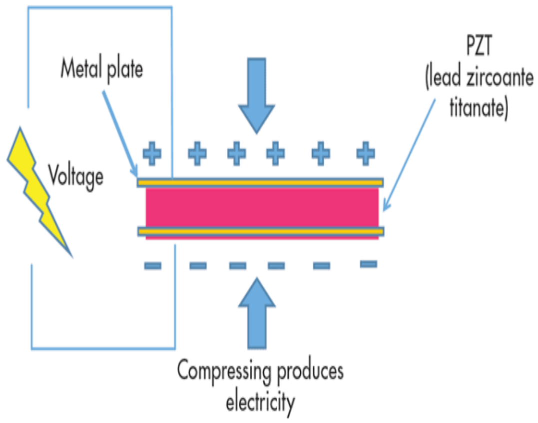
Crystals of certain materials will produce an EMF when they are put under mechanical pressure. The stronger the pressure applied the greater the generated EMF. These are used in various applications including record players and microphones.

The EMF generated can range from 10mV to 10kV.

One of these is lead zirconate, and when a crystal of lead zirconate is compressed with a sharp hammer type action it can produce a voltage of over 1000 volts.

Although this does not release enough energy to pass significant current flow, it can be used to produce a spark to ignite gas appliances, many gas barbeques and gas cookers use these for their ignitor.





Part 2: Electrochemistry, cells and batteries

Cells and batteries

The first battery was demonstrated nearly 200 years ago and batteries have been extensively researched since then.

Even so, there is much yet to be learned about the details of cell chemistry.

Cells and batteries exist in all aspects of our life as they are an efficient way to make electricity portable.

In addition, cells and batteries provide backup power during electrical grid outages for a variety of critical functions.

New cell types and significant improvements in the performance of batteries have encouraged the increased use of batteries throughout our society.

As the world has become increasingly addicted to electricity, mobility and portable electrical equipment, batteries are playing a greater role in all aspects of our life.

Batteries come in a variety of shapes and sizes. Some are tiny enough to fit in watches while others are large enough to power a submarine.

There are batteries that are used once and thrown away and there are batteries that are recharged and reused thousands of times.

Some batteries are used several times every day while others may sit for ten years before they are ever used.

Obviously for such a wide range of uses, a variety of battery types are necessary. But all of them work from the same basic principles.

As cells are active chemical systems, they are sensitive to how they are used, the environment around them, and even how they have been treated in the past.

Let’s take a closer look at some different types of cells and batteries.

Cell and battery construction terminology

Term	Definitions
Cathode	The positive terminal of the cell or battery when being discharged
Anode	The negative terminal of the cell or battery when being discharged
Electrolyte	A conductive fluid or paste that is used to move electrons between the anode and the cathode
Electrodes	A conductor made of a specific material which is used for the creation of EMF in the cell

How a cell works

Within the cell, the chemical reaction causes ions to be transported from one electrode to the other.

Electrons react with the active materials of the positive electrode in "reduction" reactions that allow electrons to move through the electrolyte to the negative electrode.

At the negative electrode - "oxidation" reactions between the active materials of the negative electrode and the charge flowing through the electrolyte results in a surplus of electrons that can be “donated” to an external circuit.

For every electron generated in an oxidation reaction at the negative electrode, there is an electron consumed in a reduction reaction at the positive electrode.

As the process continues, the active materials become depleted and the reactions slow down until the cell is no longer capable of supplying electrons. At this point the cell is discharged.

Types of cells and batteries

As we have mentioned, the world of cells divides into two major types:

- Primary cells.
- Secondary cells.

Primary cells

Primary cells have a chemical action that destroys the electrodes and the electrolyte so primary cells cannot be recharged. They are discarded when they become discharged.

Examples are:

- *Carbon-zinc* dry cells as used in torches and portable radios.
- *Lithium cells* as used in calculators and cameras.

Secondary Cells

Secondary cells are cells in which the chemical action is reversible so when they become discharged, they can be recharged by applying a DC charging current to them. This will need to be supplied from a separate DC source such as a battery charger or a generator.

Examples are:

- *Lead-acid cells* as used in car batteries.
- *Nickel-cadmium alkaline cells* as used in standby power supplies, some heavy vehicles, boats and emergency lighting systems.

The Carbon-Zinc dry cell

A carbon-zinc dry cell is the common lower cost dry cell ("battery") used in intermittent low drain applications such as torches, radios, small toys and clocks. They offer a good storage life.

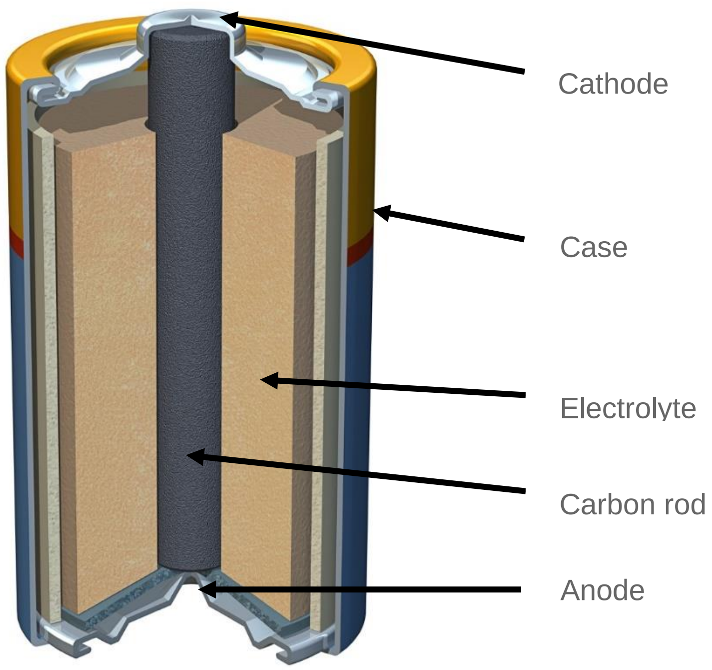
It is classed as a dry cell because its electrolyte is not a liquid but is a moist paste made of aluminium chloride.

Its zinc container is the cathode and it has a carbon rod as its anode.

In good condition the carbon-zinc cell produces an EMF of 1.5 volts and it is considered to be discharged when this falls below 1 volt.

The discharge cycle damages the zinc cathode and weakens the electrolyte so that recharging is not possible.

These are commonly used in AAA, AA, C and D sizes for different applications.



Lead-acid batteries

Even though lead acid batteries are fairly old technology, in the world of rechargeable batteries they still hold their own and represent about 60% of all batteries sold worldwide.

Lead-acid batteries are fairly economical and have a high tolerance for abuse. The fact that they are used almost exclusively for starting, lighting, and ignition systems in petrol and diesel cars and trucks is testimony to that.

Lead-acid batteries also provide motive power for everything from forklifts to submarines. Lead-acid batteries are also mainstays of the backup systems that provide power when the electrical grid fails.

The flooded lead-acid battery

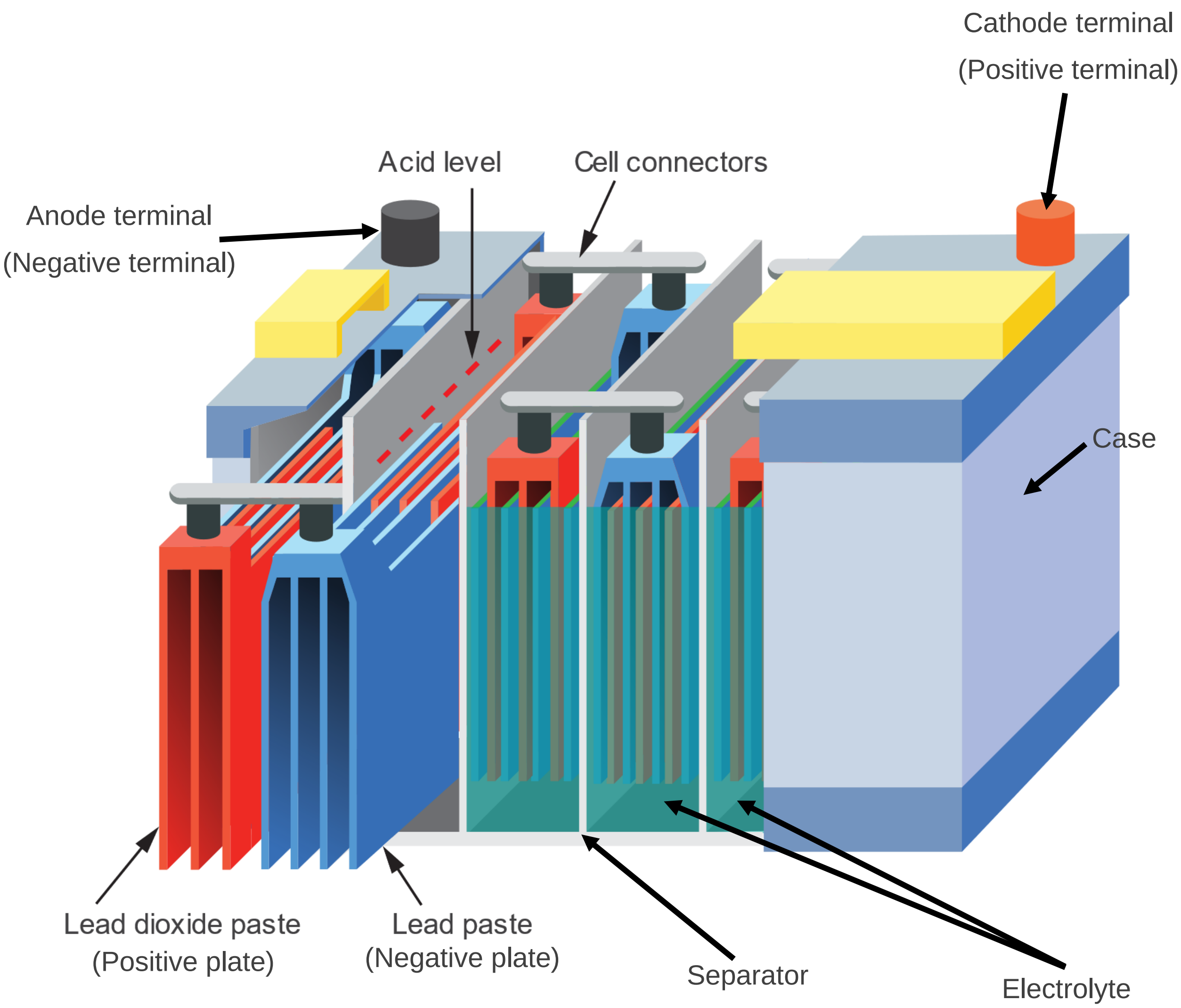
All flooded batteries consist of electrodes immersed in a pool of electrolyte. They vent flammable gases externally on overcharge.

Each cell in these batteries produces a nominal EMF of 2 – 2.2 volts and a battery will normally contain six cells, so the battery voltage is 12 - 13.2 volts.

In a fully charged state, the active material on the positive plate is lead peroxide and the negative plate is spongy lead.

The electrolyte is dilute sulphuric acid. Both of the plate materials have no mechanical strength so they are pasted on to grids made from lead with antimony added to give greater strength.

Each cell contains a number of plates mounted close together with a porous rubber separator between them so that the electrolyte can penetrate freely to the plates.



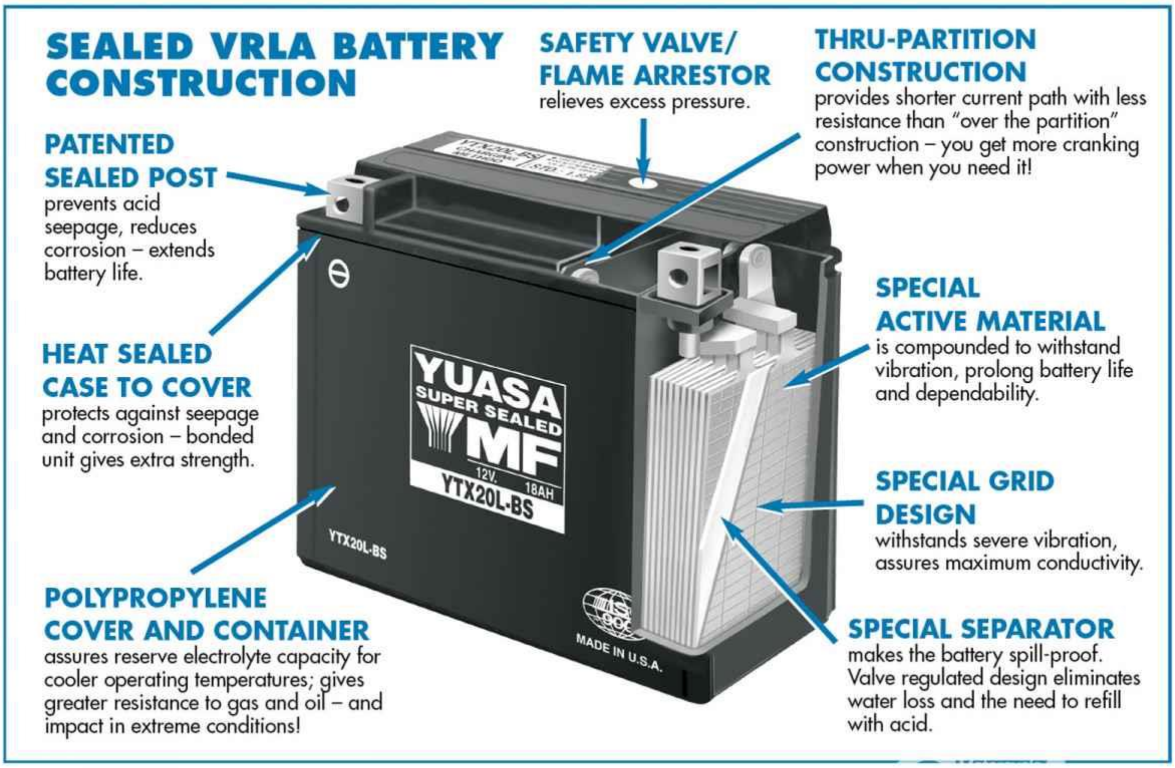
Regular water addition is required for most forms of flooded batteries although low-maintenance types come with excess electrolyte that is calculated to compensate for water loss during a normal lifetime.

The sealed lead-acid battery

Now, development of the sealed-lead battery has allowed lead technology to be used in applications such as electronics that need a clean power source.

They have gas paths between the plates that allow gases produced when overcharged to diffuse from one plate to the other where they are recombined.

This recombination provides a closed system reducing venting of gases externally under normal overcharge conditions.



Specific gravity

Because the density of the electrolyte changes during charging and discharging its density gives an accurate indication of its state of charge.

The state of charge can be measured by use of a hydrometer which draws a sample of electrolyte from the cell and the level of its float indicates the specific gravity of the electrolyte.

Definition

Specific gravity	The ratio of the weight of the electrolyte compared to a reference value (i.e. water)

A fully charged cell has a specific gravity of about 1250 and a terminal voltage of 2.2 volts. The cell is considered discharged when its specific gravity falls to 1180 and its voltage falls below 1.8 volts.

Discharging

Definition

Discharging	The battery is being used as a source of supply

When the cell delivers current (discharges) the chemical action removes sulphur from the electrolyte and deposits it on the electrodes to form lead sulphate on both plates.

This action dilutes the acidic electrolyte. When the specific gravity drops to 1180 and the cell voltage to 1.8 volt, the cell is discharged.

Charging

Definition

Charging	An EMF is applied to the cell terminals which reverses the discharge process

When a cell is recharged by passing current in the opposite direction to the discharge current, the chemical action is reversed, and the lead sulphate is removed from the plates.

The plates are restored to lead peroxide for the positive electrode, and spongy lead for the negative. The sulphur is restored to the electrolyte to increase its density.

When the specific gravity reaches 1250 and the cell voltage 2.2 volt, the cell is fully charged.

Safety precautions during charging

The chemical action during charging causes hydrogen gas to be released. This creates a danger of fire or explosion so charging areas are classed as hazardous.

The electrolyte is highly corrosive sulphuric acid, any spillage of the electrolyte should be neutralised with a solution of baking soda, washing soda, or ammonia in water and cleaned up immediately.

Any acid on the skin must be immediately washed off with soap and water and eyes flushed with large quantities of fresh water for a minimum of 15 minutes. Medical attention will be needed.

If the electrolyte is in the eyes, be sure the upper and lower eyelids are pulled out sufficiently to allow the fresh water to flush under the eyelids.

When dealing with lead acid batteries:

1. Always follow the manufacturer's instructions.
2. Never short the terminals of a battery.
3. Areas must be well ventilated.
4. No smoking, no naked flames or sparks in these areas.
5. The charging unit terminals must be connected to the battery before charging starts, and only removed after charging stops, to avoid sparking at the terminals.
6. Check the electrolyte level before and after charging – top up with de-mineralised water if necessary.
7. Any spillage of the electrolyte should be cleaned up immediately.
8. Always wear protective gear.

Battery capacity

Battery capacity is often measured in ampere hours. A Typical automotive battery may be rated at 70 amp-hours @ 3.5 Amps.

- A rating of 1 Ah means a battery has the ability to deliver 1 ampere of current continuously for one hour.
- A 10 Ah battery would be able to supply 10 amperes for one hour or 1 ampere for 10 hours or any variation in between.

Definition

Battery capacity	The amount of energy that a battery can deliver in a single discharge, normally specified in amp-hours (Ah) (or milli-amp-hours)(mAh)

Summary

- A basic cell is made of two electrodes and an electrolyte. The negative electrode/terminal is the anode and the positive one is the cathode.
- The ratio of the weight of the electrolyte is called specific gravity.
- Primary cells/batteries cannot be recharged.
- Secondary cells can be recharged.
- Battery capacity is measured in ampere hours.

Applications

Batteries come in all sizes and shapes to fit all sorts of equipment.

There are many things that determine battery choice. Here are three specific things to think about when selecting batteries.

- High or low current draw.
  - Some batteries are much better suited to handling a long-term drain at a low rate than they are a high-rate load for a short interval or vice versa.

- Rechargeable or non-rechargeable.
  - Is it convenient to charge or are there charging facilities available?
  - What is the amount of time the battery spends being charged versus the time it spends being used?

- The battery environment.
  - What temperatures are the battery required to operate in? Hot? Cold?
  - Weather conditions?

Practical and safety aspects of common cells and batteries

Type of cell	Typical applications	Practical aspects			
		Voltage	Charge/ discharge	Description	Safety considerations
Alkaline	AAA, AA, C, D cells. Remote controlled toys, cameras, portable lasers.	1.5V per cell	Non-rechargeable, capable of supplying higher high-drain loads.	Compact, usually cylindrical, dry, in zinc-cardboard/plastic cover.	Not rechargeable, may explode if charging attempted or put in a fire.
Carbon-zinc	AAA, AA, C, D cells. Torches, radios, small toys, clocks	1.5V per cell	Non-rechargeable, low current for intermittent use.	Compact, usually cylindrical, dry, in zinc-cardboard/plastic cover.	Not rechargeable, may explode if charging attempted or put in a fire.
Lead-acid	Vehicle battery, deep cycle versions are used for renewable energy systems	2.2V per cell	Low current charge over longer periods. High Current discharge for short bursts.	Bulky and heavy usually in a plastic case.	Produces flammable gasses must be used in a ventilated environment. Contain acid.
Lithium iron (LION)	Power tools, High drain devices, cell phones.	3.6V per cell	Fast charging. High current discharge limited to avoid battery overheating.	Small and encased in metal. Often packaged as batteries inside plastic battery cases	Care must be taken when charging to not overheat battery.
Mercury	Button batteries for watches, toys etc.	1.35V per cell	Non-rechargeable, constant voltage discharge.	Very small with metal cases that are the external connections	Contains mercury - requires proper disposal. Keep away from small children as if swallowed will cause severe injury.
Nickel metal hydride	AAA, AA, C, D cells. Remote controlled toys, cameras, portable lasers.	1.2V per cell	Rechargeable. Can develop discharge memory if not fully discharged.	Often packaged in standard battery format for use in battery operated equipment.	Only mildly toxic. Can get too hot if charged too fast.

Summary

- Different cell chemistries suit different applications.
- Each cell chemistry has different characteristics such as memory effect, corrosion problems, high self-discharge rate etc, ability to be recharged.
- Temperature and environmental conditions are a consideration when making choices about what batteries to use.

Electrochemistry

We have seen how electrochemistry can produce electricity. However, electricity can also create electrochemical effects.

Electrochemistry is the study of the chemical effects of electric current. When electric current flows between electrodes in an electrolyte, a chemical change occurs in the electrodes and the electrolyte, this action is called electrolysis.

Three typical examples of electrochemical effects are:

- Electrochemical corrosion
- Battery charging/discharging
- Electroplating

Electrochemical corrosion

Electrochemical corrosion is caused when two dissimilar metals with different electrode potentials are in close proximity to each other.

When an electrolyte is introduced - such as condensation, moist soil, rain water or seawater, a simple primary cell is created. The electrical potential between the metals will cause the anode metal to corrode away as it dissolves into the electrolyte.

Aluminium and steel is a common combination that causes electrochemical corrosion.

A typical scenario in New Zealand is a galvanised earth electrode and a copper water piping with moist soil between them.

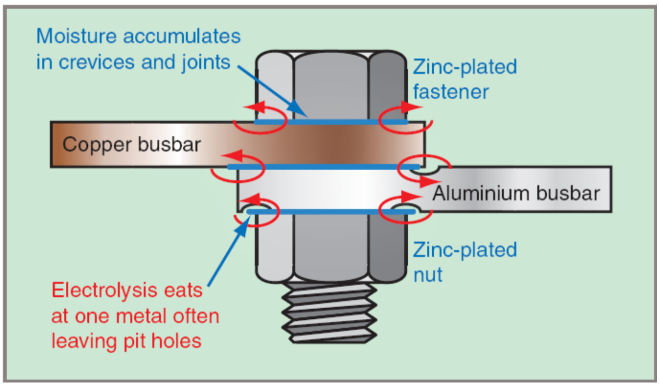
This creates a “simple voltaic cell”. There is a potential difference between these two metals (their electrode potentials are different, i.e. the zinc galvanising has an electrode potential of –0.76 V and Copper pipe has an electrode potential of +0.34 V. thus a potential difference of 1.1 V naturally exists between these metals).

Current will flow through the soil from the electrode with the lower potential (zinc in this case) to the electrode with the higher potential (copper).

Metal material is transferred from the zinc to the copper through the soil, breaking down the zinc galvanising – the zinc galvanising is being corroded, at an accelerated speed.

In the electrical industry another common combination that causes electrochemical corrosion is copper and aluminium.

Care must be taken to protect against electrochemical corrosion when aluminium and copper conductors are required to be joined.



Protection against corrosion

There are five main ways to reduce corrosion:

1. Alloying:

Some alloys form surface films that give a natural barrier to chemical action. Alloying a small percentage of chromium with steel greatly increases its resistance to corrosion.

Monel metal, an alloy containing about 70% nickel and 30% copper, is another important corrosion-resistant alloy.

2. Coatings:

The metal is separated from the source of corrosion by a protective coating. Coatings of chromium, nickel, or copper deposited by electrolysis are widely used to protect base metals, for example, chrome plating a car bumper to prevent rust.

Other metals electro-deposited are zinc, cadmium, tin and lead.

Aluminium, zinc and other metals are often applied to the base metal as a spray of liquid metal.

Inorganic coatings include glass, vitreous enamels and ceramics.

Organic coatings are the most common method of protection. Paints, varnishes, lacquers, bituminous coatings, oils and other materials are used to isolate metal from a corrosive atmosphere or electrolytic situation.

Some of this kind of coating works on the basis of producing an oxide coating that resists further corrosion. Plastic sheathing, such as PVC or epoxy resin, is frequently used to prevent corrosion.

3. Cathodic protection:

This kind of protection relies on neutralising the EMF of the electrolytic cell. An EMF of opposing polarity is connected in series with the corrosive current path. Thus, the electrolytic cell tries to drive current flow in one direction and the added voltage to drive current in the opposite direction.

The ideal result is that no current flows, and so there is no corrosion.

4. Metal purification:

The corrosion resistance of pure metals is usually better than metals containing impurities. Thus, pure aluminium resists attack much better than the ordinary commercial grades. The aluminium forms an oxide that opposes corrosion. This oxide is sometimes produced by an electrolytic process, such as anodising, to give protection and finish.

Aluminium-sheathed cables usually have an extra covering of PVC to give further protection. Where corrosion risks are high, two further layers of bituminous-impregnated hessian tapes are used.

5. **Neutralising the environment**:

We can neutralise the environment by reducing the:

- Oxygen content of air.
- Effectiveness of oxygen as a corrosive.

Adding chemicals such as sodium sulphite into an oxygen-bearing environment reduces the amount of oxygen available for corrosion but does not fully stop corrosion.

In the second method, the aim is to prevent cathode or anode reactions. An iron pipe can be coated with chromate-bearing paints that give a stable oxide-protective film.

It is the neutralising film that gives the protection, not the paint.

Other ways of neutralising the environment include using air conditioning to exclude corrosive gases.

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