Background information for teaching electricity at the primary-school level

translated from German (taken from www.sonnentaler.net) by Angela Michel and Marlene Rau

What is electricity?

by David Jasmin, La main à la pâte, Paris

Electricity primarily concerns charge: positive and negative. Opposite charges attract each other, whereas equal charges repel each other. Charge is present in all matter, and if a body has the same amount of positive and negative charge, it is described as neutral. If this balance is disturbed, the body becomes charged and can attract or repel other charged bodies around it. Electricity describes all phenomena caused by charge.

In general, we distinguish (electro)static electricity, which describes the interchange of immobile charges, from electrodynamics, which describes mobile charges, such as in an electric circuit.

Electrostatics was discovered by Thales as early as 600 BC, whereas electrodynamics received more attention only after Volta invented the battery in 1800.

Electrostatics

Despite what the name suggests, electrostatics is anything but static. On the contrary – static charges are influenced by other charges around them, and thus attract or repel each other depending on whether they are opposite or equal. Brushing your hair causes it to stand up, because each hair is an electric insulator from which electric charge is removed onto the brush by brushing. This makes the brush negatively and the hair positively charged. Each hair repels its neighbours, which are also positively charged as a result of brushing. On certain pieces of clothing, static charges tend to accumulate. If you touch a metallic conductor (or another person), the charges will dissipate, causing an electric discharge which is perceived as an electric shock – not dangerous, but also not pleasant! Sometimes charges accumulate between two flat conductors separated by an insulating layer. This property is exploited in an electrical device called a capacitor, which can store a small amount of electricity.

Electrodynamics

In electrodynamics – which is what people generally associate with electricity – electric charges also play an important role, but in this case they are mobile. Charges moving constantly in an electric circuit are what we call an electric current. An electric current can only flow if the circuit is closed and if it contains at least one conductive material along which the charge can move. A power supply unit (battery, dynamo, the power grid, etc.) is necessary to drive the charge, and a consumer load must be ‘operated’ by the electricity. The power supply unit has at least two contacts – a negative and a positive one – which set charges in motion within the circuit. Using a power supply unit and a conductor, a wide range of consumer loads can be operated: bulbs, domestic appliances, computer chips, transistors, and so forth.

At the atomic level

One way to understand electricity is to examine matter at the atomic level. At the centre of each atom, a nucleus contains uncharged neutrons and positively charged protons. This is surrounded by a cloud of negatively charged electrons. Protons and electrons attract each other, thereby binding the electrons to the nucleus. Electrons that are bound further from the nucleus require less energy to escape this binding ‘influence’. In non-conductors, electrons tend to be bound more tightly to ‘their’ nucleus than in conductors. As soon as electrons start moving in a certain direction – for example, if voltage is applied – an electric current will flow through the material. In other words, you have a conductor.

[Note from the German sonnentaler.net translator: However, this is not the only way to generate electricity at the atomic level. In solutions, for example, there are usually not only uncharged, but also a certain amount of both negatively and positively charged atoms and molecules, which also have one or more electrons ‘too many’ or ‘too few’. These are called ions. They, too, can be moved by voltage, thereby generating electricity.]

The electric battery

by David Jasmin, La main à la pâte, Paris

The electric battery was invented in 1800 by the Italian physicist Alessandro Volta. Apart from marking the beginning of a new century, this year was also a turning point in the history of electricity. The Voltaic pile, or battery, was the first source of electricity that allowed the flow of a direct current (DC, as opposed to an alternating current, AC) in an electric circuit. The original version of this battery consisted of alternating copper and zinc plates, separated by cardboard soaked in salt water. The copper and zinc plates served as the battery’s electrodes, with the salt water acting as the electrolyte. Chemical reactions between the two components generated electricity.

How does it work?

In contact with the solution (salt water), the copper electrode releases electrons and becomes positively charged. This is called the positive terminal of a battery (the cathode, marked with a plus), whereas the zinc electrode accepts electrons from the solution and becomes negatively charged. This is the negative terminal of a battery (the anode, marked with a minus). Between the two terminals (the different ends of the conductor), there is a voltage through which a constant flow of electrons is generated. The electrons flow from the negative to the positive terminal through the electric circuit. Then, within the battery, they flow from the positive to the negative terminal through the electrolyte solution, which constitutes the other part of the circuit. This closes the loop and generates electricity.

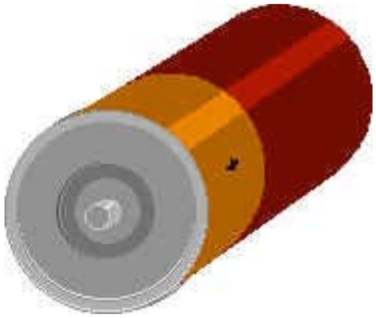

Fig. 1: Round battery

The cathode is constantly renewed by accepting electrons from the circuit to regenerate the copper that reacted with the solution. Since only the zinc electrode degrades, this process can continue until it is completely degraded.

The voltage at the different ends of the conductor depends on the type of elements used. By piling up various plates, Volta was able to achieve a maximum voltage of 24 V. In 1866, the chemist Georges Leclanché improved this system by replacing the copper electrode with a coal stick and the salt water with a jelly of manganese oxide and carbon powder, which made the battery more compact and above all portable. The modern battery was born. Over the years, the system has repeatedly been modified. Examples include the round battery with a graphite stick in the centre, the alkaline cell which uses potassium hydroxide (potash solution) as an electrolyte, and the coin cell, which is used for watches or calculators.

The accumulator

by David Jasmin, La main à la pâte, Paris

Accumulators work similarly to normal batteries. In fact, when used in cars they are referred to as batteries.

They consist of various units (cells) of lead (negative end) and lead oxide plates (positive end) separated by thin layer of sulphuric acid (the electrolyte). Car batteries usually generate 12 V.

Unlike a normal battery, an accumulator can be recharged. When it is being charged, an accumulator does not store electricity but rather chemical energy – some of which is converted back into electrical energy when discharged.

Filament bulbs

by David Jasmin, La main à la pâte, Paris

We owe this bright and brilliant invention to the American Thomas Edison and the Englishman Joseph Wilson Swan. The name filament lamp (or filament bulb) comes from the long metal filament (usually wolfram) which is heated in the bulb by an electric current passing through it. At a temperature of 3000 °C it starts glowing and produces light. In contact with air, the filament would burn rapidly. Therefore it is enclosed by a glass bulb, in which a vacuum has been created and then filled with an inert (noble) gas such as argon or krypton. A normal light bulb's average burning time is approximately one thousand hours. Its power is measured in watt; the higher the watt number, the stronger the light being emanated, and the more electricity consumed.

Light can also be produced by a fluorescent lamp. In this case, instead of a filament there is a small amount of gas conducting the electricity. If you apply voltage to the contacts of the fluorescent tube, electricity starts to flow, and the gas emits invisible ultraviolet light. When this ultraviolet light illuminates a special luminescent coating on the inside of the tube (usually phosphor), this coating then emanates visible light.

[Note from the German translator: An inherent disadvantage of a light bulb is the fact that only 2% of the input energy is converted into visible light; the rest ends up as heat. For ecological reasons, filament bulbs will be therefore be replaced by lamps generating less heat, such as fluorescent lamps, energy-saving lamps, halogen bulbs and light-emitting diodes (LEDs) in the foreseeable future.]

Common misconceptions

by David Jasmin, La main à la pâte, Paris

Electricity is a movement of electrons.

Not necessarily. This statement is only true for metals, but metals are not the only conductors. An electric current can also be sent through a conducting solution. In a battery or an accumulator, for example, electricity is transported via charged atoms or molecules (ions). This is also the case for currents passing through earth, the oceans or your body. Electricity is run through your brain and your nerve cells via potassium or sodium atoms (Source: *Electricity Misconceptions*).

The electrons passing through an electric circuit are supplied by the voltage source.

No. The electricity in a normal electric circuit is an electron current, but the electrons are not supplied by the power source. For the most part, they come from the (copper) atoms of the conductors. These electrons are already present in the wire before it is connected to the power source. The power source itself does not generate electrons, it only causes them to move through the circuit. In an electric circuit, the electrons move as a coherent body, similar to a driving belt revolving around two pulleys (or the carriages of a train). The power source only gets the driving belt going – it does not generate it. If the power source is turned off or a circuit is opened, the electrons remain where they are. (Source: *Electricity Misconceptions*).

It is more dangerous for the human body to experience a very short period of heavy current than a weaker current over a longer period.

Not necessarily. A current is not necessarily harmless just because it is weak. An electric current of 0.025 A flowing through a human body for 30 seconds can in certain cases be fatal. To get an impression of the risks we are exposed to, it is useful to know that for a body which comes into contact with 230 V, the current is 0.25 A. With alternating current, the safety voltage was set to 50 V under normal conditions and 25 V in damp rooms. It is assumed that below this voltage, electricity is not harmful to the user.

In an electric circuit the electrons flow at the speed of light.

No. In metals, electricity is generated by the movement of electric charges (the electrons). However, these electrons move very slowly, at a speed of 60 cm/hour. And yet we do not have to wait for ages when we turn the lights on or off. How does this work? Even if the electrons themselves move slowly, the energy as such is transmitted in an instant. Whenever the electrons are ‘pumped’ to the end of a wire, they drag the other electrons along in their movement, and the energy is transmitted to the rest of the circuit. To illustrate this, imagine a big wooden wheel. If you turn it, the whole wheel will move. The energy you use is instantly transmitted to the whole wheel, although the wheel itself (and therefore its atoms) have moved comparatively little.

The light emitted by fireflies is an electrical phenomenon.

No. The firefly has neither a filament bulb nor a battery but a luminous organ in its abdomen, which contains an enzyme called luciferase. This enzyme triggers a chemical reaction to emit light, a phenomenon which can sometimes be seen at night. Current research shows that certain fireflies use this light to warn their natural enemies from their bitter taste. In Southeast Asia, male fireflies use their light to attract female fireflies around them – a luminous trick.

Difficulties caused by pupils' misconceptions

by La main à la pâte, Paris

To many people, electricity means danger. In school, you can use this idea to encourage students to behave prudently.

The youngest pupils don’t always know that you need an energy source (such as a battery) to achieve any effect. From early on, they are used to pressing a button (or flicking a switch) to turn on the light or start a toy. They imagine that the effect they see is caused by something in the switch. In household appliances, there are usually two wires integrated in just one cable. Pupils therefore have the impression that the electricity is transported to the appliance through a single wire and is absorbed there. They have no concept of a current flowing back or of an electric circuit.

When the class familiarises itself with the concept of an electric circuit through practical experiments, they often get the wrong idea that each of the two battery contacts sends something into the light bulb, and when these two currents meet, light is created. Another popular misconception is that electricity is used up when it flows through an electric circuit (when in reality, the same electricity flows through a series of connections from one battery contact to the other). Moreover, pupils often wrongly connect the quality of ‘being a conductor’ with the thing itself rather than with the material of which it consists.

Practical advice to prevent accidents

Be careful:

Pupils must be told not to try repeating the experiments performed with batteries in school using an electrical socket at home.

The experiments absolutely must be built with good electrical contacts; it is particularly recommended to introduce the use of a base for light bulbs early on.

At primary-school level, the terms insulator and conductor are purely practical terms, determined by the equipment used: with a readout device that is not very sensitive (such as a lamp) water behaves as an insulator, while metals act as conductors. If a more sensitive readout device (such as an illuminating diode) is used, water however becomes a conductor.

Note of caution: Some plastics are electrical conductors.

The handling of batteries poses no danger, except in the case of a longer-lasting short circuit (when the contacts of the battery are connected through an ‘ideal’ conductor), which can lead to a development of substantial heat and the destruction of the battery, so that the corrosive liquid leaks out.

Short circuits can happen under the following three circumstances, of which the teacher should be aware:

- When pupils experiment freely and test their ideas: The teacher should warn the pupils to immediately switch off the instrument or to tell the teacher when a battery or wire heats up.
- When batteries are put away for storage. Don’t just throw them into a box – lay them down neatly next to each other, preferably in boxes made of carton or wood rather than metal.
- During transport. Often, parents are asked to provide a battery for a lesson on electricity. On the way to school, a short circuit can occur in the school bag (for example when a compass or something with a zipper is in the bag, too). To avoid this risk, the battery should be transported in a plastic bag.

Basic background knowledge

- A battery can cause electricity (an electric current) to flow in a continuous chain consisting of the battery itself and any conducting items; through this chain, one contact of the battery is connected to the other (closed circuit). As soon as the chain is interrupted, the electricity (electric current) stops flowing, even in the battery itself. If, however, you place a finger in the power socket, the electric circuit is closed, and you put yourself in grave danger.
- In primary school, a light bulb connected in series can be used as a readout device for a flowing current. With this device, materials can be separated into conductors and insulators (non-conductors).

The theory behind the assembly of a series or parallel circuit is not dealt with in primary school, though you could let the children draw the route that the electricity takes. They will then notice that a series connection consists of a single loop, whereas a parallel circuit is made up of as many loops as there are parallel consumers.

- An electric battery has two contacts, each marked plus or minus.
- The passing of electricity through a human body is a potential source of danger and can be fatal.

Further information

- Risk-free peak voltage: In a moist environment, it is dangerous to expose the human body to a voltage of more than 24 V. Therefore, the line voltage of 230 V is potentially fatal: with your feet in water it is extremely risky to use an electrical appliance such as a hairdryer.
- Batteries supply direct current, which always flows from the plus to the minus terminal within the circuit (inside the battery it’s just the other way round). The power plants supplying our line current and bike dynamos produce an alternating current. In primary school, these two types of current only have to be distinguished for practical reasons: which way round do you insert a battery into a device considering the different connections? Does the direction in which a battery-operated engine rotates depend on the direction of the current?
- In a parallel circuit of light bulbs, each bulb would glow as if it were connected individually – if a battery were an ideal voltage source, which, because of a small energy loss inside the battery, it isn’t. If you therefore connect several light bulbs in parallel, each one will glow a little less than when connected individually. This is different in a grid, as the voltage source is almost ideal: the light bulb in the living room glows as if it were connected individually regardless of whether the light in the other rooms is turned on or off. Another reason a battery is not an ideal voltage source is that its performance (i.e. the voltage at its terminals when the circuit is open) decreases after a while, even if it is not discharged. This is due to a slow modification of the substances inside the battery.

- A battery consumes more energy when connected to two parallel circuits with one light bulb each (i.e. the lifespan becomes shorter) than if both bulbs are connected in series.

Is the human body a good electrical conductor?

by Béatrice Salviat, La main à la pâte, Paris

Plenty of salt water surrounded by an insulating shell – that could be a physicist's description of the human body, for our cells are surrounded by fluids (lymph, plasma), rich in ions in solution (sodium, potassium). Our body is a mediocre electrical conductor comparable to an aqueous saline solution with the skin as its shell. If the skin is too dry, conductivity is very poor, but as soon as it gets moist, conductivity improves. The ions in solution in the moist skin can move more easily, they penetrate the skin or induce the movement of other electric charge carriers in the fluids; this movement of ions is called electricity. If you apply voltage to a body that is in contact with water, the body becomes sufficiently conductive, and the circulating electricity can be harmful. Therefore, you should avoid contact with electric appliances in wet surroundings such as in bathrooms and when your feet are in water.

Accidents involving electricity

by Béatrice Salviat, La main à la pâte, Paris

Each year, accidents involving electricity cause a number of fatalities. Many of them happen at home (due to badly insulated appliances, missing earthing, faulty tinkering with cables and appliances, or use of electrical appliances in the bathroom). Other accidents happen outdoors through contact with a ground or aerial line (such as falling onto a rail which leads a current, or entangling a fishing line in an aerial line) or through lightning strikes. Although the direct current (DC) that we are generally exposed to is harmless (from batteries, accumulators, telephone wires, low-voltage transformers for halogen lamps, for example), the alternating current (AC) from the power grid can be dangerous.

An electric current can enter the body in two ways:

- The victim touches both contacts (neutral conductor and external conductor) at the same time; a strong current flows which burns the organs between the two contact points (example: small children suckle on the coupler of an extension cord under voltage).
- More commonly, the victim accidentally touches the external conductor, while his or her naked and humid skin is in contact with the ground (earthing), thereby closing an electric circuit: the electric current flows through any parts of the body between the external conductor and the ground.

Alternating current flowing through the body can cause damage in two ways:

- Intensive muscle cramps which cause a cardiac arrest and inhibit respiratory movements.
- Electric burns.

The duration of the current running through the body influences the duration of the apnea, the risk for the heart and the development of heat, and therefore the extent of the burns.

Alternating current is dangerous at much lower amperage (about four times less) than direct current. The frequency currently used in Europe (50 Hz) is viewed as especially dangerous, since it causes very intensive muscle cramps. Above 1000 Hz, the thermal effect becomes more important.

At 9 milliampere (mA) and above, an electrical current can cause muscle contractions which lead to the victim either being ‘glued’ to the conductor (because his or her hands cramp up) or instead being repelled from it, which interrupts the electrical current but often leads to secondary injuries (fall from a ladder, etc.). For as long as this effect lasts, it can also block respiration.

Between 80 and 100 mA, the alternating current of 50 Hz (frequency of the European household current) flowing through the heart region can cause ventricular fibrillation, which is a chaotic contraction of the heart muscle fibres, with each fibre beating in its own rhythm. The heart pump then doesn’t work any more (cardiac arrest) and the victim appears to be dead.

Above 2-3 A there is a danger of the neural centres no longer functioning properly; this state can also persist after the electric flow has stopped and manifest itself as immediate fainting or breathing problems (mostly apnea), among others.

The amount of heat set free through the thermal effect of electricity explains the occurrence of burns. The heat quantity Q, normally expressed in Joule (J), is proportional to the voltage U, the amperage I and the time t, during which the current was flowing ($Q = U * I * t$).

The electric burns also continue inside the body along the entire route that the current has taken, which generally follows the paths of lowest electrical resistance (blood vessels and nerves). In practice, the risk of burns is positively linked to the voltage. The path a current has taken inside the body plays an important role, since the amount of damage depends on which organs the current has passed through.

What to do in case of an accident involving electricity

by Béatrice Salviat, La main à la pâte, Paris

If the victim is still in contact with the low-voltage conductor, the circuit needs to be opened (by switching off the current) before touching the victim – quickly switch off the main switch, or pull the plug, depending on the scenario. Otherwise the current flowing through the victim’s body will also flow through the body of anyone trying to help.

In exceptional circumstances, an electric wire can be removed with the help of appropriate insulated items (such as a plastic ruler in the case of normal household voltage, or an insulating stick or stool in the case of medium voltage).

In the case of high and peak voltage, the responsible entities for operating the current (such as the power company or railway company, for example) must be informed.

First-aid measures include checking the primary body functions, checking the victim’s eyes by looking at their pupils, and quickly searching for burn marks and estimating possible further injuries.

If the victim of an accident involving electricity suffers from cardiac arrest, attempts at resuscitation must be started immediately. In general, the level of damage to a formerly healthy heart increases with the length of time that passes between cardiac arrest and an external heart massage. If the heart is in a state of ventricular fibrillation, only a second electric pulse – applied with the help of a special medical instrument, a defibrillator – can re-establish normal heart function.

The victim should be placed in a suitable resting position (recovery position) until medical help arrives; don’t forget to cover and calm the victim if awake. Of course, any risk of a second accident should be avoided (especially if the ground is moist), by clearly marking cables and conducting tubes, and ensuring that they will not be put under voltage again.