ESSENTIAL IDEAS IN ELECTRONICS: CURRENT

In this first part of our look at current, **Torben Steeg** discusses and explains some basic principles

PREFACE

Earlier articles on voltage (Spring 2005 and Summer 2005 issues) 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 and can be measured with a voltmeter
- When measuring a voltage, the two voltmeter leads are placed 'across' the potential difference; that is, to measure the difference in potential between two places the voltmeter leads are attached to those two places
- A voltage is created by separating electrical charges
- Energy is used to separate charges and this is transformed into electrical energy
- A range of methods exists to separate electrical charges and produce useable electrical energy

These articles can be downloaded from the Electronics Education website at **www.iee.org/EduCareers/Schools/elec_ed.cfm.**

This article turns the spotlight on electrical current.

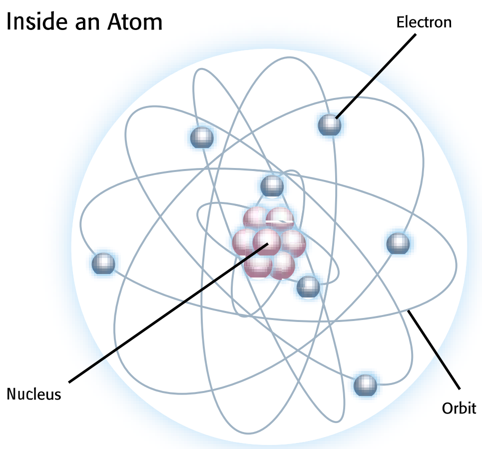

Fig1: a simple model of an atom

OPPOSITE CHARGES ATTRACT

You need to know two basic ideas from physics to enable you to understand current.

The first idea is that a fundamental property of the elementary building blocks of matter is that they can carry an electric charge. Some have negative charge (such as the electron), some have positive charge (such as the proton) and some, like the neutron, are uncharged, or neutral. Atoms are built from a mix of electrons, protons and neutrons so that the positive and negative charges cancel out and the atom itself is neutral.

The voltage articles, mentioned above, noted that energy can be used to remove an electron from an atom, creating two charged particles; the electron (negatively charged) and the remainder of the atom (positively charged, called an ion). This process is called ionisation.

The second idea from physics is that objects with the same charge repel each other but objects with opposite charges attract each other. So, a pair of electrons will be pushed away from each other, but

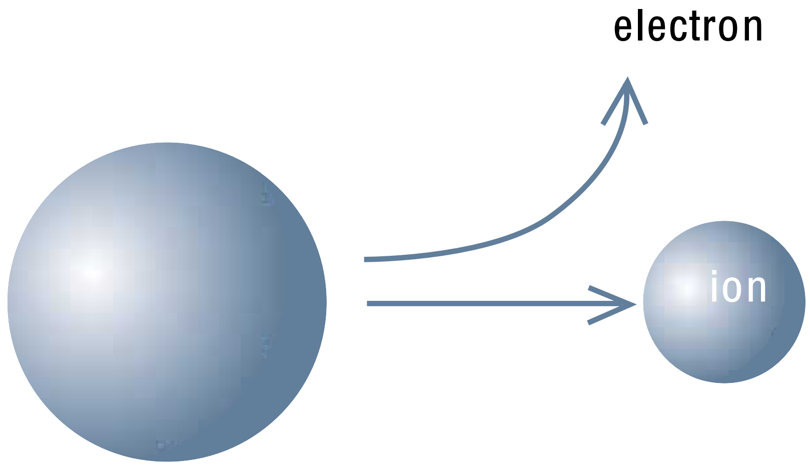

Fig 2: **Ionisation**

an electron and a proton will attract each other. (Incidentally, quantum mechanics was developed to provide an explanation of how electrons and protons in an atom remain separate despite the attraction between them – but that is another story.)

Now, we have seen, in previous articles, that a voltage, or potential difference, is created by separating electrical charges. Why, you might well ask, if these separated charges are attracted to each other, don't they simply fly back together? Well, in systems that generate electricity they do just that as soon as the energy source that is being used to separate the charges is removed; for example if a generator stops spinning in its magnetic field, or light stops falling on a solar panel, the voltage will disappear. But as long as the energy source generating the voltage remains in place, the only way that the charges can be reunited is if the positively and negatively charged sides of the generating system are connected somehow.

The positively charged side of a generating system is called the positive voltage. The negatively charged side is called negative. Slightly confusingly, the 'negative' side is usually also assumed to be 0V.

CONDUCTORS AND INSULATORS

If separated charges are to be reunited, then, since most practical electronic systems are solids, it is the electrons that have to move; the ionised atoms are still fixed in their place in the solid material.

There are some electrical devices that make use of fluids (liquids or gases) and in which both electrons and positively charged ions can move. Examples include the ionisation chamber in domestic smoke detectors and fuel cells.

It turns out that not all materials allow electrons to move through them; those that do not allow electron flow are called insulators. Those that do allow electrons to flow are called conductors.

Both conductors and insulators are required for the correct working of an electronic system. For example, both air and most plastics are quite good insulators. This means that electrons can't travel from the negative to the positive side of a battery through the air around a battery. Plastics are used extensively in electrical and electronic equipment to prevent electrons flowing where they shouldn't – in particular to coat electrical wiring to prevent electrons flowing into the users of the equipment; and causing an electric shock.

On the other hand metals, in particular, tend to be good conductors and are used to allow electrons to move towards the positive voltage. ➔

Nothing is a perfect insulator. If a voltage is big enough and the insulation is thin enough, the insulation will 'break down'; it will start to allow electrons to move. Lightning is a dramatic example of what happens when the insulation of air breaks down. This is also the reason why it is so dangerous to climb electricity pylons; the risk is less that you will touch the wires and more that by getting close to the wires you make the insulation gap thinner and likely to break down – allowing a huge number of electrons to move through the air, and then you, to the ground.

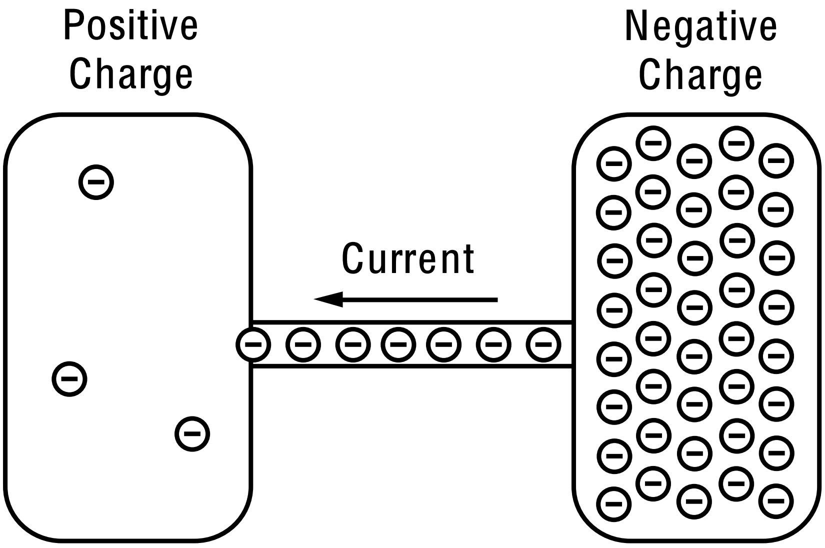

Fig 3: current flow in a conductor

This movement of electrons through a conductor, towards the positive side of a voltage difference, is called an electrical current.

> **The term 'current' to describe the movement of electrons was adopted by early investigators of electrical phenomena by analogy with the use of the word to describe the movement of water in a river or the sea.**

MEASURING CURRENT

The size of a current is measured in Amps (symbol 'A', formally the unit is the Ampere, but 'Amp' is used universally).

For example, 2A, 100mA (1mA is a thousandth of an Amp, i.e. 10^{-3}A).

More precisely, if a coulomb (1C) of charge is passing a point on a conductor every second then the current is defined as being IA.

> **1 coulomb is the charge equivalent of about 6×10^{18} electrons. That's 6 million million million electrons (6,000,000,000,000,000,000) passing the point where you are measuring, every second.**

A current of 1A represents quite a large current; for example many household electrical items require several amps of current to make them work and the maximum current that can be drawn from a domestic mains socket is 13A. However, currents in electronic circuits are typically measured in mA.

The size of a current depends on two factors; the voltage driving the flow of electrons and the 'resistance' to electron movement that the conducting material has. Resistance is a new electrical concept that will be thoroughly discussed in a future article in this series; for now we can consider resistance to be a measure of how good a conductor a material is.

Resistance is measured in Ohms (symbol 'Ω' – the Greek letter omega); a perfect conductor would have a resistance of 0Ω, a perfect insulator a resistance of ∞Ω (infinite resistance). In real work in school electronics you will find that short lengths of wire have effectively 0Ω and poorly conducting parts of a circuit will be measured in MΩ.

The way that current depends on voltage and resistance is described by Ohm's Law:

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}} \qquad I = \frac{V}{R}$$

Thus current is directly proportional to voltage (the higher the voltage, the higher the current) and inversely proportional to resistance (the higher the resistance, the lower the current).

> **Strictly, Ohm's law, as Georg Ohm originally defined it, relates only to electrical conduction in straight lengths of metal wire. However the mathematical relationship he discovered is much more widely useful than this and continues to be known as Ohm's law.**

To measure current in a circuit you need to 'break into' the circuit with an ammeter (a meter that measures Amps) at the point where you wish make the measurement – this way the entire flow of electrons you are measuring will pass

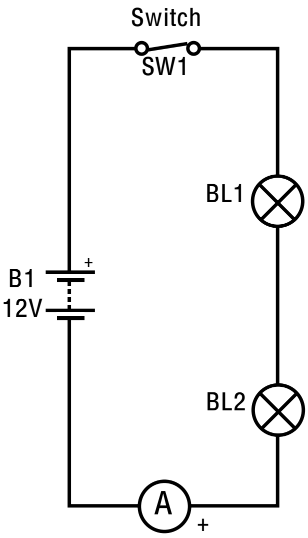

Fig 4: **using a meter to measure current in a circuit**

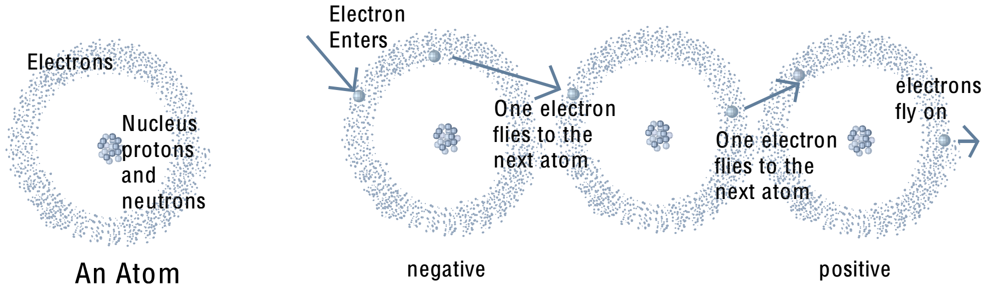

Fig 5: **electron drift in a metal conducting**

through your meter. In this diagram it would not matter where you placed the ammeter - the reading would always be the same.

Note in Fig 4 that the positive side of the ammeter (the side with the '+' symbol) is connected to the side of the circuit 'break' closest to the positive side of the power supply. The other side of the meter (called the negative side) is connected to 0V.

It anything but very simple circuits, such as that shown in Fig 4, it is generally too difficult to make a break in a circuit to measure current. Instead you can measure the voltage (with a voltmeter) and the resistance (with an ohmmeter) and use Ohm's law to calculate the current.

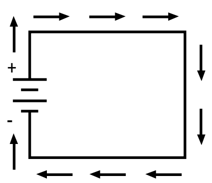

Fig 6: **conventional flow notation**

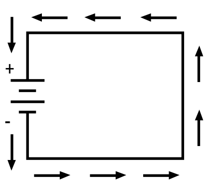

Fig 7: **electron flow notation**

HOW ELECTRONS FLOW IN A METAL

The description of current so far could have given the impression that electrons move along a wire freely in much the same way that cars go down a road.

The situation is actually rather different. A conductor (like every material) is made of atoms. What is special about metals is that their outer electrons are loosely connected. Sometimes these loose electrons are described as a 'sea' of electrons. Note, however, that the material is neutral – the electrons move fairly freely between atoms, but each atom keeps the right number of electrons. As an electron joins a new atom, the atom will become negative and lose an electron to a nearby atom. This atom takes in the electron and in turn looses one to another atom.

Even without a voltage being present the speed that electrons are moving within the material is around a million metres per second, but this motion is random, so there is no net movement of charge, or current.

When any conductor (eg metal wire or a resistor) has a voltage across it, electrons are attracted towards the positive side of the voltage and they drift in that direction.

CONVENTIONAL CURRENT

We know from the above that the direction of electron flow is towards positive in a circuit.

Unfortunately, when key early definitions were created (mainly by Benjamin Franklin) about charge flow, they were based on assumptions about the way that charge was moving that turned out to be wrong; he called materials that he assumed to have a deficiency of charge 'negative'. We now know that these negative materials actually have an excess of electrons (and so electrons, when they were discovered were deemed to be negative). Having defined some materials as positive and others as negative, it was logical to define the flow of charge as being from positive to negative. By the time it had been established that electrons actually move in the opposite direction the convention that current flows from positive to negative was firmly established and continues today in most engineering fields (the underlying logic of what happens in a circuit is not affected by which way round humans define positive and negative).

This means that you have to be ready to deal with the fact there are two current flow notations widely accepted in electronics. ■

The next article in this series will look in more detail at the phenomenon of electrical resistance.