2 Electricity and electronics

1. Electrical circuits
2. Electrical quantities
3. Series and parallel circuits
4. Electromagnetic control systems
5. Electronics

LEARNING SITUATION

Design and build an electric car

In this unit, you'll design and build an electric car. You'll produce a video showing how your car works. You can then post this video online, for example, on a blog.

1 Electrical circuits

An electric circuit is a path for the flow of negatively-charged particles called **electrons**. These particles can flow as electric **current**[1].

Electric current is a continuous flow of electrons through a circuit.

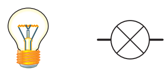
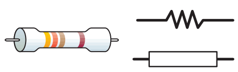
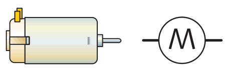
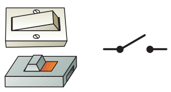
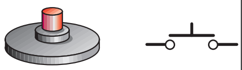
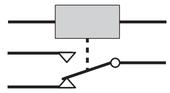
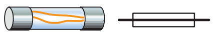
Parts of an electric circuit

An electric circuit consists of various **components**: generators, conductors, switching **device**[2] and loads.

Generators provide electric current and **conductors** carry it through the circuit. **Switching** devices control the flow of electricity, while **loads** transform it into other types of energy, such as light, heat or motion.

Circuit diagrams

We use standard symbols in diagrams of electric and electronic circuits. This makes the diagrams easier to understand.

Generators			
Electrochemical cell		Battery	
			
Loads			
Light bulb	Resistor	Motor	Bell
			
Switching devices			
Switch	Push-button	Three-way switch	Relay
			
Safety components			
Fuse			
			

CLIL activities

1. Use the Internet to find out the difference between conductors, insulators and semiconductors. Give examples of each.
2. Listen to four sentences. Write true or false. Correct the false sentences.
3. Work with a classmate. List the electrical devices in your home. Explain if they're easy and safe to use.

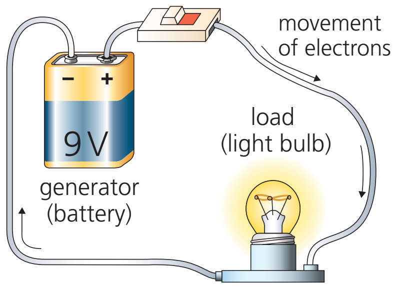
[1]**current:** continuous, flowing movement.

[2]**device:** tool or machine that performs an action.

Electric charge

Electric charge is the property of matter responsible for electric phenomena. Negatively charged particles called electrons flow as electric current.

The SI unit of electric charge is the coulomb. One coulomb (C) equals 6.25×10^{18} electrons.



2 Electrical quantities

Voltage

The amount of energy that a generator (a cell or battery) can transfer to the electrons in a circuit depends on its electrical tension or **voltage** (**V**).

A generator creates a potential difference (electromotive force) between two points in a circuit. This causes electrons to flow from one point to the other. The energy transferred to the electrons is measured in volts.

Electric current

Electric current (*I*) is the charge or number of electrons that flow through a conductor in a second. It is measured in **amperes** or **amps** (**A**). One amp equals a flow of one **coulomb**[1] per second through the cross-section of a conductor.

$$I = \frac{Q}{t}$$

$$1\text{A} = \frac{1\text{C}}{1\text{s}}$$

[1] **coulomb:** the amount of electricity that one ampere carries in a second.

Electrical resistance

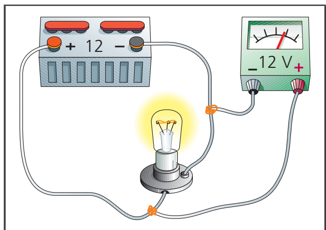
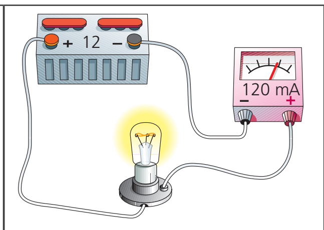
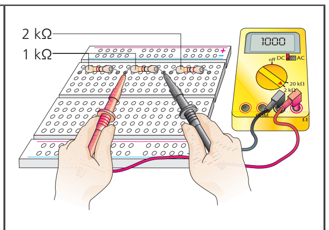
Electrical resistance (*R*) is a measure of how easily electrons flow through the components of a circuit. It is measured in SI units called **ohms** (**Ω**).

Electrical resistance depends on the length (*L*) and cross-sectional area (A) of a component. Longer components offer more resistance, while a larger cross-section gives electrons more room to flow. Electrical resistance also depends on the material used to make a component. Some materials offer more resistance than others.

$$R = \rho \frac{L}{A}$$

Measuring electrical quantities

We can use a multimeter to measure voltage, electric current and resistance.

		
A **voltmeter** measures voltage. We connect it **in parallel** to the component that we are checking.	An **ammeter** measures electric current. We connect it **in series** so that all the current flows through it.	An **ohmmeter** measures electrical resistance. We connect it **to opposite ends** of a component.

Electrical resistance and Ohm's law

The resistance (***R***) of a material is equal to the voltage (***V***) divided by the intensity of electric current (***I***) passing through it. This is Ohm's law, which we can express in three ways:

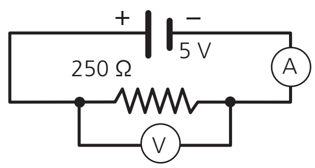
$$\boldsymbol{V = R \cdot I} \qquad \boldsymbol{I = \frac{V}{R}} \qquad \boldsymbol{R = \frac{V}{I}}$$

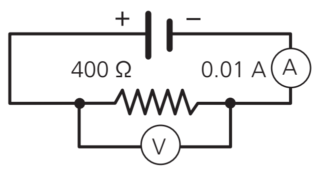
When there is more resistance, less current can flow. When there is less resistance, more current can flow.

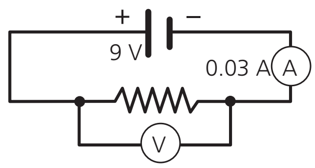
CLIL activities

4 Listen and copy four questions into your notebook. Then, answer them.

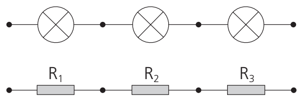
5 Calculate the values that will appear on the measuring instruments in each of the circuits below. Then, find the power each resistor consumes.



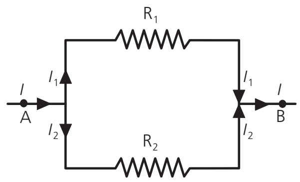




3 Series and parallel circuits

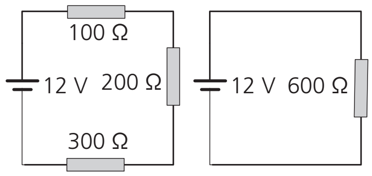
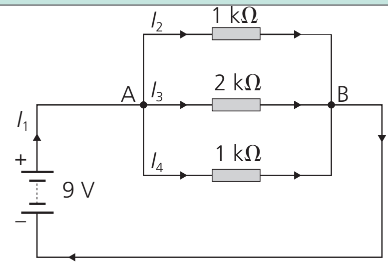


In a **series circuit**, the current flows along one path through all the components.



In a **parallel circuit**, the current flows along more than one path to each of the components.

Analysing series and parallel circuits

Series circuit	Parallel circuit
1 **Series:** We calculate the total resistance.  $R_T = R_1 + R_2 + R_3$ $R_T = 100\ \Omega + 200\ \Omega + 300\ \Omega = \mathbf{600\ \Omega}$	1 **Parallel:** We calculate the total resistance.  $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ $\frac{1}{R_T} = \frac{1}{200\ \Omega} + \frac{1}{300\ \Omega} + \frac{1}{600\ \Omega}$ $\frac{1}{R_T} = \frac{3}{600\ \Omega} + \frac{2}{600\ \Omega} + \frac{1}{600\ \Omega} = \frac{6}{600\ \Omega}$ $R_T = \frac{600}{6} = \mathbf{100\ \Omega}$
2 We use Ohm's law to calculate the total current. $I_T = \frac{V_T}{R_T} = \frac{12\ \text{V}}{600\ \Omega} = \mathbf{0.02\ A}$	2 We use Ohm's law to calculate the total current. $I_T = \frac{V_T}{R_T} = \frac{12\ \text{V}}{100\ \Omega} = \mathbf{0.12\ A}$
3 We use Ohm's law to calculate individual loads. $V_1 = I_T \times R_1 = 0.02\ \text{A} \times 100\ \Omega = \mathbf{2\ V}$ $V_2 = I_T \times R_2 = 0.02\ \text{A} \times 200\ \Omega = \mathbf{4\ V}$	3 We use Ohm's law to calculate individual currents. $I_1 = \frac{V_T}{R_T} = \frac{12\ \text{V}}{200\Omega} = \mathbf{0.06\ A}$ $I_2 = \frac{V_T}{R_2} = \frac{12\ \text{V}}{300\Omega} = \mathbf{0.04\ A}$

Analysing combination circuits

A **combination circuit** has some components connected in series and others connected in parallel. We analyse them as follows:

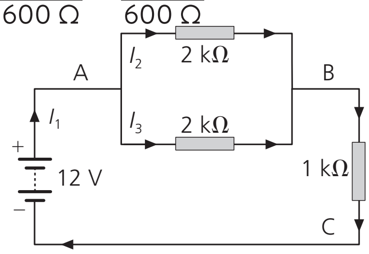
1 Calculate the total resistance of the components in parallel.

$$\frac{1}{R_T} = \frac{1}{R_2} = \frac{1}{R_3} = \frac{1}{200\ \Omega} + \frac{1}{300\ \Omega} = \frac{3}{600\ \Omega} + \frac{2}{600\ \Omega} = \frac{5}{600\ \Omega}$$

$$R_{23} = \frac{600}{5} = \mathbf{120\ \Omega}$$

And in series.

$$R_T = R_1 + R_{23} = 80\ \Omega + 120\ \Omega = \mathbf{200\ \Omega}$$



2 Use Ohm's law to calculate the total current.

$$I_T = \frac{V_T}{R_T} = \frac{12\ \text{V}}{200\ \Omega} = 0.06\ \text{A}$$

3 Use Ohm's law to calculate the individual loads.

$$V_1 = I_T \times R_1 = 0.06\ \text{A} \times 80\ \Omega = 4.8\ \text{V} \quad V_{23} = I_T \times R_{23} = 0.06\ \text{A} \times 120\ \Omega = 7.2\ \text{V}$$

4 Use Ohm's law to calculate the individual currents.

$$I_2 = \frac{V_T}{R_T} = \frac{7.2\ \text{V}}{200\ \Omega} = \mathbf{0.036\ A}$$

CLIL activities

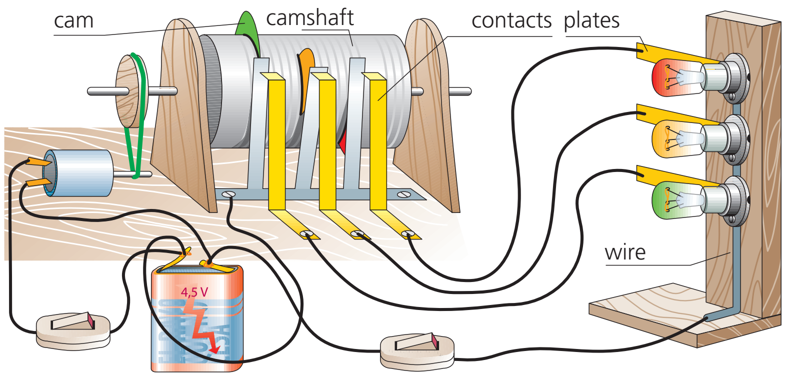
6 The solar cell below provides 0.5 V and 300 mA. If our project for this unit requires 1.5 V and consumes 600 mA, how many cells will we need and how should we connect them?

④ Electromagnetic control systems

An **electromagnetic control system** activates parts of a machine at the right moment for a certain amount of time. This allows the machine to function.

Cam switch controller

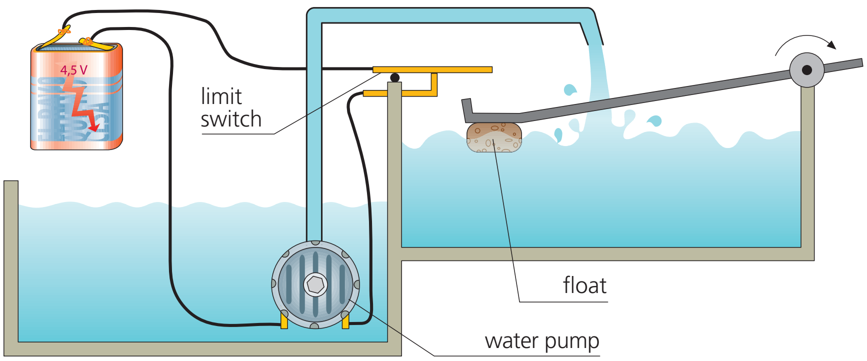
The device in the picture below uses a **cam**[1] to control when and how long each light is turned on. The cams push the metal contacts together for a short period of time. This happens once every time the camshaft rotates.



Limit switch

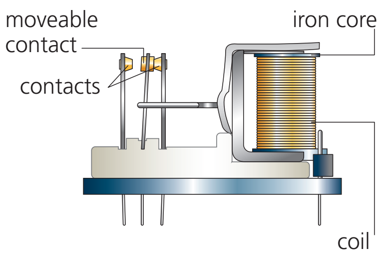
A **limit switch** has two possible positions: open and closed. Some limit switches are **normally closed** and others are **normally open**. Limit switches change position when they are activated.

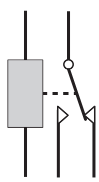
The water pump in the picture below has a limit switch. When the float rises, it activates the switch, opens the circuit and turns off the pump.



Relay

A **relay** has a **coil**[2] that becomes magnetic when electricity passes through it. The coil attracts a moveable contact and closes the circuit. When the electricity stops flowing, the contact returns to its original position. Doorbells and buzzers often use relays.





[1]**cam:** a piece that slides or rotates to create a linear, up and down movement in another piece.

[2]**coil:** spiral-shaped wire used to create a magnetic field or electrical resistance.

CLIL activities

7 Listen and answer the questions about traffic lights.

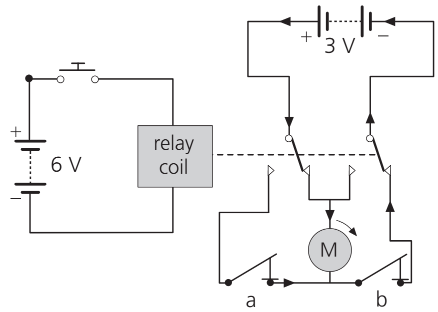
a. When was the first electric traffic light used?

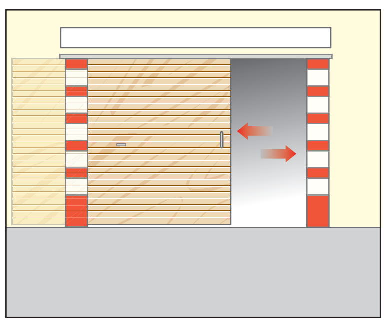
b. What type of control system do modern traffic lights use?

c. What sends signals to turn the lights on and off?

d. What happens when there isn't any electricity?

8 Explain how this circuit works to open and close a garage door automatically. The push-button *P* has to be positioned on the floor and the two limit switches, *a* and *b*, need to be positioned at either end of the door.





5 Electronics

Electronics involves the study of circuits and components that modify the intensity, direction and properties of electric currents.

Electronic components

Fixed resistances or resistors

A fixed resistance (or **resistor**) opposes the flow of electric current. Its value in ohms (Ω) is shown by a code of coloured stripes. The first two stripes give us a two-digit number. The third stripe tells us how many zeroes to add. The fourth stripe gives the tolerance, which is the maximum deviation from the labelled value.

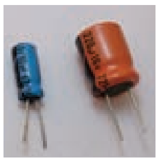
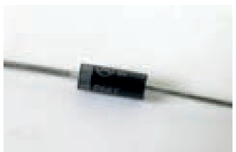
	gold	black	brown	red	orange	yellow	green	blue	purple	grey	white
number			1	2	3	4	5	6	7	8	9
multiplier	×0.1	×1	×10	$\times 10^2$	$\times 10^3$	$\times 10^4$	$\times 10^5$	$\times 10^6$	$\times 10^7$	$\times 10^8$	$\times 10^9$
tolerance	± 5%										

Variable resistances or potentiometers

The value of a variable resistance (or **potentiometer**) can be adjusted between zero and the maximum value specified by the manufacturer.

Resistances affected by physical factors

- **Thermistors** are affected by **temperature**. There are two types:
  - **PTC** (positive temperature coefficient): the higher the temperature, the more resistance the thermistor offers.
  - **NTC** (negative temperature coefficient): the higher the temperature, the less resistance the thermistor offers.
- **Light dependent resistors** (LDR) can be used as light sensors because they offer less resistance when there is more light.

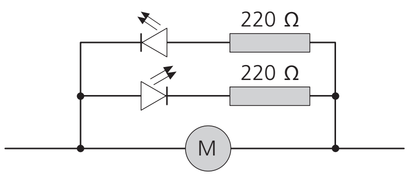
Capacitors	Diodes
	 
A capacitor can store electrical energy and use it to power a device, such as a light bulb. The charge that a capacitor can store is measured in **farads** (**F**).	A **diode** only allows current to flow in one direction. It has two electrodes: an **anode** (A) and a **cathode** (K). A light emitting diode (**LED**) produces light when current flows through it.

CLIL activities

9 How are capacitors similar to batteries? What happens when a capacitor is depleted? Write your answers in your notebook.

10 Listen to the four students. What mistakes do they make? Correct them in your notebook.

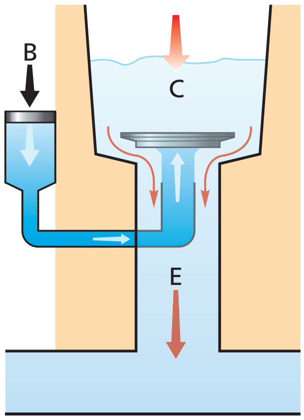
11 We can use the diagram to show the direction a motor rotates in. Explain how.



Transistors

A **transistor** is a switch that is activated by a small electric current. Transistors are made of semiconductor materials and have three electrodes: the base (B), the collector (C) and the emitter (E).

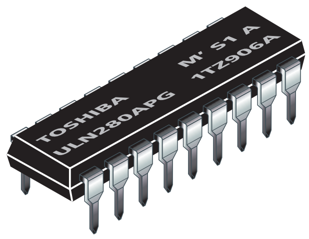
- When no electrons are flowing through the base, electrons cannot flow from C to E. The transistor is in **cutoff**.
- When a lot of electrons are flowing through the base, the route from C to E is totally open. The transistor is in **saturation**.
- When the flow of electrons through the base is between the cutoff and saturation levels, the transistor is in an active state. The flow of electrons from C to E is **proportionate**[1] to the flow of electrons through B.



Integrated circuits

Integrated circuits contain a variety of miniature electronic components, such as transistors, resistors and capacitors. For example, a UL-N2803A integrated circuit has eight pairs of Darlington transistors.

Integrated circuits can be **analogue** or **digital**. We can use them to make amplifiers, radio receivers, microprocessors and other devices.



[1]**proportionate:** the same in size and amount; equal to.

CLIL activities

12 Research these different types of transistors and write a description of each in your notebook: 2N2222, 2N3055, BC548, BC558, BD137, IRF540, TIP120.

13 Make a list of the components you'll need for your electric car circuit. Identify the ones which you have in the workshop and make a budget for any components you don't already have.

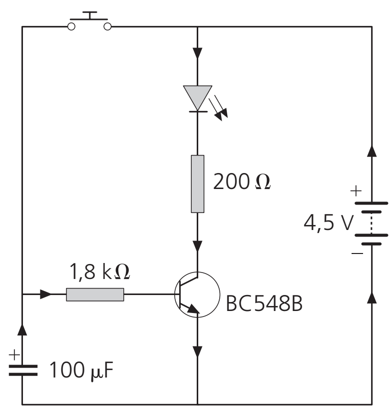
Basic devices with electronic components

We can build various devices with the electronic components discussed in the previous section. Here are two examples:

A timer

The first diagram on the right represents a timer that shuts off automatically.

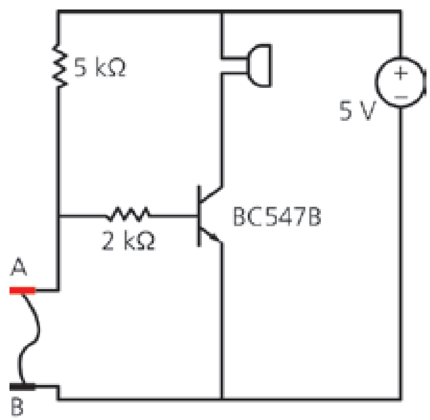
- At first, there is no current flowing through the base. The transistor is in cutoff. When we push the button, current flows through the base, the transistor is activated and the LED turns on. The capacitor also begins to charge.
- When we release the button, the LED stays on for some time, using current from the capacitor. When the capacitor runs out of energy, the transistor cuts off and the LED turns off.



A security alarm

The second diagram on the right represents an alarm that rings when a cable breaks.

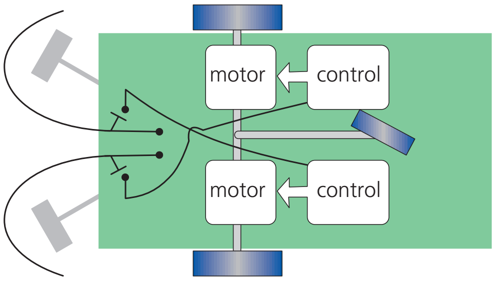
- When the cable (AB) is connected, electrons do not flow through the base. The cable is an easier route for the electrons to follow.
- When the cable is broken, electrons flow through the base. When the base is saturated, current flows from the collector to the emitter. This activates the alarm bell.



Design and build an electric car

There are many different types of electric vehicles, including cars, drones, wheelchairs, lifts, trains and even electric scooters and bikes. They all use an electric motor and a mechanical system that converts the rotary motion of the motor into linear motion. Electric motors have a simple design, require little maintenance and can be powered by renewable energies.

The objective of this project is to design and build a **zero-emission electric car** using components of electrical and electronic circuits.



Research

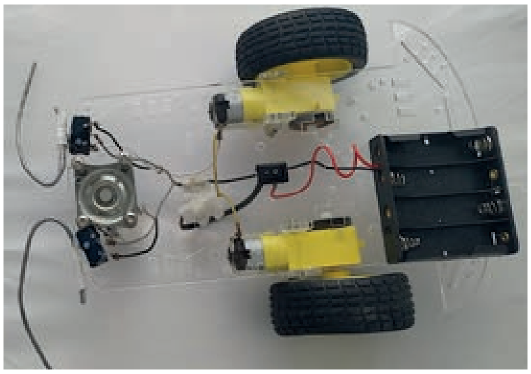
1. Find a broken or unused toy or electrical device. Analyse its components and how it works.
2. You'll need a charging station to charge all the vehicle batteries for the class. Find information about commercial battery chargers and how to build one. Discuss the solutions with your classmates and choose the best one.

Development

3. Bear in mind the following requirements for your electric car.
   - It must be able to move automatically, avoiding any obstacles. Alternatively, it can include manual controls for changing its direction of movement.
   - It must make an intermittent sound when it moves or when it collides with an object.
   - It must have movement indicator lights.
   - You can use recycled materials for the chassis, such as wheels, motors and switches from unused toys.
   - The vehicle body must conceal all the circuits and mechanisms.
   - The car must be powered by rechargeable batteries or solar panels.
4. Test your electronic circuit with simulation software and then build the car. Remember to respect health and safety regulations.
5. Film your car in motion and publish the video on your blog.

Share your findings

6. Write a report. Include:
   - a list of the materials used for the chassis and body, and the mechanical and electrical components;
   - a diagram of the electrical circuit and measurements taken on that circuit;
   - an analysis of the energy consumption of your vehicle, with measurements of the current flowing from the battery and consumed by each component;
   - the results of the simulation;
   - the design of the vehicle body;
   - a list of links to websites where you found information;
   - ideas for improvement.



Toy with two limit switches that function as antenas to detect obstacles