UNIT 5

Electrical circuits

WORK ON YOUR KEY COMPETENCES

LS

Design and build a solar lamp

Can you imagine your life without electricity? In many parts of the world, there isn't any electricity. People do household chores by candlelight or by burning wood.

In this unit, you'll design and build a solar-powered lamp with photovoltaic panels that will be useful for people who live without electricity. The lamp should be easy to take apart and repair.

OXFORD PROJECTS

Go to your GENiOX Desktop.

Think and discuss

1. Look for an image of the Waterlight on the Internet. Find information about its design. Which parts of the design encourage the use of sustainable objects?
2. What other devices could obtain electrical energy from renewable energy sources?
3. Many homes generate their own electricity. With your classmates, discuss the advantages and disadvantages of generating your own electricity. Would this be a good idea for your school? Why or why not?
4. Read the UNDP data in the text and analyse how the use of renewable energy relates to the SDGs.

A lamp powered by seawater

Waterlight is a device with a sustainable design that provides electrical energy from the ionisation of salt water. With only half a litre of salt water, it can produce light for 45 days. This is a revolution for millions of people around the world who can't access electricity.

An estimated 840 million people in the world don't have access to electricity. M. Mojica created the Waterlight project 'to light up the lives' of the Wayúu community in Colombia, 'to bring light to La Guajira, but also to extend to anywhere it is needed'.

Waterlight makes it possible to have light where there is no electricity, so that 'artisanal production, fishing or educational studies can continue during the night'.

The device provides electrical energy from the ionisation of salt water. In the process, an electrolyte consisting of salt water triggers a reaction, transforming the magnesium inside it into electrical energy.

Made from fully recyclable and resistant materials, the design of the Waterlight lamp is inspired by the Wayúu community and their traditional art, representing the local fauna and flora, and their connection to the sea.

According to Mojica, design is 'key' to the future sustainability of the planet.

Source: elagoradiario.com (September 2021, translated and adapted)

This invention improves people's lives and helps preserve the environment, since, according to UNDP data:

- 1 in 7 people still have no access to electricity. Most of them live in rural areas of the developing world.
- Energy is a major contributor to climate change. It accounts for around 60% of global greenhouse gas emissions.
- More than 40% of the world's population, which is around 3 billion people, use fuels for cooking that are bad for their health and for the environment.

1 What's electricity? Electric charge and current

If you rub a pen with a piece of material and then put it close to some bits of paper, the pen attracts the paper. *Why do you think this happens?*

1.1. Electric charge

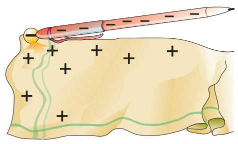
If we want to understand why objects or bodies **attract**[1] or **repel**[2] each other, we need to know about the structure of matter and the concept of electric charge.

Electric charge is the property of matter that's responsible for electrical phenomena.

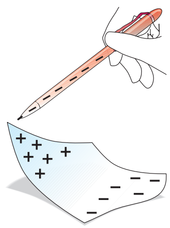
To understand the electrical phenomena of attraction and repulsion, we start with the fact that matter is made of atoms and that atoms are made of smaller particles:

- Electrons: these have a negative charge and are responsible for electrical phenomena.
- Protons: these have a positive charge.
- Neutrons: these don't have any charge.

In general, matter is neutral. This means that it's not electrically charged because there's a balance between the number of negative charges (electrons) and positive charges (protons).



Sometimes electrons move from one material to another. When we rub a pen with a cloth, the cloth passes electrons to the pen and the pen becomes negatively charged. Now the pen is electrified, but the charges are at rest (they don't move around the electrified material). We call this **static electricity**.



If we put the electrically-charged pen close to a piece of paper, the electrons on the edge of the paper closest to the pen repel away. The edge becomes positively charged. This is why the pen now attracts the piece of paper.

[1]**attract:** cause something to move towards it.

[2]**repel**: cause something to move away from it.

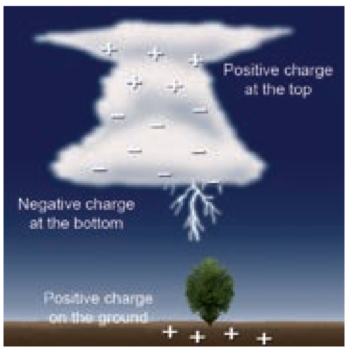
CLIL activities

1 Answer the questions in your notebook.

a. What are particles with a positive charge called?

b. What's static electricity?

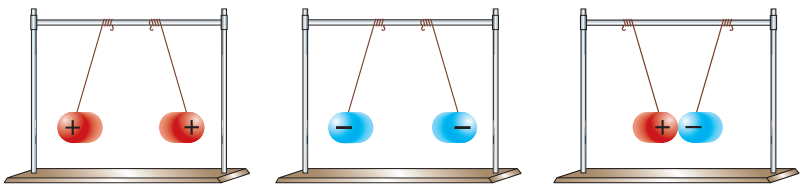
2 A lightning bolt is a huge flash of light. It happens because of a concentration of electric charge on a cloud. This flash can jump from one cloud to another or to the ground. Search for information about how lightning starts and explain it in your notebook. Look at this picture to help you.



CLIL activities

3 Find out where the word *electricity* comes from. Why did they choose this word?

4 Work with a partner. Look at these pictures:



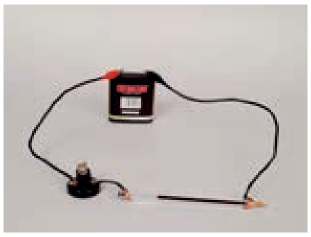
How do electric charges with the same sign behave? What about charges with opposite signs?

1.2. Electric current

In the same way that water flows in a pipe, electrons can move through certain materials and create an electric current.

Electric current is the continuous movement of electrons through a conductive material.

In one of the circuits below, we've inserted a metal spoon and in the other one, we've inserted a plastic pen. *In which circuit is the bulb on? What materials allow electric current to pass through them? Which ones don't?* Think about what causes this. Discuss with your classmates.

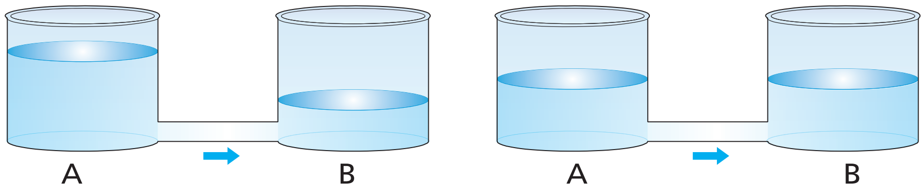


We can now make a first classification of materials:

- **Conductive materials or conductors.** They allow electric current to pass through them. Metals are good conductors of electricity.
- **Insulating materials or insulators.** They don't allow electricity to pass through them. Plastics, wood and ceramics are examples of insulators.

What produces electric current?

Look at this comparison with how liquids behave. Containers A and B have different levels of liquid in them. *What happens when we connect them?*



When does the liquid flow from one container to another? How's this similar to electric current?

For electrons to move through a conductive material, we need an **imbalance**[1] of charges between the two ends of the material. That means there must be a large **quantity**[2] of electrons in one end and not many in the other end.

[1]**imbalance:** a situation in which two parts aren't equal.

[2]**quantity:** the amount or number of something.

The speed of current

When we press the switch on a lamp, the light comes on immediately. We might think that this is because electrons move very quickly, however, they don't. The average speed of an electron moving through a copper cable is 0.07 cm/s. It would take 24 minutes for an electron to go along a 1 m copper cable.

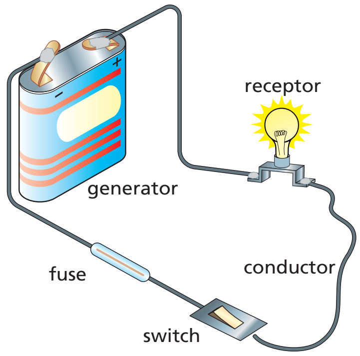
The lamp switches on quickly because there's a large quantity of free electrons in the conductor. In copper, for example, there are around 10^{22} free electrons in every cubic centimetre.

CLIL activities

5. **If you rub a metal rod with a piece of cloth, it won't attract a piece of paper. Why not? Write your answer in your notebook.**
6. **Why aren't light switches and plugs made of metal? What are they made of? Why?**
7. **Work with a partner. Find out the five most conductive metals.**

2 Electrical circuits, components and symbols

[1]**pole:** either of two opposite points.



Can you explain what an electrical circuit is? What components has it got and what does each one do?

An **electrical circuit** is a set of connected components that an electric current can flow through.

It has a generator, receptors, control and protection components and conductors that allow the electricity to flow.

2.1. Generators

A generator produces and supplies the energy a circuit needs to keep the electrons moving around it. It has two **poles**[1]: a negative pole and a positive pole.

Generators can be:

- **Batteries or cells:** these use chemical processes to produce a current.
- **Alternators or dynamos:** these transform motion into current.
- **Photovoltaic solar cells:** they use energy from the Sun to produce electric current.
- **Hydrogen cells:** these mix hydrogen with oxygen in the air to produce energy.

The last two types of generators aren't very common, but they're better for the environment.

2.2. Receptors

Receptors receive electrical energy. They transform the electrical energy into a different type of energy that we can use. Look at the following table which shows different receptors, the useful energy they get and the effect that they produce.

Receptor	Useful energy	Effect produced
electric resistor	thermal or calorific	gives heat
bulb	light	gives light
motor	mechanical	produces movement
bell	acoustic	produces sound

Electrons leave the generator, taking energy with them and flow through the circuit until they arrive at the opposite pole. Along the way, they can find different elements that use some of that energy. This use of energy produces different effects, such as switching on a bulb or starting a motor.

Activities

8 Name the objects in the photos in the margin. What type of generators do they use? What do you think produces their motion? What type of energy do we get from them? Write your answers in your notebook.

9 Why's it important to recycle batteries? Research.

2.3. Control components

Control components allow us to direct or stop the flow of electric current. The most common ones are:

- **Two-way switch.** It has two positions: one that allows the current to flow and the other one to stop it.
- **Three-way switch.** This directs the current to flow out of one of its two **exits**[1].
- **Push-button.** This is similar to a two-way switch but it returns to its original position when we stop **pressing**[2] it.

[1]**exit:** a way out of something.

[2]**press:** to push part of a device in order to make it work.

Main circuit breaker panel in a home

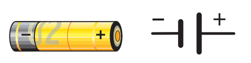
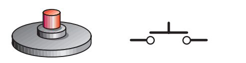
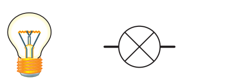
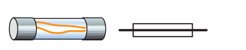
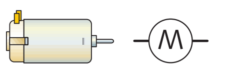
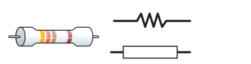
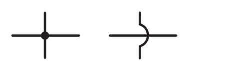
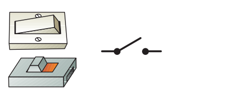
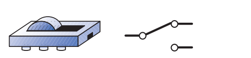
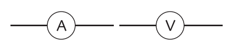
2.4. Protection components

Protection components stop the flow of current when it gets too high. This protects other components in the circuit from damage.

We use **fuses** and **thermal magnetic circuit breakers**. Circuit breakers are usually in the main breaker panel in all buildings.

2.5. Symbols

We use a set of symbols to draw electric circuits. This table shows the most common ones:

Component	Symbol	Component	Symbol
battery		push-button	
bulb		fuse	
motor		bell	
resistor		crossed wires and bridge	
switch		connection	
3-way switch		ammeter and voltmeter	

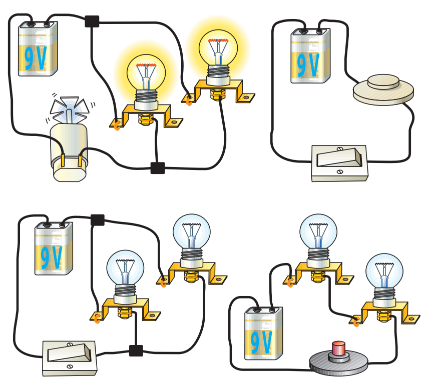
CLIL activities

10 Three-way switches let us switch the same light on and off from different places. Are there any three-way switches in your home? Where are they? Are there any devices with push-button switches? What do they control? Tell your classmate.

11 Listen and draw the circuit that the teacher describes. Use the symbols in the table above.

12 Draw the circuits on the right in your notebook. Use the correct symbols.

13 LS Look for information about solar panels. How do they work? What characteristics do they have?



3 Electrical quantities

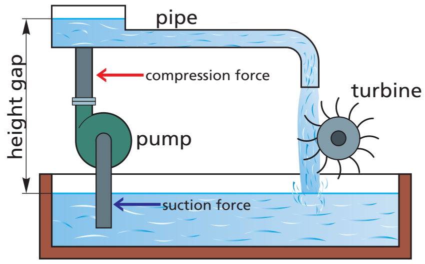
240 V 300 mA

240 V 5W

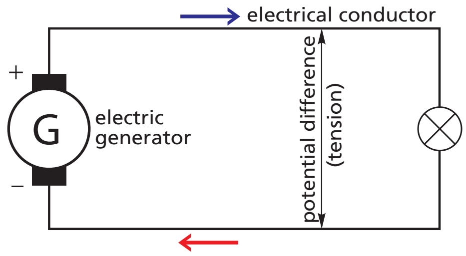
Have you ever looked at the characteristics of a mobile phone charger? What about a bulb? What are the differences between different batteries?

3.1. Voltage, current and resistance

Look at the following illustrations. One represents an electrical circuit and the other represents a water circuit.



Water circuit



Electrical circuit

What makes the water flow in the water circuit? What about the electric current in the electrical circuit?

The **charge** is the amount of electricity stored in an object.

It's equivalent to the volume of water in the upper container in a water circuit. We measure charge in **coulombs (C)** and we use the letter **Q** to represent it.

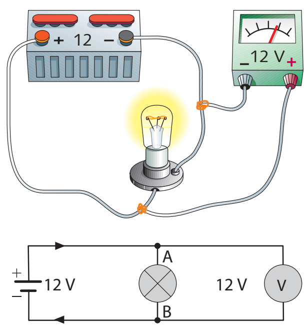
The basic electric quantities are **voltage**, **current** and **resistance**. We'll look at these in more detail in the following sections, using the water circuit comparison to help us.

Voltage

Voltage or **tension** is the difference between the electrical energy at two points in a circuit.

The charge always moves from the points where the energy is higher to the points where it's lower. This energy is equivalent to the height of water in a water system. So, if there's no voltage, there's no current.

We represent **voltage** with the letter ***V***. We measure voltage in **volts (V)**.



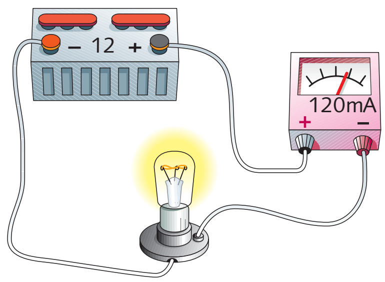
Connection of a voltmeter

To measure voltage, we use a **voltmeter**, which we connect **in parallel** with the component or generator whose voltage we want to measure.

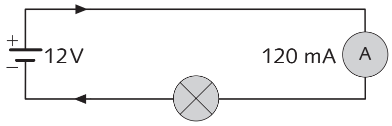
If we connect a voltmeter to a very high voltage, we may damage it.

Current

Current is the amount of electric charge passing through a specific point in a circuit in one second (the flow of electrons at that point). We represent **current** with the letter ***I***. We measure current in **amperes or amps (A)**.



To measure current, we use an **ammeter**. We connect the ammeter **in series** to the receptor or receptors whose current we want to measure.



We also have to choose the correct scale for the current we're going to measure. We express this in amps or milliamps.

Resistance

Resistance is the opposition of the components in a circuit to the flow of electric current.

Resistance is equivalent to the **obstacles**[1] that affect the flow of the water in a turbine.

We represent **resistance** with the letter ***R***. We measure resistance in **ohms (Ω)**.

3.2. Electrical energy and power

We can transform **electrical energy *(E)*** into light, heat and motion.

The amount of energy produced or consumed in a unit of time (t) is called **power *(P)***.

We express the relationship between energy and power as:

$$P = \frac{E}{t}$$

We measure **power** in **watts (W)** and **electrical energy,** in **joules (J)** or, in most cases, in **kilowatt hours (kWh)**.

[1]**obstacle:** something that makes it difficult for an action to happen.

The multimeter

This device measures different electrical quantities (voltage, current, resistance) on different scales.

It has a rotating dial so that we can choose the best scale for each quantity.

CLILactivities

14 **Look at the picture of the water circuit on page 110. Use it to explain the electric quantities voltage, resistance and current. Write your answers in your notebook.**

The voltage is equivalent to…

15 **Calculate the energy consumed in kWh by a 85 W LED TV if we watch it for four hours every day for 30 days. (Note: divide by 1000 to get kWh.)**

16 **Listen to the teacher explaining how to use a multimeter. Answer the questions.**

a. Which quantity does he measure?

b. Which symbol stands for DC: V~ or V–?

c. Which point does the red cable touch?

d. What shape is the 9 V battery?

4 Ohm's Law. Series and parallel circuits

In 1822, **Georg Ohm** wrote about the relationship between voltage, current and resistance. In honour of this German physicist, the proportional relationship between voltage, current and electrical resistance is called **Ohm's law**, which we express mathematically as:

$$V = I \cdot R$$

This law states that:

- For a given resistance, **voltage and current are directly proportional quantities.** This means that if the voltage **doubles**[1], for example, the intensity will also double. So, if the voltage reduces by one third, the intensity will also reduce by one third.
- For a given voltage, **current and resistance are inversely proportional quantities.** In other words, if you increase the resistance of the elements in the circuit, the current that circulates through it will decrease proportionally. So, if the resistance doubles, the current will reduce by a half.

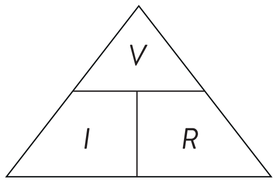
We can express Ohm's Law in two other ways:

$$I = \frac{V}{R} \qquad R = \frac{V}{I}$$

[1]**double:** become, or make something become, two times as much or as many.

CLIL activities

17 **Here's a diagram that can help us remember Ohm's Law. Work with a partner. Express this important law in three ways by hiding one quantity and working out the relationship with the other two quantities.**



18 **Draw a graph showing the relationships between:**

a. voltage (x-axis) and current (y-axis) in a given resistance.

b. current (x-axis) and resistance (y-axis) in a given voltage.

19 **Calculate:**

a. the resistance if I = 2 A and V = 5.5 V.

b. the voltage if I = 8 A and R = 4 Ω.

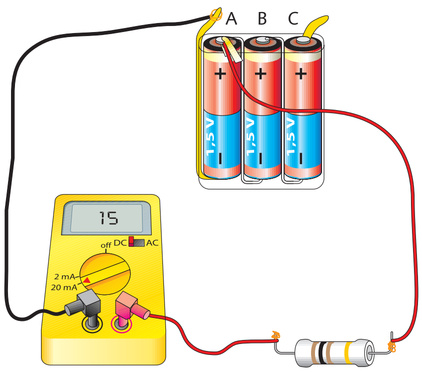
20 STEAM **Check Ohm's Law. Follow the instructions below and answer the questions.**

a. Build the circuit in the picture on the left. Close it by putting the crocodile clips in positions: A, then B, then C.

b. Note down the current shown on the ammeter each time, as shown in this table:

Position	Current	Resistance	Current (measured)
A	1.5 V	100 Ω	15 mA
B	3 V	100 Ω	30 mA
C	4.5 V	100 Ω	45 mA

c. Use a spreadsheet to show your results.



21 LS **What current (*I*) will flow though the elements in the circuit you are designing for your project?**

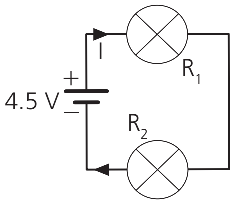
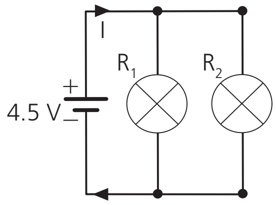
4.1. Series and parallel circuits

Look at the circuits in the photos on the right:

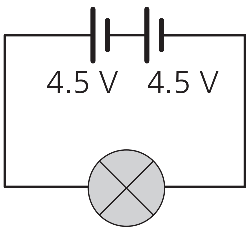
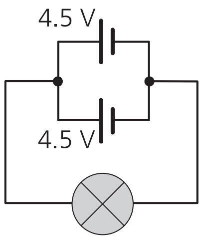
a. *How did we connect the bulbs?*

b. *What will happen in the first circuit if one of the bulbs breaks? Will the same thing happen in the second circuit?*

Connecting receptors

In series	In parallel
 All the receptors share the voltage from the battery. The current that flows through them all is the same. The total resistance is $R_T = R_1 + R_2$.	 All the receptors share the current from the battery. The voltage at the ends of each receptor is the same as that of the battery. The total resistance is $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$.

Connecting generators

In series	In parallel
 The total voltage in the circuit is the sum of the voltage of each battery: In this case: V_T = 4.5 V + 4.5 V = 9 V	 In this example: V_T = 4.5 V. Both batteries in the circuit supply current. The bulb will light for longer and we can connect receptors that need more current.

CLIL activities

22 How do you think the sockets and lights in a home are connected: in series or parallel? (Hint: What happens when a bulb stops working?) Write your answer in your notebook.

23 Listen to the teacher explaining the difference between series and parallel circuits. Take notes about:

path of current *current* *voltage* *applications*

24 Build a series circuit and a parallel circuit. Both circuits should have a battery, a switch, connecting cables and three bulbs. If one of the bulbs stops working, will the series circuit keep working? What about the parallel circuit?

5 The effects of an electric current. Using electricity sensibly

Why do an iron and a toaster produce heat when you plug them in? Discuss with your classmates.

As we've seen, the energy that an electric current transmits causes different effects on the receptors. The electrical energy in them transforms into different types of energy – heat, light or motion – which we can use.

5.1. Heat

When electrons crash into the atoms of the material they're flowing through, some of the energy transforms into heat. This is called the **Joule effect**.

The resistor is the element that produces heat. Appliances such as irons, kettles, hairdryers and toasters all have them.

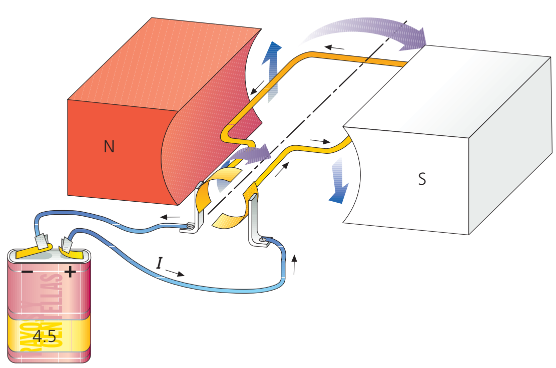
5.2. Light

There are different ways to produce light with electricity:

- Incandescent or halogen bulbs produce light when an electric current passes through a metal **filament**[1]. Most of the energy is lost in the form of heat.
- Some gases emit light when an electric charge flows through them. We use this technology in fluorescent tubes, neon and xenon bulbs. However, the gases they contain are **toxic**[2].
- In LED bulbs, electrons move through a semiconductor to produce light. These are the most **efficient**[3] in transforming energy into light.

5.3. Motion

Motors are devices that transform electrical energy into motion. They work with the forces of attraction and repulsion between a magnet and a conductive wire inside them. This wire has one or more **loops**[4] which carry the electric current.



[1]**filament:** thin wire.

[2]**toxic:** contains poison.

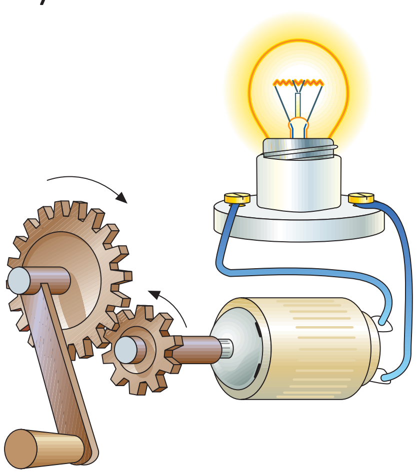
[3]**efficient:** doing something with no or little wasted energy.

[4]**loop:** in the shape of a circle.

CLIL activities

25 In your notebook, name three different electrical appliances that use a. heat, b. light and c. motion.

26 If we make the axle in an electric motor move with enough speed, we can turn it into a generator. Can you think of any objects that work this way?



5.4. Using electricity sensibly

Do you have any idea of the amount of electrical energy that you consume? Or the impact that this consumption has on the environment? What can you do about it?

Here are some ways that we can save electricity when we use **domestic appliances**[1], light, electronic devices and heating/cooling:

Domestic appliances
• Use dishwashers and washing machines only when they're full. Use cold-wash programmes. • Keep the fridge and freezer doors open for the least amount of time possible. • Switch off devices when you aren't using them, even ones with a standby mode.
Lights
• Make the best use of natural light. • Turn off lights when you don't need them. • Use LED bulbs (they last longer and consume less energy).
Heating and cooling
• Try to keep the indoor temperature pleasant without using the air-conditioning/heating too much. • The main side of a building should face south to benefit from the light and heat of the Sun. • To reduce energy bills, use good **insulation**[2] in walls, ceilings and windows.

[1]**domestic appliance:** machine that makes tasks at home easier to do.

[2]**insulation:** a protective material that we put in or around an object to stop heat passing through or from it.

CLIL activities

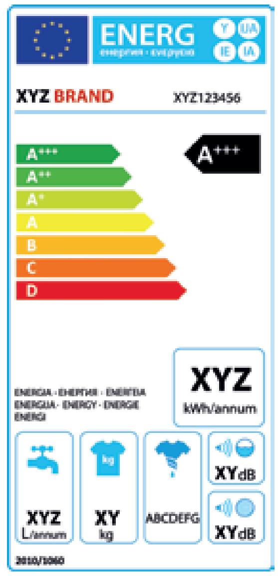
27 Complete the table in your notebook and decide which appliance is more economical. Assume that the price of a kilowatt hour is €0.14.

Fridge-freezer with A+ efficiency		Fridge-freezer with C efficiency	
Price (€)	477	Price (€)	395
Energy consumption (kW · h/year)	215	Energy consumption (kW · h/year)	480
Lifespan (years)	15	Lifespan (years)	15
Total consumption during lifespan (kW · h)	...	Total consumption during lifespan (kW · h)	...
Energy cost at end of lifespan (€)	...	Energy cost at end of lifespan (€)	...
Total cost (€)	...	Total cost (€)	...

28 LS Record in the instruction manual of your project, some indications of how to use the product correctly to save energy and avoid deterioration.

CLIL activities

29 Listen to the salesperson talking about the energy label below. Answer the questions.



a. What does it tell us?
b. Where can we find it?
c. Is it obligatory?
d. What colour is the box with the energy efficiency class of the product?
e. What other information does it show?

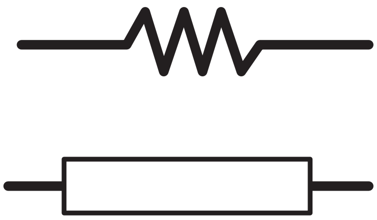
30 Work with a partner. Make a list of ten domestic appliances in your home. Order them according to the amount of energy they use. Make a poster and present your findings to the class. Make suggestions to limit the amount of energy used by some of these appliances in the home.

6 LEDs and resistors

An **LED** (light emitting diode) is a device that emits light very efficiently. However, there's a problem: we can't connect LEDs directly to a battery, so we must first limit the current flowing through them.

To limit the strength of the current, we connect a **resistor in a series circuit with the LED**.

6.1. Fixed resistors



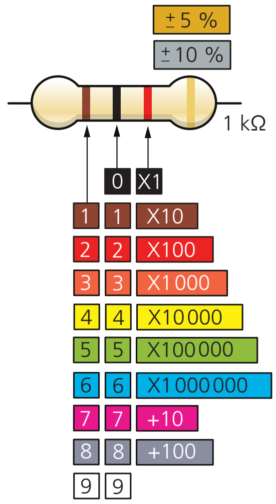
Symbols for a fixed resistor

In a series circuit, resistors obstruct the flow of the current through it.

We use them to limit the current going through other components and in voltage dividers to get voltages different from the voltage coming from the battery.

A colour code shows the values of a resistor in ohms.

0	black
1	brown
2	red
3	orange
4	yellow
5	green
6	blue
7	purple
8	grey
9	white
±5 %	gold
±10 %	silver

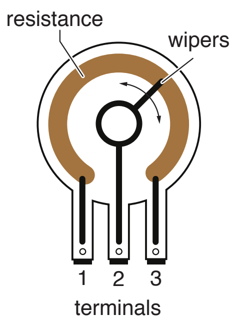


The first two stripes show the value of the first two digits in the resistor. The third stripe is the number of zeros we need to add. The last stripe is the tolerance or the range of the value shown.

CLIL activities

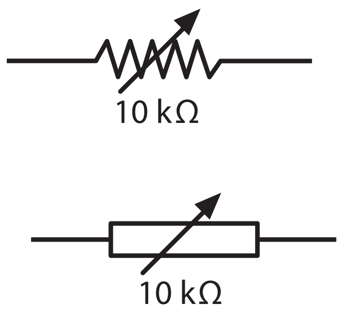
31 Draw a four-band resistor in your notebook with a value of 82 kΩ and a tolerance of 5%.

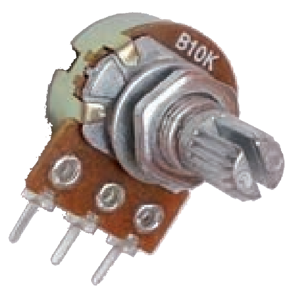
32 If we have a 100 kΩ potentiometer, what's the resistance between terminals 1 and 2. And between 1 and 3?



6.2. Variable resistors or potentiometers

Variable resistors allow us to change their resistance value with a dial. We use them, for example, in volume controls, lighting dimmer switches and temperature controls.



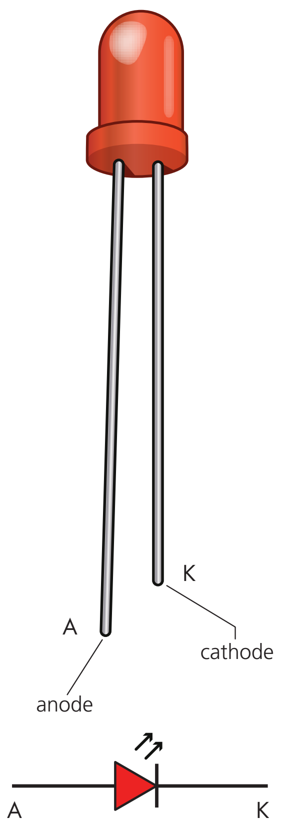


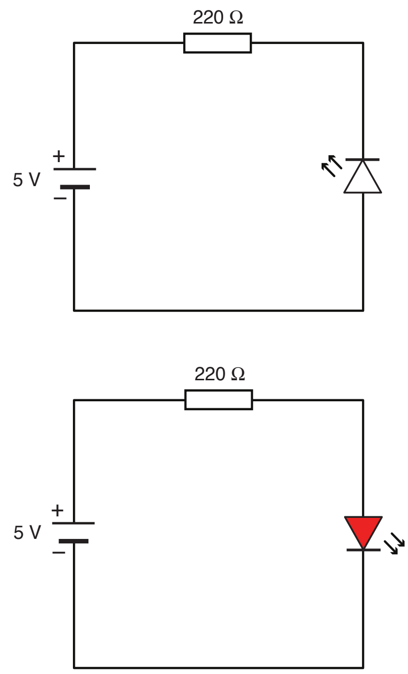
6.3. LED

A **diode** is a semiconductor that only allows electric current to flow in one direction. It has two legs or pins called the anode and the cathode.

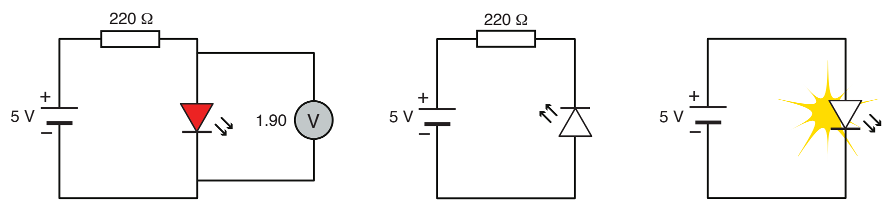
An **LED** is a semiconductor that transforms electric current into light.

We use a resistor and make sure that the current from the positive pole of the battery passes through the anode of the LED. This diagram can help you to understand this better:





For the LED to work properly, the current usually flows through it between 10 mA and 20 mA. We can get this current by putting a resistor in series with the LED:



In the first circuit, the voltage at the ends of the resistor is the same as the voltage from the battery minus the voltage at the ends of the LED (1.9 V shown on the voltmeter). If we apply Ohm's Law, we can calculate the current flowing through the resistor, which is the same as the current flowing through the LED:

$$I_{LED} = (5 - 1.90) / 220 = 0.014 \text{ A} = 14 \text{ mA}$$

In the second circuit, the diode is the wrong way around, so the current doesn't flow. Finally, in the last circuit, we've taken away the resistor. The current's so strong that the LED has broken.

What's a semiconductor?

Semiconductors are materials that can behave as insulators or as conductors, depending on the environment. They're the basis of all modern electronic components.

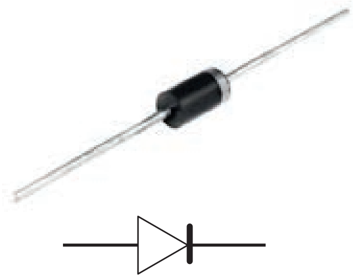


Image and symbol of a diode

CLIL activities

33 LS **You want to connect an LED light to a battery. Answer the questions in your notebook:**

a. Which pole of the battery do you connect to the anode and which pole goes to the cathode?

b. Which cable do you connect the resistor on?

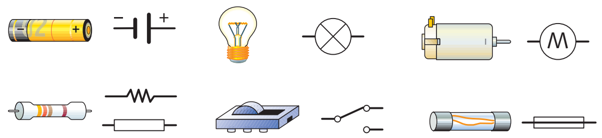
34 LS **In the example on this page, the power that the battery delivers is $P = V \cdot I = 5 \text{ V} \cdot 14 \text{ mA} = 70 \text{ mW}$. Calculate the power that's used by the resistor and the LED. Would this circuit work for your lamp? Why or why not?**

This would / wouldn't work for the lamp because...

35 LS **For your solar-powered lamp, you'll need high-intensity white LEDs. Find information about them.**

Revision activities

36 Which elements correspond to the following symbols: fuse, switch, light bulb, battery, motor and resistor.



37 Name the elements in this circuit and draw their symbols:

38 Draw the above circuit. Add a voltmeter and an ammeter to measure the voltage at the ends of the bulb and the intensity of the current flowing through it.

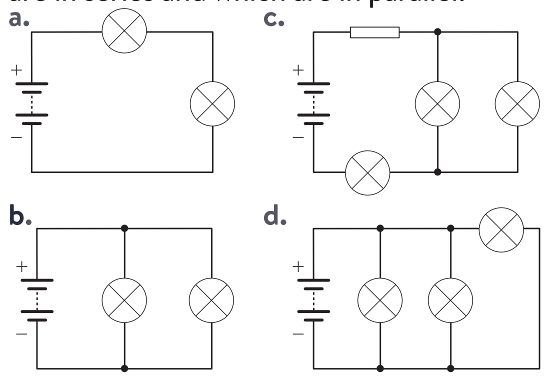
39 Calculate the energy consumption of the following appliances over one year if they have each been on for 100 hours:

Appliance	Power (W)
Vacuum cleaner	1 500
Hairdryer	1 000
Iron	1 200
Toaster	700
Electric razor	40

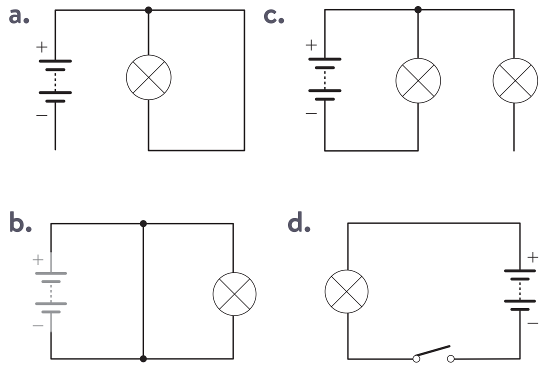
40 Complete this table in your notebook:

Quantity	Symbol	Unit	Unit symbol
Current	*I*	Amps	...
Voltage	...	Volts	...
Resistance	*R*	...	...
Energy	...	...	kW · h
Power	...	...	W

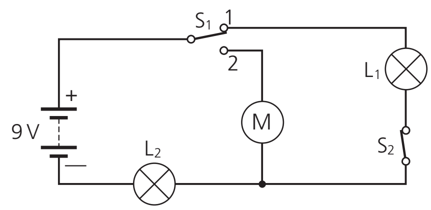
41 Which elements in the following circuits are in series and which are in parallel:



42 Analyse these circuits and explain whether or not they'll work and why:



43 Look at the circuit and complete the table.



Position of switches	Lamp L_1	Lamp L_2	Motor M
S_1: position 1 S_2: on	...	...	...
S_1: position 2 S_2: on	...	...	...
S_1: position 1 S_2: off	...	...	...
S_1: position 2 S_2: off	...	...	...

44 Design a circuit that allows you to change the direction of rotation of a motor. Draw the diagram.

45 Design a circuit to switch on one red and one green LED. You have a 4.5 V battery and two 220 Ω resistors and a three-way switch.

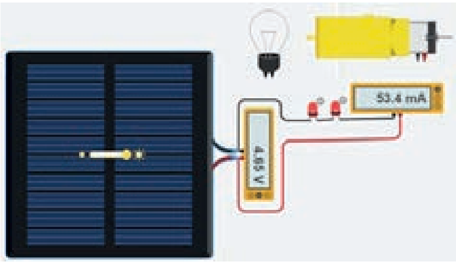
46 Solar panels are made up of photovoltaic solar cells which transform sunlight into electrical energy. What percentage of the solar energy they receive do they use? What does this percentage depend on?

Solar panels are characterised by their peak power (W*p*) and efficiency.

The peak power is the maximum power that the panel can deliver under standard conditions: 1000 W/m^2 of solar radiation and 25 °C of panel temperature.

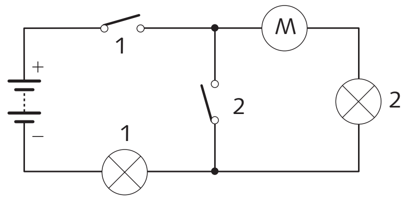
To calculate the peak power, make the following circuit and vary the potentiometer. Write down the voltage and current values. Calculate the power from these and find the W*p*.

Assuming that on a sunny day the sun radiates 1 kW/m^2 on the Earth's surface, calculate the efficiency of the solar panel. To do this, divide the peak power you have already found by the power received from the sun. You'll need to know the surface area of the panel.



The power delivered to the panel depends on several factors. Calculate the peak power again. Change the orientation of the panel, the angle and simulate a cloudy day by putting a translucent sheet between the panel and the light source.

47 Say what will happen in this circuit if:

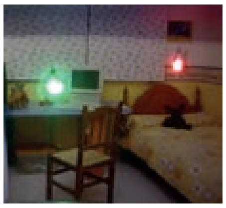


a. the motor burns out.
b. bulb 1 fails.
c. bulb 2 fails.
d. we switch on/off switch 1.
e. we switch on/off switch 2.

48 Copy the table in your notebook and use Ohm's Law to complete it.

Voltage	Current	Resistance
...	0.75 mA	6 kΩ
9 V	...	18 Ω
1.5 V	1 mA	...

49 At our school fair, there'll be an exhibition called *Living Pictures*. The exhibition will include lights, sounds and some moving parts. Design an image and the corresponding electric circuit.



50 Draw a table using a word processing program with all the electrical components in this unit: name them in English and Spanish, include a picture and symbol.

51 Explain the meaning of the information that appears on a charger for a laptop : Input: 230 V AC, Output: 19.5 V DC 2.31 A 45 W

Study skills

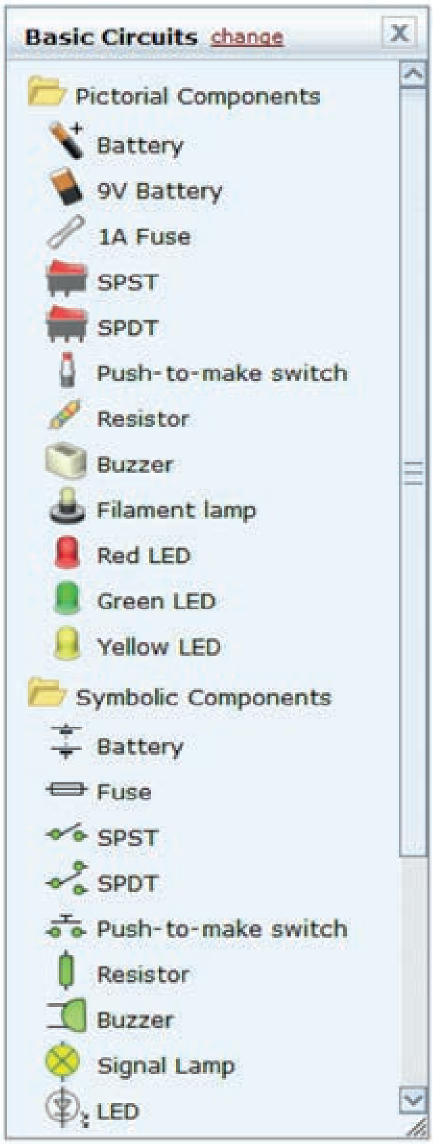
I Write a summary of this unit answering these questions:

- *What's a circuit? What flows through it?*
- *What's electric current composed of?*
- *What elements does a circuit have? How do we represent them?*
- *What quantities can we measure in a circuit? How are these quantities related to each other?*
- *How do we measure voltage and current?*
- *How can we connect two elements to each other in a circuit?*
- *What are the effects of electric current?*
- *How can we use electricity sensibly?*
- *What's an LED? How do we connect one in a circuit?*

II Draw a concept map of the unit based on these concepts: *circuit, electric current, generator, receptor, conductor, voltage, current, resistance, Ohm's law, series and parallel connections, LED.*

III Create your own glossary with the most important terms in this unit. Include these: *charge, voltage, electric current, receptors, electrical symbols, energy efficiency, effects of the electric current, short circuit, LED, resistance.*

Passnotes | Revision activities | Concept map

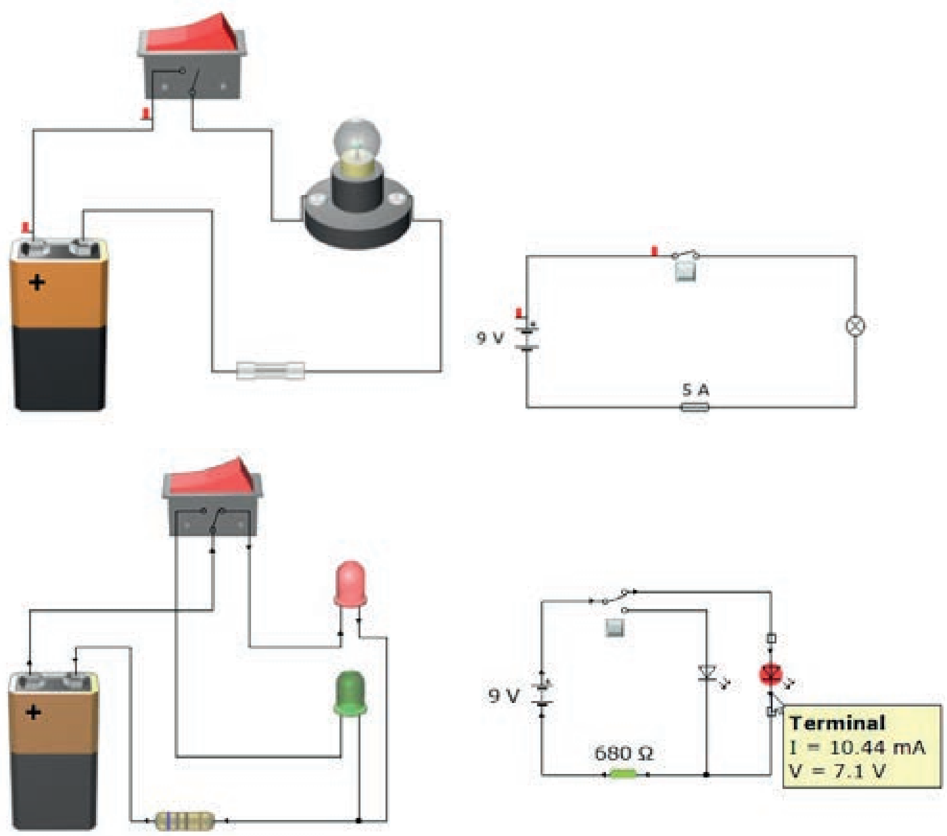


Circuit simulators

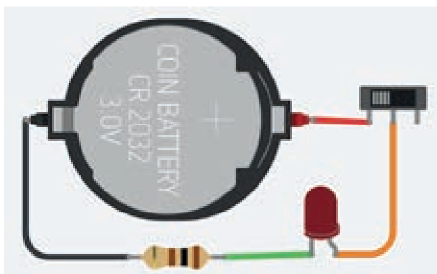
There are computer programs that allow us to experiment with the operations of electric circuits before assembling them. They're called simulators. Among the most commonly used is the **Yenka** simulator (formerly **Crocodile Technology**).

Yenka Basic Circuits (www.yenka.com) groups together, in a window, the components that we can use in the circuit. Two possibilities appear: Pictorial Components, with practically real images in three dimensions, and Symbol Components, which uses standardised symbols.

To assemble a circuit, we simply select the components and drag them to the work area. Then, we join them with lines that represent the cables.



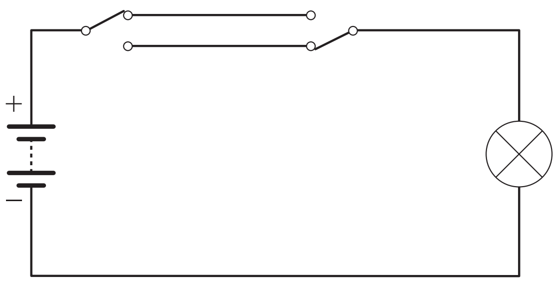
Another simulator is **TinkerCad** (www.tinkercad.com) which is a free online application. It incorporates measuring instruments and all the components that we've studied in the unit, such as batteries, switches, bulbs and LEDs.



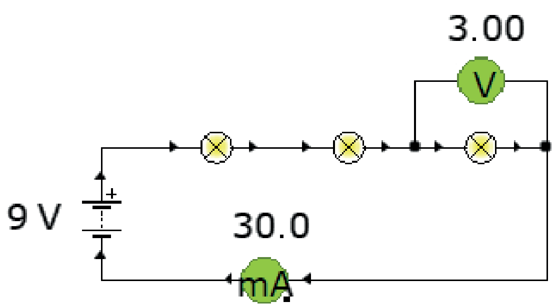
Practice

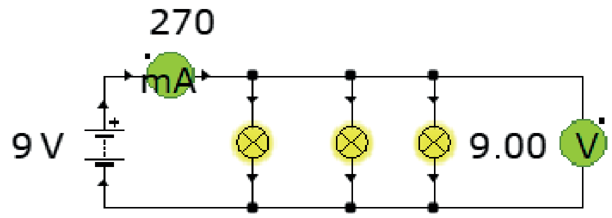
Using a circuit simulator, answer the following questions:

1. Make a list of the electrical components in the program you've chosen.
2. Build a circuit with a battery, a buzzer and a switch. Do you think that in practice we can use this circuit? What component would you change?
3. In the circuit in activity 2, the following energy transformation occurs: chemical energy of the battery → electrical energy → sound.
   a. What component would you substitute in the circuit to get light?
   b. And to obtain mechanical energy?
4. Assemble a circuit with a 1.5 V battery and a motor (Electronics → Outputs). Make a note of the revolutions per minute (rpm) of the motor and the current coming out of the battery. What happens to these quantities if we use a 4.5 V battery?
5. Look at the following diagram that represents a light with a switch. Could you explain how it works? Assemble the circuit and check its operation. Where can we find this circuit in our everyday life?

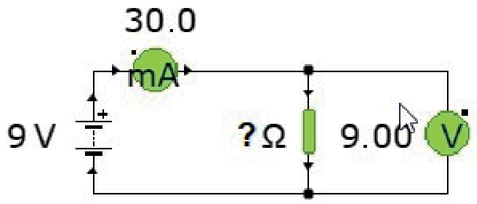


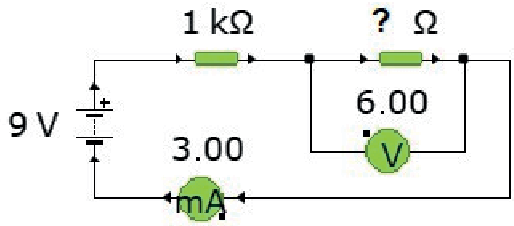
6. Assemble the following circuits. Check that, in a series circuit, the battery voltage is distributed between the receptors and that, in a parallel circuit, the current is distributed.





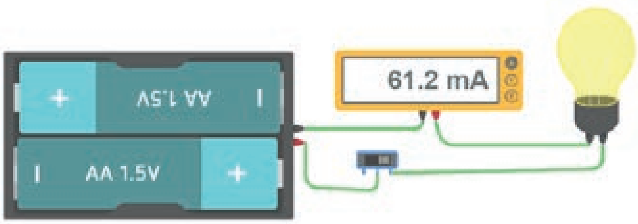
7. In the following circuits, we don't know the value of a resistor. Simulate them and try to work it out.



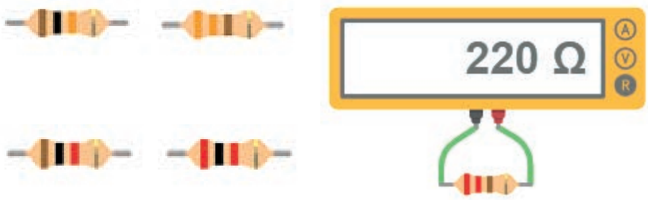


Using the Tinkercad simulator, do the following activities:

8. Assemble the circuit show below. You'll need two 1.5 V batteries, a switch, a lamp and the multimeter. Replace the battery with one with four 1.5 V units. What current does the ammeter show? What would happen if you used a single 1.5 V unit?



9. Look at the colour code and state the value of each resistor. Then measure its value using the multimeter and check your predictions. What happens if you join any two resistors in series and measure them? What happens if you put them in parallel?



Constructing circuits

Constructing circuits is based on two fundamental aspects: their design, which we can carry out schematically, as we've already seen, and making the correct connections.

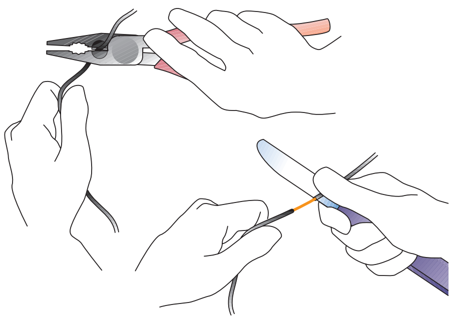
For a circuit to work, we need to use conductive materials to make sure that electrons can flow. Often, circuits don't work because of a bad connection between the components.

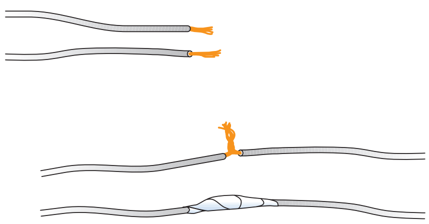
Connecting two cables

We can join two cables in a circuit in two ways: physically or using choc block connectors.

Physical union

1. Peel back the ends of both cables.
2. Join and twist the filaments together.
3. Fold and insulate them with electrical tape.



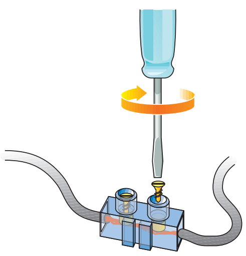


Union with choc block connectors

Choc block connectors are prefabricated parts that join two cables together and insulates them. It's a plastic wrapper that contains two copper tubes and two screws that clamp each end of a cable against the sides of the tubes.

How to use a choc block connector:

1. Unscrew the choc block connector.
2. Insert the cables.
3. Screw the choc block connector back on.
4. Check that the cables have been fixed in place.



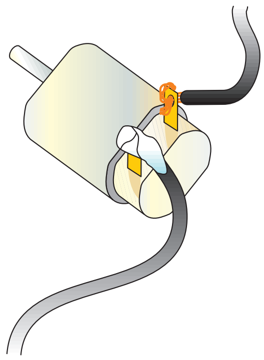
Connecting a motor

The problem with connecting motors is that on one hand their connecting elements are fragile, and on the other hand, we usually have to remove these connections to be able to reuse the device.

Physical union

This works best for motors with holes in the contacts.

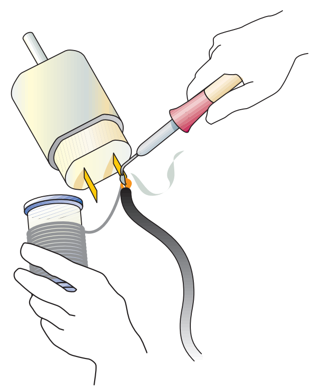
1. Peel back the end of a cable.
2. Trim several filaments. Twist and tie the filaments to the motor brush.
3. Fix the filaments in place with electrical tape.



Soldering

If the motor contacts consist of two plates, we have to solder the cables.

1. Solder the filaments to the motor contacts.
2. Leave a bit of cable to join the motor to the rest of the circuit.



The electric soldering iron is a simple device that has an electrical resistance inside that heats a tip of copper or a special alloy.

We solder with a wire made of an alloy of tin and lead, 60% and 40%, respectively.

We must be very careful when using the soldering iron, as the metal tip reaches very high temperatures. Always hold it by the plastic handle. When you finish a solder task, place the soldering iron in its holder.

Safety rules for working with electric current

We've seen that electricity and, especially, electric current are very useful for humans. But, as you already know, starting from a voltage of 24 V, electric current is also dangerous. An electric shock from our home network (230 V) can be fatal.

We must also remember that water is a conductor of electricity, which means that we can receive electric shocks through it. For this reason, we should follow some basic precautions to avoid accidents with electricity in our homes:

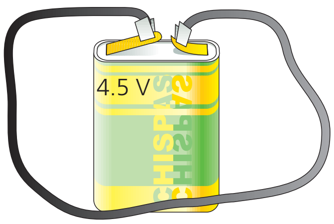
1. Dry your hands before using electrical appliances.
2. Don't clean an electrical appliance with a damp cloth.
3. Don't insert metallic objects into sockets.
4. Don't pull the cable to unplug an appliance.
5. Use a suitable extension lead to connect multiple devices to the same socket.
6. Be especially careful with electricity when you're getting out of the shower.
7. Don't leave devices that can overheat switched on.
8. Don't overload adapters (devices with multiple outlets) by plugging in too many appliances.
9. Follow the manufacturer's technical instructions for each appliance.
10. Disconnect the electricity supply before carrying out repairs, such as changing a lightbulb, or if there is any sign of a fault in the system.
11. Never use a broken or bare cable. It could give you an electric shock. Change the cables before they get into a bad condition.
12. Insulate all connections you make.
13. Connect all household appliances to the ground, as well as any individual metal parts (structure, taps, heating pipes); then any discharge will go into the ground.
14. Use choc block connectors instead of electrical tape to make electrical connections.

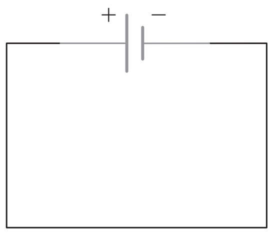
A short circuit

What would happen if a cable was connected directly from one pole of the battery to the other?

If this happened, the electric current would pass freely from one pole to the other and the battery would quickly run out. We call this a short circuit.

The battery in this illustration will short circuit and its power will drain very quickly.





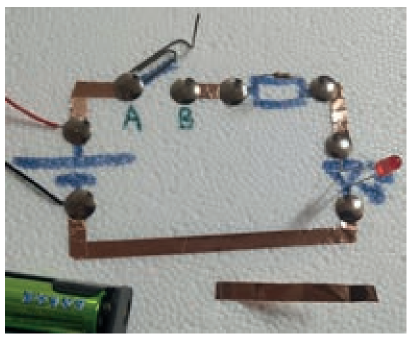
If the short circuit occurred in our home network, the circuit breakers would switch off immediately. This cuts the power supply. If these elements don't exist, the installation could be destroyed and there could even be a fire.

Warning

Electricity can cause the following damage to our bodies: burns, muscle paralysis, loss of consciousness and, in the most serious cases, death from cardiac arrest.

Practice

1 **We can make electrical circuits using adhesive copper tape. Make a circuit like this one:**



Then, use a multimeter to measure the current between points A and B, as well as the tension in the resistor and the LED. Carry out the same measurements with LEDs of other colours.

Emerging technologies and sustainability

Storing electrical energy

In order to achieve net zero greenhouse gas emissions **(climate neutrality)** we must renewable energy sources. Renewable electricity production often depends on variable factors such as wind and sunlight. We need to store this energy so that it's available whenever we need it.

There are several ways to store electrical energy:

<table>
<tr><th colspan="2">Batteries</th><th>Electrical systems: supercapacitors and superconducting magnets</th></tr>
<tr><td colspan="2">Batteries use chemical reactions to create electric current. They consist of two electrodes (an anode and a cathode) and an electrolyte that allows ions to flow between the electrodes.

They're easily scalable: they can be joined in series to increase the voltage and in parallel to increase the power supplied.
There are several types of batteries: lead-acid batteries used in combustion vehicles; lithium-ion (Li-ion) batteries for tablets, laptops and mobile phones; or nickel-cadmium (Ni-Cd) and nickel-metal hydride (Ni-MH) batteries for other electronic devices. The more modern lithium polymer (LiPo) batteries have a higher energy density.</td><td>Graphene supercapacitors charge in seconds and provide high power. They can function as miniaturised batteries and form part of wearable electronics and the Internet of Things (IoT).
Magnets made by superconducting coils store electrical energy in the coils. They don't lose energy but they do need cryogenic temperatures to operate.</td></tr>
<tr><th>Pumped storage hydroelectric power stations</th><th>Mechanical systems: compressed air and flywheels</th><th>Thermal storage systems</th></tr>
<tr><td rowspan="3">This consists of filling water deposits located higher than reservoirs to gain potential energy. This energy can be transformed into electrical energy when necessary.
This is the most widely-used energy storage system in Europe.
</td><td rowspan="3">High-pressure compressed air can be stored in containers for subsequent production of electrical energy.
Flywheels consist of metal discs capable of storing kinetic energy.
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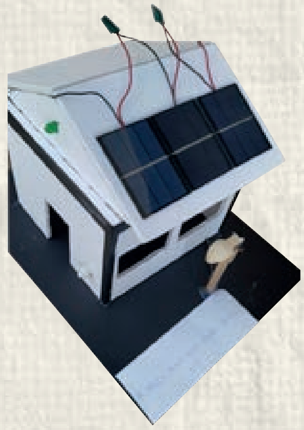
<tr><th>Hydrogen</th></tr>
<tr><td>Hydrogen is the basis of fuel cells in which we obtain electrical energy by combining it with oxygen.
Obtaining hydrogen requires external energy that doesn't always come from renewable sources.</td></tr>
</table>

Activities

1. With the help of your teacher, set up a circuit that shows the charging and discharging of a capacitor. You'll need a battery, a switch, an electrolytic capacitor, an LED and a resistor.

Work on your key competences

Design a solar lamp



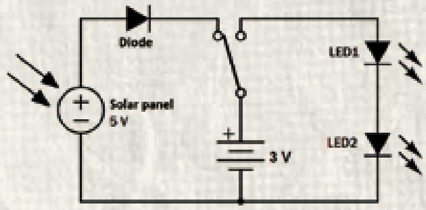
There are communities with no electricity supply and where the use of renewable energies would improve the quality of life. However, renewable energies may not be practically possible in some of these communities.

The **aim** of this project is to provide a sustainable source of lighting for people who don't have access to electricity, using simple circuits and with an attractive design.

Designing the circuit

1. **Look for information about the components you're going to use and design the control circuit for the lamp.**

   You'll probably need one or two photovoltaic panels, a protection diode, a switch, several white high-brightness LEDs, rechargeable batteries and battery holders, and cable to connect the components. Please note that lithium batteries need a special charging process. Use the more common nickel-cadmium (Ni-Cd) or nickel-metal hydride (NiMH) batteries.



Possible electric circuit and battery

Testing the prototype

2. **Before you assemble your final object, test that the circuit works.**

   You'll need to put a limiting resistor in series with each LED. These resistors consume energy in the form of heat. A very high value will cause the current, and therefore the light, to be weak. Conversely, with a very low value, the current will increase and the battery power will be maximised. Never exceed the maximum current. Experiment with different types of connections for the LEDs to the battery. Start by placing two diodes in series with the battery, measure the current flowing through them and check that the lighting is adequate Don't use a value less than:

$$R_{min} = \frac{(V_{battery} - V_{LED})}{I_{maxLED}}$$

   Check that the voltage provided by the solar panel (or panels) is higher than the voltage of the battery. If it isn't, the battery won't charge. Note that you'll lose about 1 V at the protection diode.

Designing the prototype

3. **Don't forget.**
   - The design should be innovative and attractive.
   - Include some element so that you can carry the lamp.
   - Include recyclable and ecologically-friendly materials that are easy to take apart. In addition, it should have elements that reflect the customs or culture of the specific community which you are making it for.

Construction and evaluation

4. Make your lamp.
   - Plan the construction process.
   - Divide the tasks among the members of the group.
   - Set up intermediate tests to check everything is working correctly.

5. **Write the project report. Remember that the report must be signed by all members of your group. The report must include:**
   - Your individual sketches and ideas, the group's final idea, process sheets, budgets, drawings and plans showing different views.
   - The materials you've used. Say whether they are reused or recycled.
   - A schematic drawing of the electrical circuit.
   - User instructions for how to take the lamp apart and possibilities for reusing the different components.

Task guide