ESSENTIAL IDEAS IN ELECTRONICS:

Voltage (Part 2)

In this second and final part of our look at voltage, **Torben Steeg** explores what an electric potential actually is and how a voltage (potential difference) can be created.

PREFACE

Part 1 of this article on voltage introduced the following key ideas:

- A signal in a system is a voltage
- A voltage is a difference in electric potential between two places
- Voltage is formally called potential difference
- Being a difference measurement, voltage is analogous to height
- Voltages can be measured with a voltmeter
- When measuring a voltage, the two voltmeter leads are placed 'across' the voltage; that is, to measure the difference in potential between two places the voltmeter leads are attached to these two places.

Part 1 can be downloaded from the Electronics Education website at www.iee.org/EduCareers/Schools/elec_ed.cfm.

This second and final part of the article explores what an electric potential actually is and how a voltage (potential difference) can be created.

ATOMIC PHYSICS!

You probably know the simple model of an atom that describes it as a positively charged nucleus (centre) surrounded by negatively charged electrons. Overall a complete atom is uncharged because the charge on the nucleus is exactly balanced by the charges on the electrons.

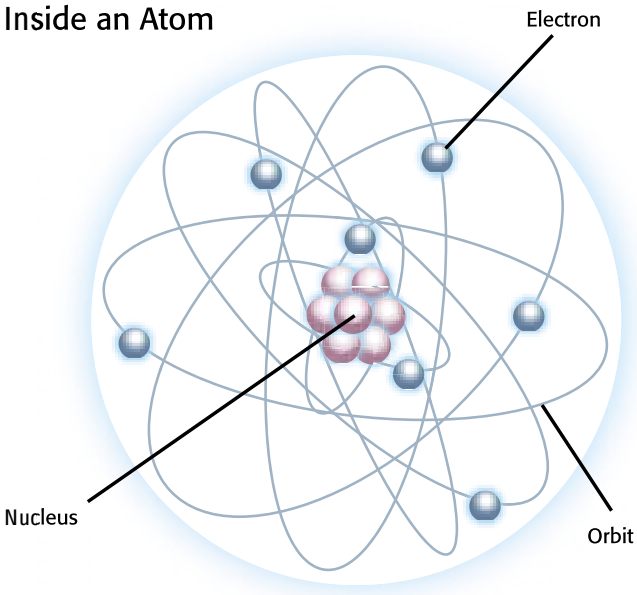

Fig 1 **A simple model of an atom**

However, if an electron is removed from an atom, it – and the material it is a part of – becomes positively charged. In the same way, the object that holds the removed electron will become negatively charged. There is now a difference in electric charge between the two items. ➔

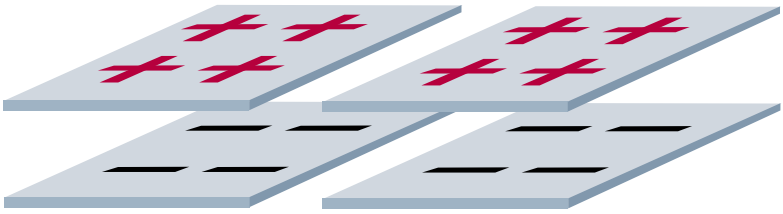

Fig 2 **Separated charges create a voltage**

This difference in electric charge creates a potential difference, or voltage. The size of the voltage is directly proportional to the size of the charge difference. The charge on a electron is tiny, so to create a useful voltage a very large number of charges have to be separated.

The unit of charge is called a Coulomb (C) and 1C is the charge equivalent to about 6×10^{18} electrons. That's 6 million million million electrons (6,000,000,000,000,000,000).

The charge on a single electron is about 1.6×10^{-19}C, or 0.00000000000000000016C.

The actual voltage created by a particular charge separation depends on the area over which the separated charges are spread, the separation distance and the electrical properties of the material between the charges.

ELECTRIC POTENTIAL

Moving charges apart to create a potential difference requires energy because each negative electron is being pulled away from a positive nucleus against the force of attraction. This is similar to the way that energy is needed to lift an object, like a bottle of water, up in the air against the attractive force of gravity (which you can think of as a mass separation).

Separating a coulomb of charge to create a voltage of 1V requires 1J (Joule) of energy. This is quite a small amount of energy; electrical energy use in homes is often measured in 'Kilowatt-hours' (kWh) where 1 kWh = 3.6 million Joules.

We know that energy can't be destroyed – so what happens to the energy used in creating the charge separation? The answer is that it is transformed into electrical potential energy. Again this is very much like the way that the energy used to lift the water upwards against the pull of gravity is transformed into gravitational potential energy; if the water is poured out the potential energy is transformed into kinetic energy (energy of movement) as the water accelerates downwards. This kinetic energy can, in turn, be harnessed to do useful work, for example in a hydroelectric power station. The amount of energy released depends on the difference in height between the start and the end of the drop and the amount of water.

In a similar way the potential energy of separated electrons can be released to do useful work. If the electrons are allowed to return to the positively charged atoms from which they were separated, their potential energy will be released and can be harnessed. To do this requires an electric circuit made of a conductor that allows the electrons to return. The details of this will be discussed in the next article in this series on current.

To summarise, separated charges create an electric potential difference (a voltage). The size of this potential difference is measured in volts. When measuring the size of an electric potential difference you are measuring the difference in electric potential between two places. Separating charges requires energy. When separated charges are reunited, the energy is released and can be harnessed for useful work.

SEPARATING CHARGES

So, it seems that all we need to do to create useable electrical energy is to create a voltage by separating charges. There is a number of ways that charges can be separated; five of these are outlined here:

- Rubbing
- Electromagnetism
- Chemistry
- Photoelectric effect
- Piezoelectric effect

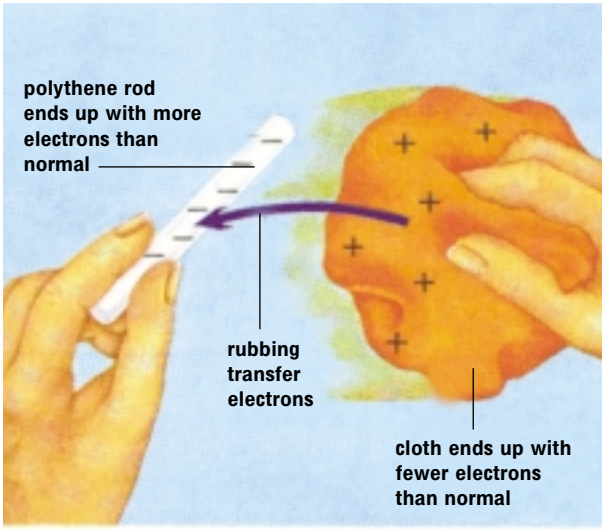

Fig 3 **Separating charges by rubbing**

RUBBING

When different types of materials rub against each other, electrons can be moved from one material to another. This causes a charge separation, but one that isn't generally useful; the amounts of separated charge are generally too small to do anything practical with. However engineers have recently been investigating whether the rubbing of your clothes as you walk could be used to generate enough useable electricity to charge a mobile phone.

ELECTROMAGNETISM

This is currently the method used to generate the greatest amount of electricity in the world.

When an electron is moved through a magnetic field a force is created that pushes the electron. An electron in a conducting wire is pushed to one end of the wire, so creating a voltage along the wire. If you can arrange for the wire to keep moving in the magnetic field then you will have a continuous force on the electrons; as you release the potential energy by allowing electrons to flow back through a circuit and do useful work, more electrons will take their place and you will have a permanent potential difference. An electrical generator is, put simply, a device that keeps wires moving through a magnetic field to produce a permanent and useable potential difference.

Clearly energy has to be used to keep the wire moving through the magnetic field and this can come from a wide range of sources, these include:

- Burning fossil fuels. Despite fears about global warming, this remains the main source of energy for electricity generation. Some of the energy from burning petrol or diesel in a car is used to run the car electrics.
- Nuclear power. Argued by some to be the solution to fears about global warming and rejected by others as simply too dangerous.
- Renewable sources. Wind, waves, rivers, solar heating and biomass (growing plants to burn) all ultimately come from the energy of the sun. Tidal energy is created by the pull of the moon on the earth. Geothermal energyis heat tapped from the earth's crust.
- Human power. For example a dynamo on a bike or the winding of a spring in a wind up radio. →

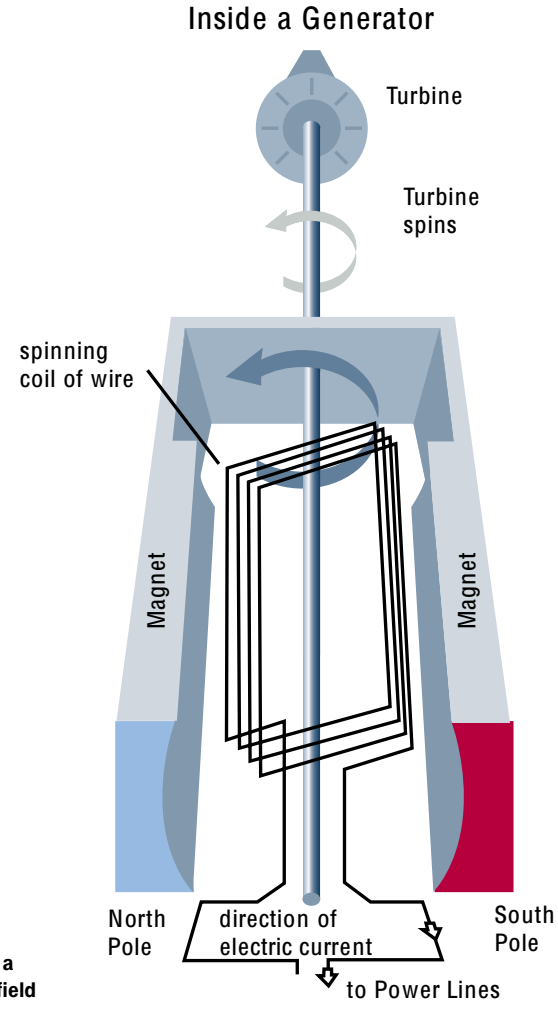

Fig 4 **Separating charges by moving a wire in an electric field**

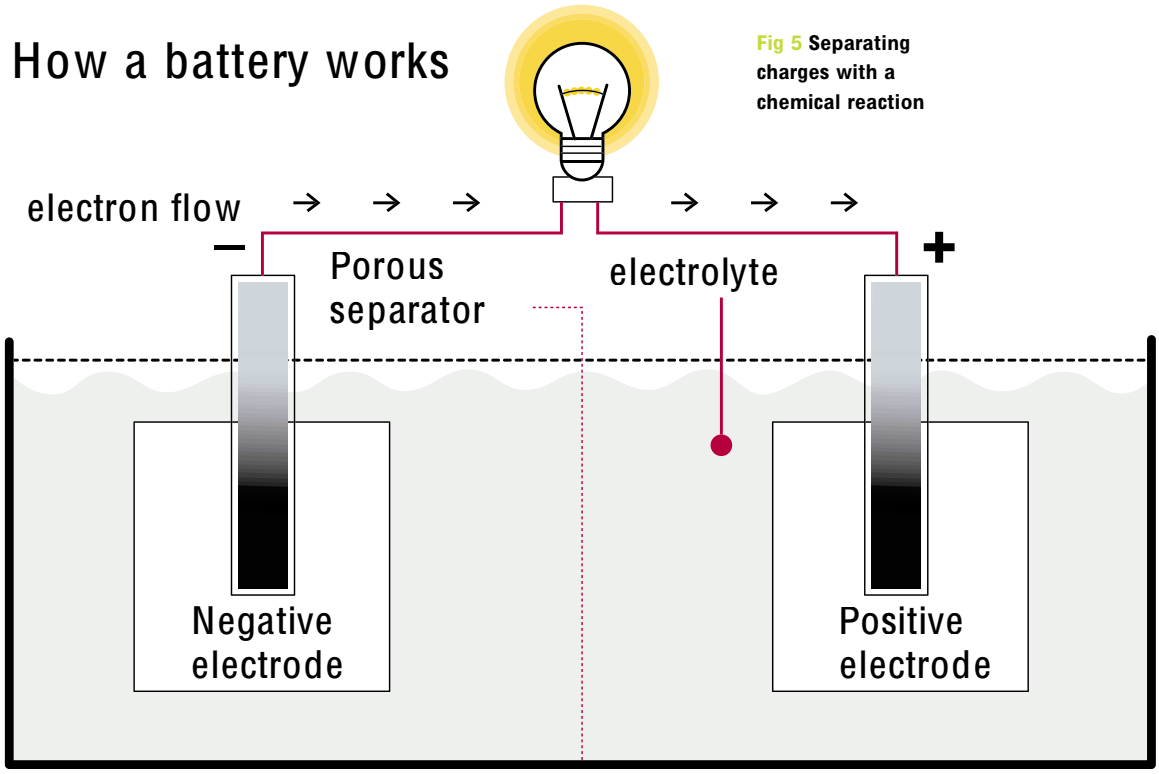

Fig 5 **Separating charges with a chemical reaction**

CHEMISTRY

Some chemical reactions can be used to separate charges. A chemical cell (often called a battery – though usually a battery is a collection of cells) contains chemicals that react together; as the potential difference caused by the reaction rises it suppresses the reaction, for example in common batteries the reaction stops occurring at a voltage of 1.5V. When the battery is used the voltage drops slightly and the reaction starts up to maintain the voltage – until all of the chemicals have reacted and the battery is 'dead'.

Fuel cells use a rather different chemical technology to generate charge separation. In a basic fuel cell hydrogen and oxygen are combined to create water; this is a chemical reaction that releases energy and the cell is designed to use this energy to separate charges creating a voltage of about 0.7V. The main difference between a fuel cell and a battery is that, when the hydrogen in a fuel cell runs out the cell can be refuelled by adding more hydrogen (the oxygen used come from the air).

It is worth noting that the chemicals used in both chemical and fuel cells have to be made in some way – usually using electricity generated by one of the other methods noted here. However, both batteries and fuel cells are useful for situations where electrical power is

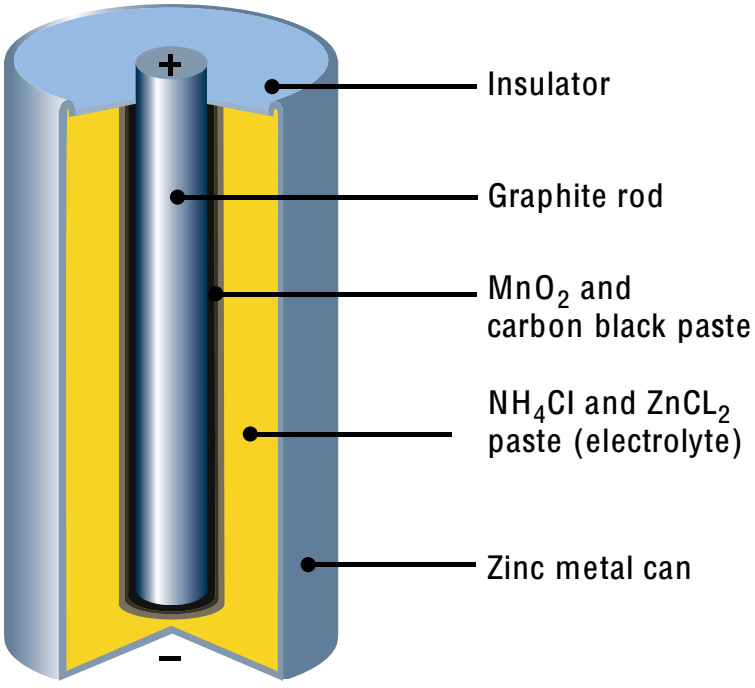

Fig 6 **How a cell contains a chemical reaction**

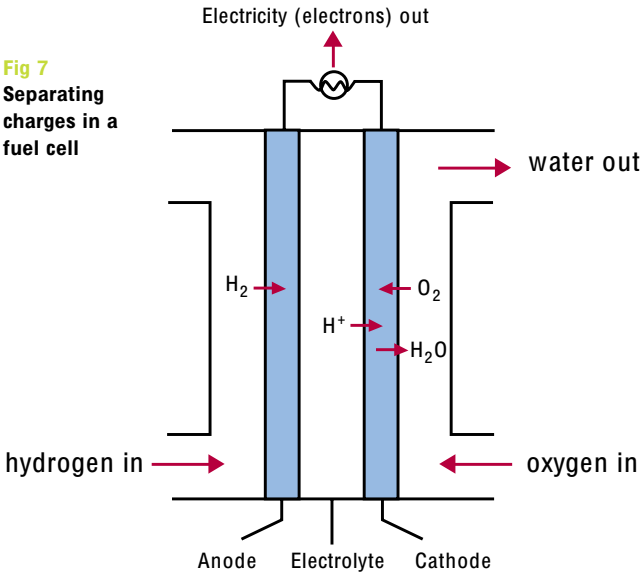

Fig 7 **Separating charges in a fuel cell**

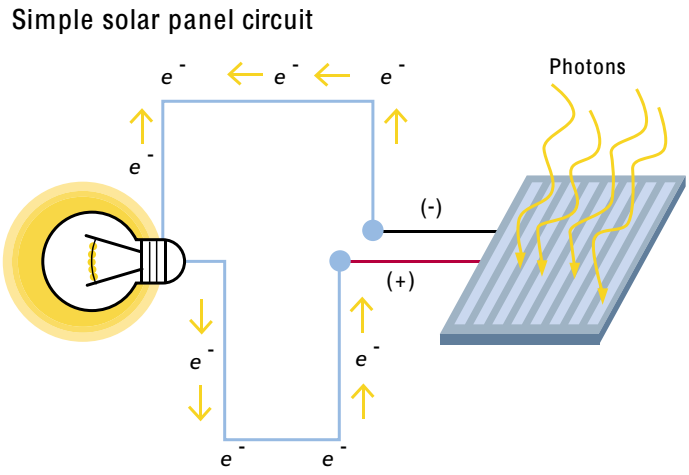

Fig 8 **Using light to separate charges in a solar panel**

wanted away from mains electricity; in portable consumer goods and for transport. Increasingly, you will find fuel cells replacing batteries in products such as mobile phones.

PHOTOELECTRIC EFFECT

Certain materials release electrons when light falls on them. This is called the photoelectric effect and can be used to separate charges. Although first explained by Albert Einstein a hundred years ago, it is only recently that the cost of 'solar cells' based on the closely related photovoltaic effect has become low enough to make them a realistic cost-effective way of generating electricity.

PIEZOELECTRIC EFFECT

When you apply pressure to some crystalline materials you get a charge separation within the crystal. The resulting voltage across the crystal can be very high. This effect is commonly used to create a spark to light a flame in hobs and gas fires and also in 'crystal' microphones. In most situations it would be impractical to generate a constant source of separated charges using this effect as this would mean constant rapid pressurising of the crystal.

However, as with charge separation through rubbing, engineers have recently been investigating whether the constantly changing pressure in your shoes as you walk could be used to generate enough useable electricity to charge the battery in a mobile phone or MP3 player.

Fig 9 **Separating charges in a crystal using the piezoelectric effect**

a] when the crystal is squeezed a potential difference is created
c] when the crystal is stretched the potential difference is reversed
c] repeatedly squeezing and stretching the crystal produces a varying (alternating) voltage