Online Radio & Electronics Course

Reading 2

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BASIC ELECTRICITY - PART 2

THE THREE BIG NAMES IN ELECTRICITY

Without calling them by name, we have touched on the three elements always present in operating electric circuits:

Current: A progressive movement of free electrons along a wire or other conductor that produces electrostatic lines of force.

Voltage: The electron-moving force in a circuit that pushes and pulls electrons (current) through the circuit. Also called electromotive force.

Resistance: Any opposing effect that hinders free-electron progress through wires when an electromotive force is attempting to produce a current in the circuit.

We will be talking a lot about these three properties of an electric circuit and how they interact with each other.

A simple electric circuit

The simplest of electric circuits consists of:
Some sort of an electron-moving force, or source, such as that provided by a dry cell, or battery; a load, such as an electric light; connecting wires, and a control device.

A pictorial representation and the electric diagram of a simple circuit are shown in figure 6. The diagram on the right in figure 6 is called a schematic diagram and is much easier to draw. The control device is a switch, to turn the bulb on and off. In effect the switch disconnects one of the wires from the cell. In our circuit the switch could be connected anywhere to turn the bulb on and off.

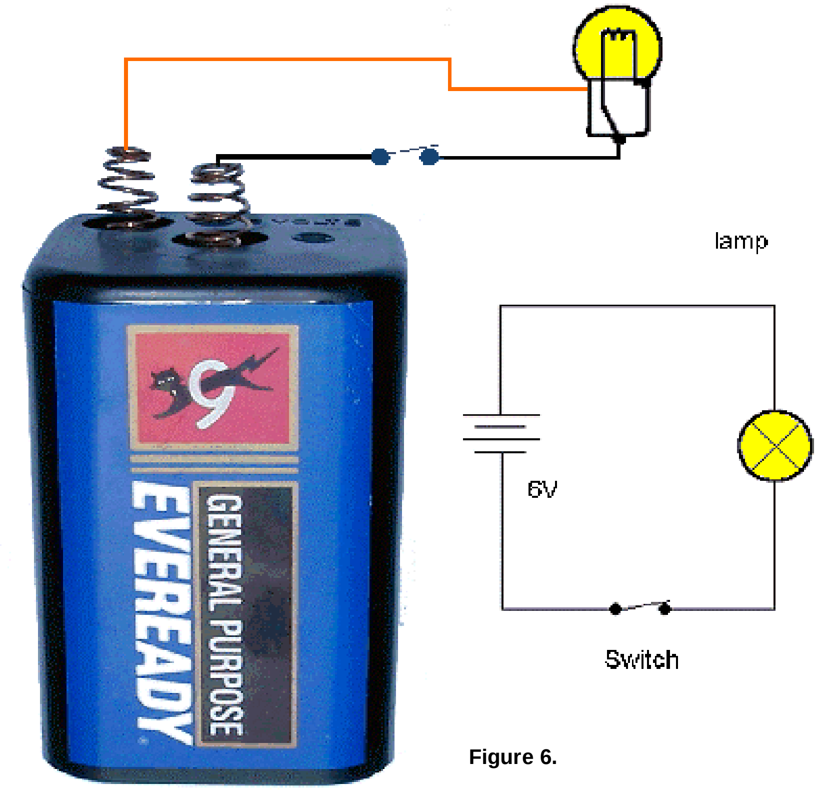


Figure 6.

In our circuit the light bulb is the load. Although the wires connecting the source of electromotive force (the dry cell) to the load may have some resistance, it is usually very small in comparison with the resistance of the load and is ignored in most cases. A straight line in a schematic diagram is considered to connect parts electrically but does not represent any resistance in the circuit.

In the simple circuit shown, the cell produces the electromotive force (voltage) that continually pulls electrons to its positive terminal from the bulb's filament and pushes them out the negative terminal to replace the electrons that were lost to the load by the pull of the positive terminal. The result is a continual flow of electrons through the lamp filament, connecting wires, and source. The special resistance wire of the lamp filament heats when a current of electrons flows through it. If enough current flows, the wire becomes white-hot and the bulb glows and gives off light (incandescence).

Current

A stream of electrons forced into motion by an electromotive force is known as a current. Here we have a definition of electric current:

Current is the ordered movement of electrons in a circuit.

In a good conducting material such as copper one or more free electrons at the outer ring are constantly flying off at a high rate of speed. Electrons from other nearby atoms fill in the gaps. There is a constant aimless movement of billions of electrons in all directions at all times in every part of any conductor. This aimless or random movement of electrons is not an electric current as there is not yet movement in any one direction. Only when a voltage is applied do we get an ordered movement of electrons.

When an electric force is applied across the conductor (from a battery), it drives some of these aimlessly moving free electrons away from the negative force toward the positive. It is unlikely that any one electron will move more than a fraction of an inch in a second, but an energy flow takes place along the conductor at approximately 300,000,000 meters per second (actually 299,792,462 m/s).

Notice that I said the energy flow in the circuit is very fast (almost the speed of light - but not quite). The speed of the electrons in a circuit - or the current flow is in fact very slow. I won't bore you with calculations, however I did once calculate how fast the electron flow was in a typical circuit and it came to be about walking speed. Electron flow or current flow is very slow. The effect of an electric current at a distance through a conductor on the other hand is very fast. If you really want to see a calculation on the speed of electricity see the article ‘How fast is electricity’ in the downloads section of the web site.

If you have trouble with this, and many do, think about how fast water travels in a pipe. The dam where the water comes from may be many kilometres away from the tap. When you turn the tap on the water comes out immediately does it not? Did the water travel all the way from the dam to the tap in an instant? I am sure you would agree that it did not. If I tried to tell you that it did you would most probably laugh at me and say the water was already in the pipe, all you did by turning the tap on was to make the water move in the pipe between the dam and the tap.

Similarly the electrons are already in the wire (conductor). When we close a switch in the circuit and apply an electromotive force all we are doing is making all the electrons move in the conductor at the same time. It may take a very long time for an electron leaving the source to reach the load if in fact it ever does.

How fast are marbles?

Let's do another analogy to make sure we have got this clear. Suppose a pipe was connected between Sydney and Melbourne. Imagine if we blocked off one end of the pipe and filled it with marbles until we could not fit anymore in. We now unblock the pipe and we have a crowd of people at each end to witness the experiment to see how fast marbles travel. The two crowds are in contact by telephone or radio and anxiously waiting the big moment. One too many marbles are about to be inserted into the full pipe. As soon as a marble is inserted in Sydney, a marble drops out in Melbourne. The effect of pushing a marble into the pipe in Sydney caused an immediate result or effect in Melbourne. The newspapers report "Eccentric experimenter proves that marbles travel at the speed of light". Is this right?

I hope you are shaking your head and saying no. The marble, which fell out of the pipe in Melbourne, was sitting there ready to fall out as soon as the marble was pushed in at the Sydney end. So marbles definitely do not travel at the speed of light any more than do electrons in a conductor. The marbles were already in the pipe just as the electrons were already in the conductor.

The effect of an electric current at a distance is almost instantaneous; however the speed of the electrons is very slow.

A source of electric energy does not increase the number of free electrons in a circuit; it merely produces a concerted pressure on loose, aimlessly moving electrons. If the material of the circuit is made of atoms or molecules that have no freely interchanging electrons, the source cannot produce any current in the material. Such a material is known as an insulator, or a non-conductor.

The amount of current in a circuit is measured in amperes, abbreviated 'A' or Amp. An ampere is a certain number of electrons passing or drifting past a single point in an electric circuit in one second. Therefore, an ampere is a rate of flow, similar to litres (or marbles) per minute in a pipe.

The quantity of electrons used in determining an ampere (and other electrical units) is the coulomb, abbreviated 'C'. An ampere is one coulomb per second. A single coulomb is 6,250,000,000,000,000,000 electrons. This large number is more easily expressed as 6.25×10^{18}, which is read verbally as "6 point 25 times 10 to the eighteenth power". "Ten to the eighteenth power" means the decimal place in the 6.25 is moved 18 places to the right. This method of expressing numbers is known as the powers of 10 and is handy to use when very large or very small numbers are involved.

Electromotive force or voltage

The electron-moving force in electricity, variously termed electromotive force (emf), electric potential, potential difference (PD), difference of potential, electric pressure, and voltage (V), is responsible for the pulling and pushing of the electric current through a circuit. The force is the result of an expenditure of some form of energy to produce an electrostatic field.

An emf (I like to read this as 'electron-moving force') exists between two objects whenever one of them has an excess of free electrons and the other has a deficiency of free electrons. An object with an excess of electrons is negatively charged. Similarly an object with a deficiency of electrons is positively charged. Should two objects with a difference in charge be connected by a conductor, a discharge current will flow from the negative body to the positive one.

Instead of saying negatively or positively charged all the time it is easier to say '-Ve' or '+Ve'

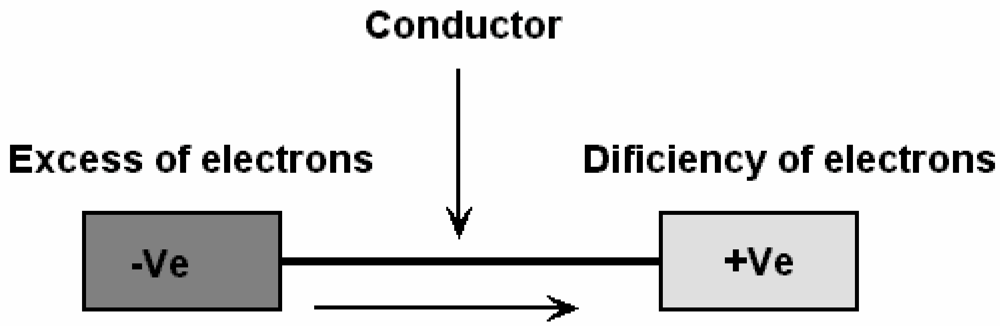
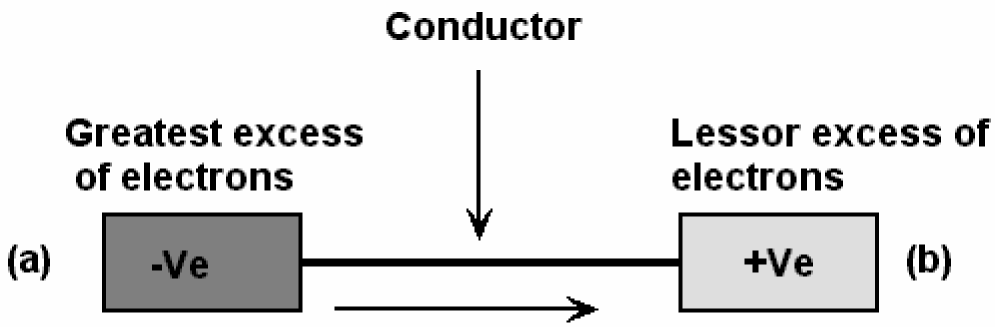


Fig. 7 - Current flow from negative to positive

An emf also exists between two objects whenever there is a difference in the number of free electrons per unit volume of the objects. In other words, both objects may have a negative charge but one is more negative than the other. The less negative object is said to be positive with respect to the more negative object.



(a) is negative with respect to (b)

Fig. 8 - Current flow from most negative to less negative

In the electrical trades it is common to hear of current flow from positive to negative. This is called the conventional direction of current flow. This is just what it says, a convention (popular method). Current flow *is* electron flow and it is from negative to positive.

The unit of measurement of electric pressure, or emf, is the Volt (V). A single torch dry cell produces about 1.5 V. A wet cell of a storage battery produces about 2.2 Volts per cell.

NOTE: A battery is a collection of cells (like a battery of cannons). There is no such thing as an AA battery, it is an AA cell. On the other hand a 9 volt transistor battery or a car battery are examples of real batteries because they are constructed from a number of cells connected together (in series) - more on this later.

A volt can also be defined as the pressure required to force a current of one ampere through a resistance of one ohm.

PRODUCING AN ELECTRON-MOVING FORCE (VOLTAGE)

1. Chemical (cells and batteries)
2. Electromagnetic (generators)
3. Thermal (heating the junction of dissimilar metals)
4. Piezoelectric (mechanical vibration of certain crystals)
5. Magnetostriction (filters and special energy changers called transducers)
6. Static (laboratory static-electricity generators) remember our hair comb experiment.
7. Photoelectric (light-sensitive cells)
8. Magnetohydrodynamics (MHD, a process that converts hot gas directly to electric current)
9. Piezo-electricity – some materials produce a voltage when physical pressure is applied to them.

We will be discussing most of the above in more detail as we go through this course.

Effects of an electric current

These are the main effects:

1. Heat and light – current flowing in a conductor causes the conductors temperature to increase. If the temperature increases sufficiently the conductor will become incandescent and radiate light.

2. Magnetic - a conductor carrying a current will produce a magnetic field around the conductor.

3. Chemical – electroplating, charging batteries. An electric current is able to cause a chemical reaction.

THE BATTERY IN A CIRCUIT

In the explanations thus far, "objects," either positively or negatively charged, have been used. A common method of producing an emf is by the chemical action in a battery. Without going into the chemical reactions that take place inside a cell, a brief outline of the operation of a Leclanche cell is given here.

Consider a torch cell. Such a cell (two or more cells form a battery) is composed of a zinc container, a carbon rod down the middle of the cell, and a black, damp, paste-like electrolyte between them. The zinc container is the negative terminal. The carbon rod is the positive terminal. The active chemicals in such a cell are the zinc and the electrolyte. The materials in the cell are selected substances that permit electrons to be pulled from the outer orbits of the molecules or atoms of the carbon terminal chemically by the electrolyte and be deposited onto the zinc can. This leaves the carbon positively charged and the zinc negatively charged. The number of electrons that move is dependent upon the types of chemicals used and the relative areas of the zinc and carbon electrodes. If the cell is not connected to an electric circuit, the chemicals can pull a certain number of electrons from the rod over to the zinc. The massing of these electrons on the zinc produces a backward pressure of electrons, or an electric strain, equal to the chemical energy of the cell, and no more electrons can move across the electrolyte. The cell remains in this static, or stationary, 1.5 V charged condition until it is connected to a load.

Have a look at the diagram below of a Leclanche cell just to get an idea of the construction.

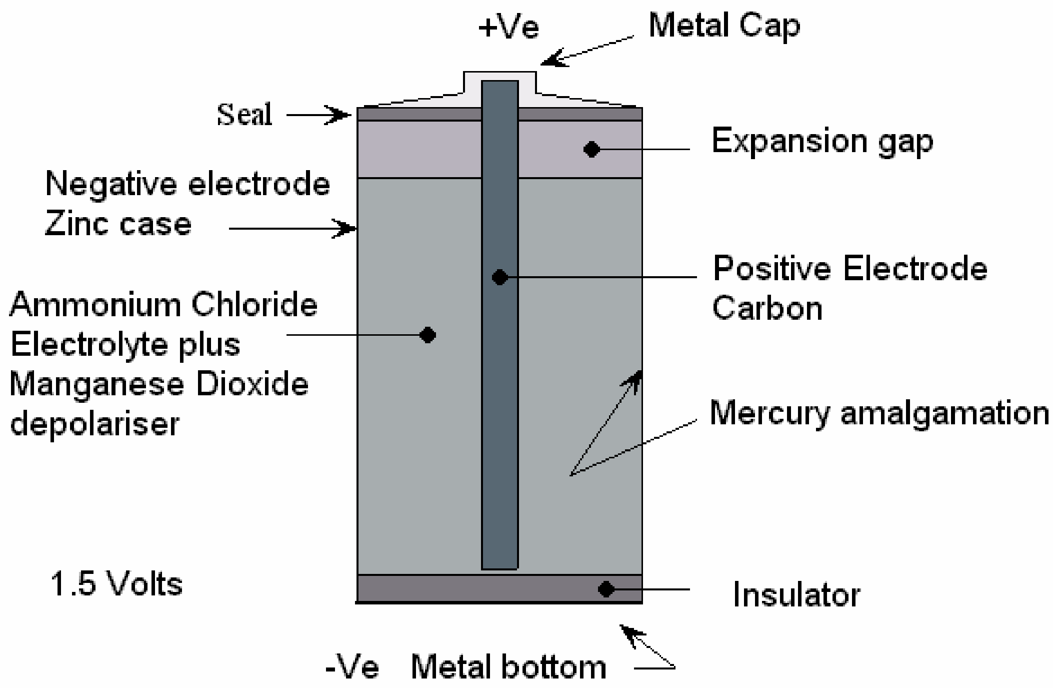


Fig. 9 - The Leclanche dry cell

If a wire is connected between the positive and negative terminals of the cell, the 1.5 V of emf starts a current of electrons flowing through the wire. The electrons flowing through the wire start to fill up the deficient outer orbits of the molecules of the positive rod. The electron movement away from the zinc into the wire begins to neutralise the charge of the cell. The electron pressure built up on the zinc, which held the chemical action in check, is decreased. The chemical reaction of the cell can now creates a flow of ions through the electrolyte, maintaining a current of electrons through the external wire as long as the chemicals hold out.

Note that as soon as the wire begins to carry electrons, the electrolyte also has ions moving through it. This motion produces an equal amount of current through the whole circuit at the same time. This is a very important concept to understand. There are no bunches of electrons moving around an electric circuit like a group of racehorses running around a track. A closed circuit is more like the racetrack with a single lane of cars, bumper to bumper. Either all must move at the same time, or none can move.

In an electric circuit, when electrons start flowing in one part, all parts of the circuit can be considered to have the same value of current flowing in them instantly. Most circuits are so short that the energy flow velocity, 300,000,000 meters per second, may be disregarded for the present.

Figure 10.

At left – the first three are cells – from left to right 'C' cell, 'D' cell, 'AA' cell. On the far right is a 9 volt transistor battery – if you open one of these you will find 6 cells inside connect in series. 6 x 1.5 = 9Volts.
Something to try –
Break open the case of an old 6 volt "lantern" battery – you won't make a mess and you will clearly see 4 individual cells inside.

Ionisation

When an atom loses an electron, it lacks a negative charge and is therefore positive. An atom with a deficiency of one or more electrons is called a positive ion. On the other hand if an atom were to gain an electron, albeit temporarily, it is a negative ion.

In most metals the atoms are constantly losing and regaining free electrons. They may be thought of as constantly undergoing ionisation. Because of this, metals are usually good electrical conductors.

Atoms in a gas are not normally ionised to any great extent, and therefore a gas is not a good conductor under low electric pressures. However, if the emf is increased across an area in which gas atoms are present, some of the outer orbiting electrons of the gas atoms will be attracted to the positive terminal of the source of emf and the remainder of the atom will be attracted toward the negative. When pressure increases enough, one or more free electrons may be torn from the atoms. The atoms are ionised. If ionisation happens to enough of the atoms in the gas, a current flows through the gas. For any particular gas at any particular pressure, there is a certain voltage value that will produce ionisation. Below this value, the number of ionised atoms is small. Above the critical value more atoms are ionised, producing greater current flow, which tends to hold the voltage across the gas at a constant value. In an ionised condition the gas acts as an electric conductor.

Examples of ionisation of gases are lightning, neon lights, and fluorescent lights. Ionisation plays an important part in electronics and radio.

Types of current and voltage

Different types of currents and voltages are dealt with in electricity:

1. Direct current (dc). There is no variation of the amplitude (strength) of the current or voltage. Obtained from batteries, dc generators, and power supplies.

2. Varying direct current (vdc). The amplitude of the current or voltage varies but never falls to zero. Found in many radio and electronic circuits. A telephone is a good example of varying direct current

3. Pulsating direct current (pdc). The amplitude drops to zero periodically (such as our light bulb circuit if it was repeatedly switched on and off).

4. Alternating current (ac). Electron flow reverses (alternates) periodically and usually changes amplitude in a more or less regular manner. Produced in ac generators, oscillators, some microphones, and radio in general. Household electricity is alternating current.

Resistance

Resistance is that property of an electric circuit which opposes the flow of current. Resistance is measured in Ohms. The higher the resistance in an electric circuit the lower will be the current flow. The symbol used for resistance is the Greek letter omega Ω. If a circuit with an electric pressure of 1 volt causes a current of 1 ampere to flow, then the circuit has a resistance of 1 Ω.

What's in a name?

We have learnt quite a few new terms. Some of these terms are actually take from people's names. These people were usually pioneers in the fields of physics, electricity or electronics. Read the very short biographies below and think about the person's name and what it represents in an electric circuit.

George Simon Ohm. Born March 16, 1789, Erlangen, Bavaria [Germany]. Died July 6, 1854, Munich. German physicist who discovered the law named after him, which states that the current flow through a conductor is directly proportional to the potential difference (voltage) and inversely proportional to the resistance.

Andre-Marie Ampere. Born Jan. 22, 1775, Lyon, France. Died June 10, 1836, Marseille. French physicist who founded and named the science of electrodynamics, now known as electromagnetism. Ampère was a prodigy who mastered all mathematics then existing by the time he was 12 years old. He became a professor of physics and chemistry at Bourg in 1801 and a professor of mathematics at the École Polytechnique in Paris in 1809.

Allesandro Giuseppe Antonio Anastasio Volta. Born Feb. 18, 1745, Como, Lombardy [Italy]. Died March 5, 1827, Como. Italian physicist whose invention of the electric battery provided the first source of continuous current. He became professor of physics at the Royal School of Como in 1774 and discovered and isolated methane gas in 1778. One year later he was appointed to the chair of physics at the University of Pavia.

Charles Augustin de Coulomb. Born June 14, 1736, Angoulême, France. Died Aug. 23, 1806, Paris. French physicist best known for the formulation of Coulomb's law, which states that the force between two electrical charges is proportional to the product of the charges and inversely proportional to the square of the distance between them.

Goerges Leclanche. Born 1839, Paris. Died Sept. 14, 1882, Paris. French engineer who in about 1866 invented the battery bearing his name. In slightly modified form, the Leclanche battery, now called a dry cell, is produced in great quantities and is widely used in devices such as torches and portable radios.

End of Reading 2.
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