GS Yuasa E-Learning Support Documentation

Lead Acid Battery Operation

Overview:

This support documentation has been designed to work in conjunction with the GS Yuasa e-learning course “Lead Acid Battery Operation” and covers of the following subjects:

- **Principles of electricity**
- **What is a battery?**
- **Generating a voltage**
- **Electrochemical reaction**
- **Battery discharge process**
- **Battery recharge process**
- **Summary**

Principles of electricity

What is electricity?

Electricity is a form of energy that flows along a conductor such as a copper wire in the form of electrons. The force that pushes the electrons through the conductor is known as a potential difference and is measured in Volts. The rate of electron flow through the conductor is known as current and is measured in Amps

What is a battery?

Voltaic cell

A battery is a source of electrical energy stored in chemical form that can be released in a controlled way when required. This is known as a voltaic cell. A voltaic cell is constructed of two different metals or metallic compounds known as positive and negative electrodes which are kept apart by a separator and immersed in an electrolyte.

*An electrolyte is a liquid substance which acts as a medium to conduct electricity. Through the addition of acids, alkaline solutions or salts water becomes an electric conductor i.e. an electrolyte.

There are two types of battery, primary which are used until discharged and then disposed of and secondary which can be recharged and reused.

Lead acid battery

A lead acid battery is a secondary type battery that uses compounds of lead as its electrodes which take the form of plates and a dilute solution of sulphuric acid (H_2SO_4) as its electrolyte.

Positive plates are made from lead dioxide (PbO_2) and negative plates of porous lead (Pb).

The positive and negative plates are connected, arranged alternately in a pack, kept apart by a separator and submerged in the electrolyte solution.

Generating a voltage

Potential difference & voltage

When connected to an electrical circuit and an electrical consumer is switched on a load is placed on the battery. This starts a chemical reaction between the negative plates and the electrolyte creating a potential difference and electron flow between the negative and positive plates. This release of electrical energy is then used to power the electrical consumer resulting in the battery becoming discharged.

Recharging the battery reverses the chemical reaction between the plates and the electrolyte storing electrical energy in chemical form for reuse when required.

Electrochemical reaction

Atoms

An atom is the smallest part of a chemical element that can exist and are made up of positively charged protons, neutral neutrons and negatively charged electrons. Protons and neutrons form the core or nucleus of the atom around which the negatively charged electrons orbit. Atoms with equal numbers of protons and electrons are neutral in charge.

Ions

An ion is a charged atom. It is charged because the number of electrons is not equal to the number of protons in the atom. An atom can acquire a positive charge or a negative charge depending on whether the number of electrons is greater or less then the number of protons. Atoms transfer electrons between each other to achieve a neutral charge.

Negative ion

A negative ion has more electrons than protons in the atom and will therefore have a negative charge.

Positive ion

A positive ion has fewer electrons than protons in the atom and will therefore have a positive charge.

Ionisation

A battery uses the chemical reaction between the plates and the electrolyte to produce ions and a flow of electrons. This process of ionisation within a battery converts neutral atoms into positive ions by removing electrons and negative ions by adding electrons.

Like the North and South poles of a magnet positively and negatively charged ions are attracted to and bond with each other to share electrons and form neutral atoms.

Lead acid battery ionisation process

Within a lead acid battery, the negative plates, positive plates and the electrolyte are made of different compounds. They all have a neutral charge as they have the same number of protons as electrons.

Positive plate

The positive plates are made from lead dioxide (PbO_2). The lead ions have a positive charge of 4+ meaning that there are 4 less electrons than protons in each atom. The oxygen ions known as oxide have a negative charge of 2- meaning that there are 2 more electrons than protons. To form a neutral lead dioxide molecule, the lead and oxide ions bond together to cancel out their charge state. To achieve this, two oxygen ions bond with a single lead ion. As two negatively charged oxygen ions are needed to cancel the positive charge of the lead ion we use the Greek word prefix di meaning two to identify the number of oxygen ions used. This process results in the compound lead dioxide.

Negative plate

The negative plates are made from porous lead. Porous lead has an equal number of protons and electrons and is therefore neutral in charge.

Electrolyte solution

The electrolyte solution contains sulphuric acid which is a compound of hydrogen and sulphate ions. The hydrogen ions (H) have a positive charge of 1+ meaning there is 1 less electron than protons in the atom. The sulphate ions (SO_4) have a negative charge of 2- meaning there are two more electrons that protons in the atom. To form a neutral sulphuric acid molecule, the hydrogen and sulphate ions bond together to cancel out their charge state. Two positively charged hydrogen ions are needed to cancel the negative charge of the sulphate ion. This process results in the compound sulphuric acid (H_2SO_4).

Battery discharge process

Negative plate

The discharge process begins as soon as an electrical load is applied to the battery. This takes the form of a chemical reaction between the negative plate and the sulphuric acid in the electrolyte solution. The sulphuric acid begins to break down into positively charged hydrogen ions (H+) which move to the positive plate and negatively charged sulphate ions (2-) which move to the neutral porous lead atom on the negative plate. The porous lead atom on the negative plate becomes ionised and negatively charged as the sulphate ion attempts to bond with it. To complete the bonding process and achieve a neutral charge state the lead atom must become positively charged. It therefore releases 2 negatively charged electrons. These 2 free electrons can now flow through the electrical circuit through the applied load and on into the positive plate.

Positive plate

The two negatively charged electrons from the negative plate arrive at the positive plate and bond with the positively charged lead ion (4+) in the neutral lead dioxide molecule. This causes the charge of the lead ion to change from (4+) to (2+) as there are now only two more protons than electrons in the lead ion, altering what is known as the oxidisation state of the lead ion. Negatively charged sulphate ions (2-) produced from the breakdown of the sulphuric acid bond with the positively charged lead ion (2+) on the surface of the plate creating a neutral molecule of lead sulphate and releasing negatively charged oxygen ions into the electrolyte. The two hydrogen ions (H+) approach and bond with the negatively charged oxygen ion (2-) creating a neutral molecule of water (H_2O). The battery is now discharged.

Battery recharge process

Positive plate

When a charging source is applied to the battery the ionisation process between the positive plate and the electrolyte is reversed. Two electrons are forcibly removed from the lead sulphate molecule ($PbSO_4$) causing the charge and oxidisation state of the lead ion to change from (2+) to (4+). The 2 free electrons now flow back through the charging device into the negative plate. There are now four more protons than electrons in the lead ion. The water (H_2O) in the electrolyte begins to break down into positively charged hydrogen ions (H+) and negatively charged oxygen ions (2-). The negatively charged oxygen ions (2-) move to the positive plate and displace sulphate ions (SO_4) into the electrolyte solution. Two negatively charged oxygen ions (2-) bond with the positively charged lead ion (4+) creating a neutral molecule of lead dioxide (PbO_2). Two positively charged hydrogen ions (H+) approach and bond with the negatively charged sulphate ion in the electrolyte solution (2-) creating a neutral molecule of sulphuric acid (H_2SO_4)

Negative plate

The two negatively charged electrons from the positive plate arrive at the negative plate and bond with the positively charged lead ion (2+). This displaces the negatively charged sulphate ion (2-) into the electrolyte creating a neutral porous lead atom on the negative plate. Two positive hydrogen ions (H+) bond with the negatively charged sulphate ion (2-) in the electrolyte creating a neutral molecule of sulphuric acid (H_2SO_4). The battery is now recharged.

Summary

Here we have been looking at individual electrons, atoms, molecules and compounds however the plates and electrolyte solution contain countless numbers of these therefore the electrochemical process take place on a vast scale and continuously during the discharge and recharge phases.