Electricity: the basics

Electric current

Electricity supply

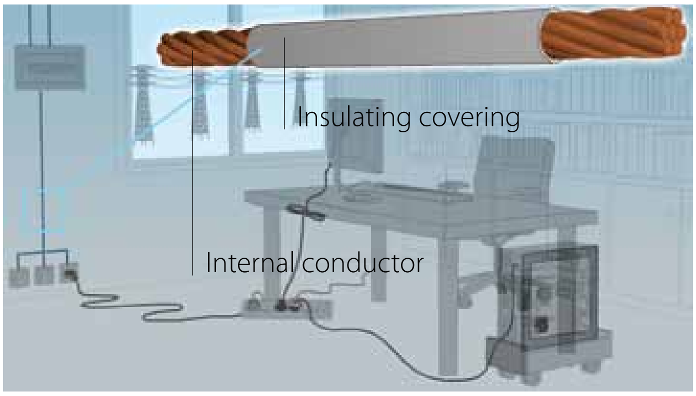
Electrical appliances, lights, computers, and other machines in our homes function to make our lives much more comfortable. All of these machines need to consume energy in the places where they are used. It is therefore necessary to supply homes and industries with the energy produced in power plants. There are different systems of energy supply.

Supply of petroleum or gas in a lorry	It is a slow form of supply that needs a lot of labor force.
Supply by electric current	Electric current is the optimal way to transport energy. It is clean, instantaneous, and very effective (there are few losses on the way).

Where does the current flow?

Depending on the amount of current distributed and on the distances it must go through, certain types of cables and connections will be used. However, they are all made up of conductive materials through which the current will pass.

- Transport of large amounts of current: high tension power lines are used as pipes for large amounts of electric current among cities and power plants.
- Distribution of current in our homes: the cables in our domestic electrical systems channel the electric current to domestic appliances, lights, and other devices that use energy in our homes.
- Inside electrical appliances, small cables, and welds mark the path that the current has to follow through various microelements and chips.



Conductors and insulatings (electric cable structure)

Conductors and insulators

Materials are classified in conductors or insulators to the flow of current. However, there are many materials in intermediate situations.

When a material lets current flow with practically no resistance, we consider it a good conductor. When the material opposes a lot of resistance, we consider it a good insulator.

In the manufacturing of cables, it is necessary to use both conductive and insulating materials.

Internal conductor: all electric cables are formed by one or more filaments of a conductive material, usually a metal, as metals are good conductors.

Insulating covering: electric cables are covered in an insulating material in order not to allow electric current to pass through them, and in a way it is possible to handle them with no risk of getting an electric shock.

Electrons and electric current

Part of the electrons in the atoms of a conductive material, for example a metal, move freely.

The movement of the electrons from one side to another creates an electric current.

In an insulating material, electrons orbit around their atoms or molecules.

The electrons cannot move freely to form an electric current.

Current

An electric current is the flow of electrons through a conductive cable. The more the electrons that pass a given point in the cable per second, the greater the electric current. This physical magnitude is called **current**.

However, current does not measure how many electrons pass per unit of time, rather the amount of **electric charge** that passes in this time.

Matter has a property called electric charge. This charge can have a positive or a negative sign.

Electric charges of an opposite signal attract each other.

On the contrary, those of the same sign repel each other. These types of forces are the ones that make charges move and form currents, for example, throughout a circuit.

Electrons are negatively charged and the electric currents we use are therefore negatively charged currents.

The direction of the current

In general, the direction of the current is represented with an arrow. As strange as it may seem, this direction does not correspond to the actual direction of the electron flow. This is due to the fact that the current is the amount of positive charge passing per unit of time and, as electrons do not have a positive charge, rather a negative one, the direction of the current is the opposite of the actual movement of the electrons.

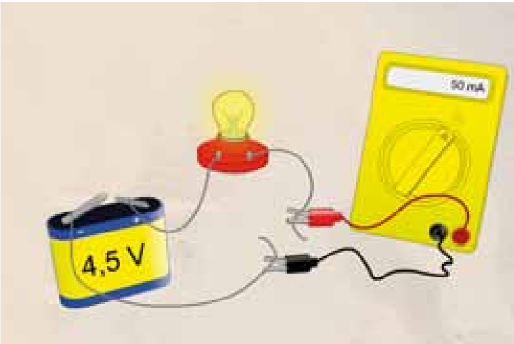
The direction of the current that is conventionally assigned to circuits is always the opposite of the actual movement of the electrons.

Electrons have a negative charge, and therefore, the electric currents we use are currents with a negative charge.

Measuring the current

In order to control electric currents, we have to be able to measure them and quantify them.

In order to measure the current, we use an apparatus called **ammeter**, which measures amperes.



Ammeter

Most devices and electric circuits only work well at a certain current.

If this is exceeded, the security devices are activated and they do not work, or they can be damaged or even cause accidents.

To measure a current, it has to enter via one of the terminals of the ammeter and exit via the other, in the same way as a current feeds a light bulb. In these cases, we say that the circuit is connected in series.

Currently, ammeters are usually incorporated in a **multimeter**, apparatus that allows measuring several electric magnitudes apart from current.

Voltage

Generators

How do we generate an electric current? Or, in other words, what can we do to a circuit in order to make a current flow through it?

There are several devices, called generators or power supplies, which allow us to achieve that a current appears in a circuit, or in other words, to generate electric current. Some examples would be the batteries, sockets, dynamos, or alternators.

Voltage

Generators are capable of supplying the energy needed to create an electric current.

This capacity can be measured and it is called **voltage**, **tension**, or **potential difference** (**p.d.**).

The greater the capacity of a generator to supply energy, the higher its voltage.

The following cases must be clear:

- Without a generator, no voltage is supplied to the circuit and no electric current is created
- When a generator, for example, a battery, supplies a certain voltage to a closed circuit, an electric current is created that supplies energy to the devices in the circuit.
- On raising the voltage, the current also increases, supplying more energy to the electrical appliances.

Measuring the voltage

The voltage is measured in **volts** (V), and the **voltmeter** is the device used to measure it.

The voltage of a generator, like that of a battery, can be measured using the pincers of the voltmeter terminals. However, sometimes we do not want to directly measure the voltage of the generator or it is not possible. In these cases, we can measure the voltage between any two points in the circuit by applying the pincers of the voltmeter to the points in question.

Voltmeter

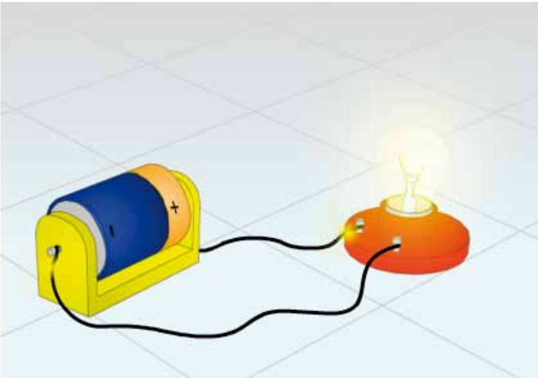
Potential drops

The sum of the potential drops at each component connected one after the other in a circuit corresponds to the total voltage supplied by the battery. We say that the potential drops throughout the components.

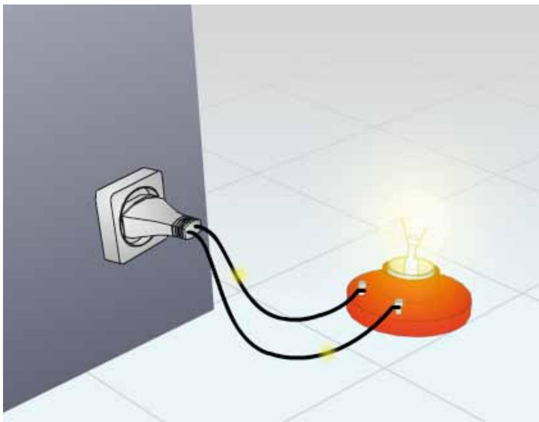
Direct and alternating currents

In the circuits that we have seen so far, the current has always had the same direction and current. This type of current is known as a **direct current** (**DC**).

There is another type of current in which the flow of electrons changes direction. This type of current is known as an **alternating current** (**AC**).



Direct current



Alternating current

Alternating current generators	Direct currents are normally generated at low voltages
The main direct current generators are the **batteries** or **accumulators**, the **solar panels** and the **dynamos**.	The main alternating current generators are **alternators**. Alternators are responsible for the production of most the electrical energy that we consume. They transform the mechanical energy from power plant turbines into electrical energy.

It is important to know that the electric supply reaches our homes in the form of alternating current.

Oscillation frequency

The alternating current of our homes has a frequency of 50 Hz.

The hertz (Hz) is the frequency unit. In alternating current, the hertz indicates the times in which current changes direction in a second.

If the frequency of a generator given in hertz is high, the current will change its direction many times each second.

Oscilloscopes are instruments that measure the frequency of the AC and, at the same time, graphically represent the variation in the current and the voltage.

Voltage compatibility

The voltage of a generator is indicated by its manufacturer. For example, the sockets in our homes provide 220/230 V of alternating current. Conventional batteries usually give 1.5 V, 4.5 V, or 9 V of alternating current.

Each electrical device needs a determined voltage and type of current (alternating or direct).

The supply voltage must also be indicated by the manufacturer. If a voltage that is too low is used, the appliance will not work correctly; if the voltage is too high, the appliance could break.

Transforming voltages

Most electronic devices require a direct current and a much smaller voltage than the 220V/230V of alternating current of the domestic power supply.

When you plug in a laptop or a cell phone, you do not plug them directly into the wall. Rather, you connect them to a **transformer**.

Transporting high voltages

At the end of the nineteenth century, there was quite a battle between defenders of the direct current (lead by Thomas Alva Edison), and the defenders of the alternating current (with its developer, Nikola Tesla, taking the lead).

Alternating current is easier to transform into high voltages, allowing it to be transported more efficiently (with much less energy loss than is the case for direct current).

Nowadays, the alternating current produced by power stations is raised to very high voltages (sometimes up to more than 100,000 V), and then transported via high-tension power lines. Finally, the voltage is lowered before it arrives at our homes.

Direct current (DC)	Alternating current (AC)
Always has the same voltage and current.	Its voltage and current oscillate rapidly (normally, about 50 times each second).
It is the current generated by batteries. It is ideal for small devices.	Elt is the current generated by alternators that is distributed on a large scale to provide the electric power supply to homes and industry.
It does not make sense to talk about its frequency because the current is always the same.	Has a frequency measured in Hz, which describes the oscillation rate.
It is not suitable for transformation between different voltages.	It is suitable for transformation between different voltages.
It is not suitable for the transport of electricity across long distances.	It is suitable for the transport of electricity across long distances.

Resistance

Consumption and power

A washing machine consumes more than a hairdryer and the hairdryer more than a light bulb. The consumption corresponds to the concept of power needed by the appliance, and it is measured in watts (W).

The power is the work performed by an appliance on a determined time. It can be calculated as the product of voltage and current: $P = V \cdot I$

Consumption and resistance

The appliances that consume the most energy, that is, those that require the most power, need more electric current to function.

At the same time, any electric current circulating through a cable or device encounters a resistance to its flow. This is due to the fact that charges never flow with complete freedom through a conductor, and even less so through an electrical appliance.

Any part of a conductor, together with any electrical device, has an associated resistance value, which measures the difficulty with which current flows through it.

Going back to the washing machine, the hair dryer and the light bulb of the previous point, in spite of the fact that they all work at the same voltage of 220 V-230 V, each of them offers a different resistance to current flow.

Controlling the current

As we have already said, excessively high currents can break the components of appliances. The use of different resistors allows us to adapt the current to the appliance in question.

A resistor is a small filament of a material, which is more or less conductive, whose resistance value is known and which, in electric circuits, is used as a resistance with regard to currents that would otherwise be excessively high.

Units of resistance

Measuring and assessing the value of the resistance of a resistor, and other elements of a circuit, is essential to control the current that flows through them when applying to them a certain supply voltage.

The unit of measurement of resistance is the ohm (Ω), and it can be measured with an ohmmeter. In the market, we will find enormous resistors (of thousands of ohms) and small ones (of only hundredths of an ohm).

Ohm's law

The current flowing through an electrical device depends on both the voltage with which it is supplied, and its resistance. There is a useful law that explains the relationship between these three properties: Ohm's law. It is expressed in this very important equation::

$$I = V / R$$

Or in words:

- To the degree to which the difference potential V is increased, the current I will also rise.
- To the degree to which the resistance R is increased, the current I will fall.

Summary table of magnitudes

MAGNITUDE	SYNONYM	UNIT	ABBREVIATION	RELATIONSHIP
Current	Amount of current	Ampere	A	$I = V / R$
Voltage	Tension, potential difference	Volt	V	$V = I \cdot R$
Resistance	—	Ohm	Ω	$R = V / I$
Power	Energy per unit of time	Watt	W	$P = I \cdot V$

Applications of electricity

We will now look at how technology transforms the electric current into energy that has a practical use. Appliances that transform electrical energy into other forms of energy are called receivers.

Electricity and heat

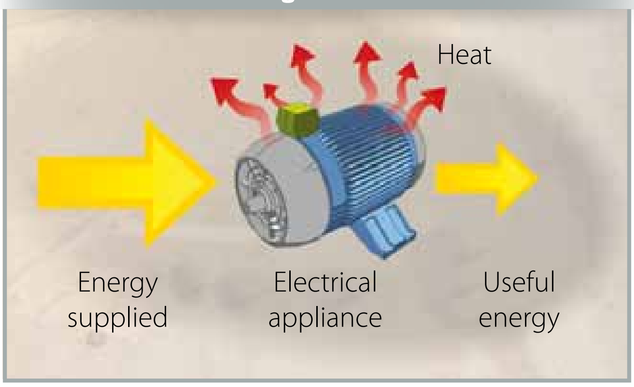
You will probably have noticed that transformers, computers and batteries heat up when they are plugged in. This happens to such a degree that cooling fans are required.

When electric currents flow, they produce heat.

The Joule effect

We have already seen how all conductors have some resistance to the flow of electricity. The electrons are slowed down when they hit atoms and each other. This process can be understood as a "rubbing" of the current against the conductor.

Losses through the Joule effect



In the same way that rubbing our hands warms us up, when a current flows through a conductor it produces heat. The transformation of part of the energy of an electric current into heat is called the Joule effect.

Losses through the Joule effect

If the transformation of electrical energy into heat energy is an undesired effect, we talk about **losses due to the Joule effect**.

These losses are important from different points of view:

- **Output:** the useful energy produced is always less than the energy supplied to the system due to energy loss in the form of heat.

- **Safety:** the high temperatures reached can impede the correct functioning of circuits and, sometimes, create a fire risk.

Harnessing the Joule effect

If the transformation of electrical energy into heat is a desired effect, we refer to it as a technological application of the Joule effect.

Why would we want this effect, and what can we use it for? Below you will see some examples.

- **Direct use of heat:** heaters, grills, electric dryers, electric ovens and most electrical appliances that we use for heating, drying and cooking, use some form of electrical resistance to generate heat using the Joule effect.
- **Indirect use of heat:** fuses are filaments that burn up and cut the current when it is too high. Therefore, they are control and safety devices.

Electricity and movement

Electromagnets are used to transform electrical energy into movement, or vice versa. This is the case with motors, electric generators, doorbells or automatic doors.

Electric currents can work as magnets, and magnets can create an electric current in a conductor.

It is these magnetic forces, created by currents in electromagnets, which are used to make the parts of appliances move.

Magnetic induction

Whenever an electric current flows through a conductor, a magnetic field is created around it. This phenomenon is called **magnetic induction**.

The current of the induced magnetic field is proportional to the current flowing through the conductor.

Magnetic fields that are strong enough and positioned correctly can be used to move motors and doors. The electrical element designed for this purpose is the electromagnet.

Electrical induction

The inverse phenomenon to magnetic induction is also possible.

Whenever there is a changeable magnetic field, electric currents are induced in the nearby conductors. This effect can also be produced with a fixed magnetic field if the conductors are moving with respect to the field. This phenomenon is called electrical induction.

Most human-produced electricity is generated in accordance with this principle. The device that makes this possible is the **alternator**.

Alternators contain a moving part called a rotor and a fixed part called a stator. One of the two parts contains magnets, and the other contains conductors in the form of coils. This produces a movement of the magnetic field with respect to the conductors, producing an electric current. This induced current changes to a rhythm, or frequency, that depends on the rotation of the rotor. For this reason, alternators always generate alternating currents.

Electricity and light

One of the most fascinating and useful effects of electricity is its ability to produce light. How does this happen? There is more than one way of creating light. Each method has its own technology and produces different physical effects. The method determines the color of the light and, above all, its efficiency. In other words, it determines the quantity of energy used to produce a given quantity of light.

The use of high efficiency emitters, while more expensive, reduces the energy consumption in homes and businesses.

Light bulbs

Many materials emit light at high temperatures. We have all seen hot coal turn red. The emission of light by hot objects is called incandescence.

In a light bulb, a filament of tungsten heats up due to the Joule effect of the current passing through it. Part of this heat is transformed into light by incandescence; the rest is lost as heat.

Parts of the bulb

- **Electrical contact:** point through which the voltage is supplied.
- **Metal case:** conducting thread to which a voltage is applied and through which a current flows.
- **Conducting wire:** element that holds the filament up inside the bulb and supplies it with the current.
- **Cooling tube:** allows the bulb to dissipate large amounts of heat.
- **Tungsten filament:** thin, coiled filament of tungsten, with a particular resistance. It heats up due to the Joule effect and produces light due to incandescence.
- **Bulb:** protective glass casing that isolates the atmosphere inside the light bulb.
- **Inert gases:** the inside of a light bulb contains no air. Instead, it contains various inert gases. If this was not the case, the oxygen of the air would rust the incandescent filament and end up breaking it.

Low consumption light bulb

Fluorescent lighting

In comparison with light bulbs, fluorescent lights transform electrical energy into light far more efficiently. To make the most of their high efficiency, it is important not to switch them on and off too often. (Turning them on requires a “preheating” that consumes a lot of energy.)

Their functioning is more complex than that of normal light bulbs.

They are made up of a number of electrical and chemical elements, and are expensive to manufacture.

Some of them, mainly mercury, are very polluting and even toxic. It is therefore necessary to handle them carefully, and if they break, to collect the pieces and never throw them in the trash (they should be taken to a recycling plant.

Electricity and communication

Electrical signals

Electricity allows the transmission of signals across great distances. An electrical signal is a sequence of variations in a current that encodes information. We can transmit these variations across cables of any length in order to communicate with one another.

This is what telephones do. This process requires the transformation of sound into electrical signals and vice versa. These transformations are made by elastic membranes that are found in microphones and loudspeakers.

How do telephones operate?

1. Microphones transform the sound waves of speech into a mechanical vibration by means of an elastic membrane.
2. This vibration is transformed into electric pulses, amplified later on, which flow through the telephone wire.
3. In the earpiece of the receiver, another elastic membrane transforms the electric pulses into a mechanical vibration that produces sound waves. The resulting sound closely resembles the sound made by the speaker.

Electromagnetic waves

In the case of cell phones, the electrical pulses must be transformed into signals that can travel great distances without cables. This is done using waves similar to radio waves. Cell phone antennae emit and receive waves of this type. They are called **electromagnetic waves** and they do not require cables: they can travel through the air and even in the absence of an atmosphere (for example, through space up to a telecommunications satellite).

How do cell phones operate?

1. By means of an elastic membrane, a microphone transforms the sound waves of speech into mechanical vibrations. These vibrations are transformed into electric pulses that flow through the electronic circuits of the cell phone.
2. The antenna transforms the electric pulses into electromagnetic waves. These waves are received by the antenna of a cell site tower, which retransmits the signal.
3. This continues until the signal arrives at the destination cell phone, where it is transformed back into electric pulses and finally sound waves.

Antennae

Electromagnetic waves have a wide range of technological applications. In telecommunications, antennae are used to both emit and receive electromagnetic signals.

Antennae function due to an important physical phenomenon: currents create magnetic and electric fields, and these fields exert an influence on currents.

How do antennae operate?

1. The flow of small currents through a **transmitter antenna** creates variations in the electromagnetic field that surrounds it.
2. Variations in electromagnetic fields travel through space and are called electromagnetic waves. The speed at which these waves travel depends on the medium (water, air, vacuum), but in general it is very high (close to the speed of light).

3. When the waves arrive at a receiver antenna, they induce small currents in it, which are then amplified by electronic devices and are used to transmit information (e.g., TV images).

Electricity and safety

Even if we are very used to living with electricity in our daily lives, we must not forget that it can be very dangerous. Unfortunately, domestic and industrial accidents involving electricity are quite common.

The human body can conduct electricity, and the flow of a current through our body can cause, among others, burns, cardiac arrest, and loss of consciousness.

In addition, short circuits and overheating in appliances can cause fires.

Prevention in electrical installations

There are some basic prevention measures that we must never forget when designing an electrical installation:

- Not to overload installations and not to exceed the power contracted. (If we use many appliances at once, the circuit breaker will cut off the electricity supply.)
- Avoid connecting many high consumption appliances in the same multiple socket.
- Keep appliances away from water.
- We must never use a hairdryer next to a full sink or bath.
- Use an earth connection for electrical appliances, in order to avoid an accidental build up of an electrical charge.

Earth connections absorb extra charges safely.

- Lightning rods must have good earth connections.
- Perform a good maintenance of the installations.
- Avoid stepping on or fraying the cables; check the connections of appliances.

Current control systems

To avoid danger and breakdowns, it is often necessary to install a system that prevents the flow of an electric current that is too large. The most common control elements are fuses and automatic switches.

Automatic control switches or residual current devices: a residual current device is an automatic switch that prevents the flow of electric current when it is too large.

The human body can conduct electricity, and the flow of a current through our body can cause, among others, burns, cardiac arrest, and loss of consciousness.

The regulations in force require that all houses must have an automatic circuit breaker, which will control the flow of current in all the installation. In cases of short circuit or accidental electrocution, the circuit breaker trips, leaving the house with no electrical supply.

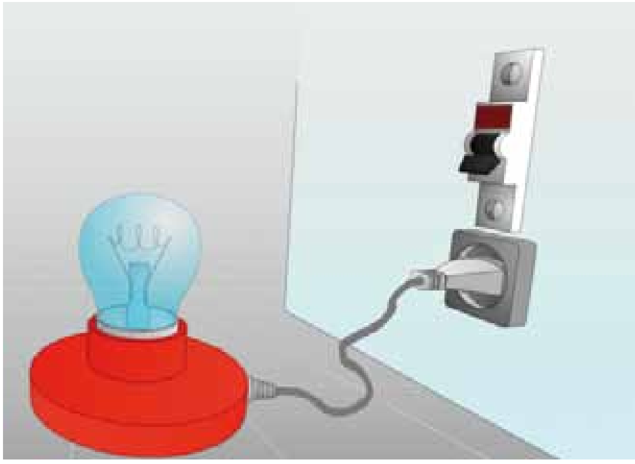
The fuse is a thin filament through which current flows, made of a material which melts when it is heated. When current passing through it is too high, it is overheated due to the Joule effect; the filament melts and cuts the flow of current.

Fuses are used a lot as control elements in electrical appliances and all types of circuits. They avoid high intensities damaging any of their elements.

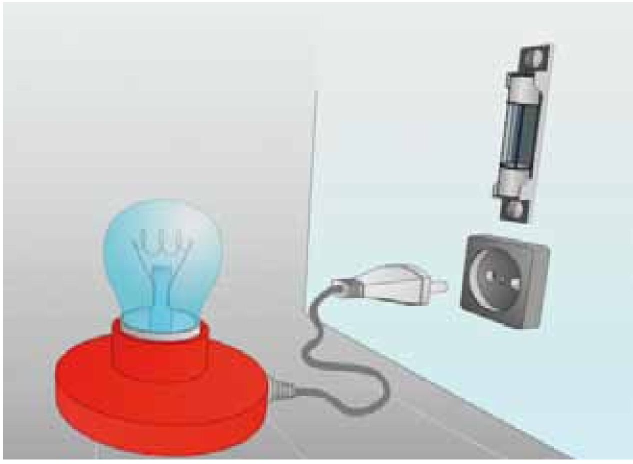
Precautions when handling

Before undertaking any electrical repair or installation, it is vital to take the following safety precautions:

- Manually trip the circuit breaker.
- Wear insulating clothing, particularly rubber-soled shoes and gloves.
- Be methodical and organized.



Automatic control switches or circuit breakers



Fuse