Understanding energy in circuits

We are learning how to:

- Describe what the voltage does in a circuit.
- Explain voltage using different analogies.

We know that an electric circuit gets its energy from a battery. The amount of potential energy within a battery is measured by the number of volts it has. Volts are the measurement of voltage.

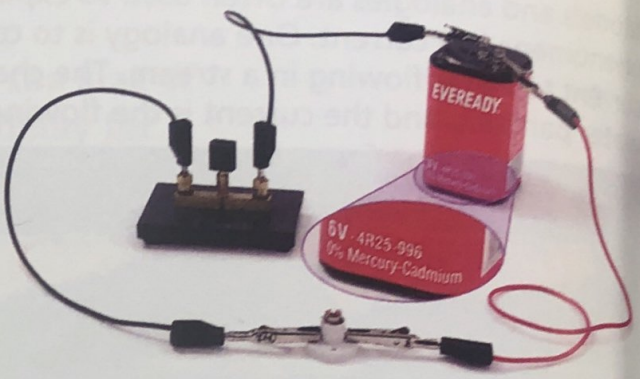


FIGURE 2.6.12a: What do we mean by voltage?

What is voltage?

We can think of **voltage** as a measure of the size of 'push' that causes a current to flow around a circuit. Because the current is a flow of charge, something is needed to make the charges move.

If there is no voltage, then there can be no current flowing because there is nothing to cause the charges to move. The larger the voltage, the bigger the 'push' and the more current that can potentially flow.

The symbol for voltage is *V* and the unit is **volts** (V).

The energy source for the voltage is usually a battery or cell, but it can also come from a mains socket. A large energy source, like a big car battery of 12 V, will provide more 'push' or voltage and hence more current than a small cell of 1.5 V.

If two cells are connected together side-by-side, the voltage across them is the sum of the voltage of each cell. This is because both cells are 'pushing' the same way.

1. Why does no current flow if there is no voltage?
2. Figure 2.6.12b shows two circuits, one with one cell and the other with three cells. If, instead, there were two cells, what reading would the voltmeter give?

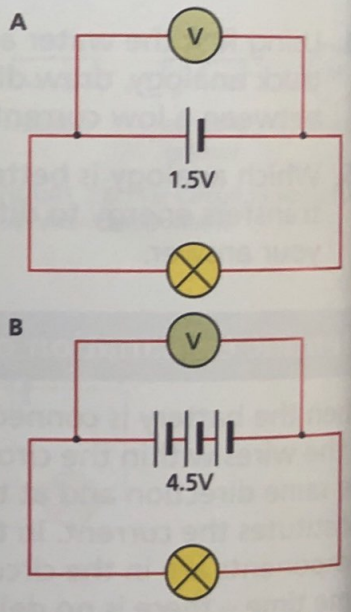


FIGURE 2.6.12b: Measuring the voltage across cells

Voltage and components

If there is a higher voltage, there will be more current flowing and therefore more energy being transferred to the components. A light bulb will be much brighter if it is connected to a 6 V battery rather than to a 3 V battery in a similar circuit. Voltage is measured using a **voltmeter** (Figure 2.6.12d).

Did you know...?

Electric eels can produce electrical discharges of around 500 V in self-defence.

igure 2.6.12c shows how the voltmeter must be connected cross a component (here a bulb) to measure the energy ifference in the current either side of the component.

3. In which of the circuits in Figure 2.6.12b will the light bulb be the brightest? Explain your answer.
4. What might happen to a motor if it were connected to the 230V mains electric supply rather than to a 12V battery?

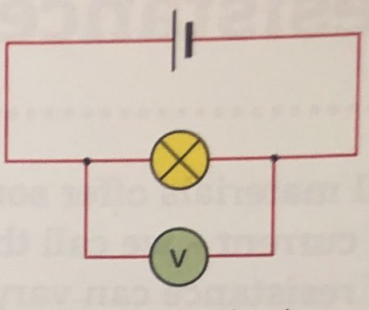


FIGURE 2.6.12c: Measuring the voltage across a bulb

Using analogies to explain voltage

magine blowing gently through a straw. The air flowing hrough the straw is like a current and the amount of push given to the air is like the voltage. If you blow harder (more oltage) there is more air flow (more current).

A very high waterfall is also like a large voltage. It will ransfer a lot of energy to the water (charge), making the iver flow very fast (a large current). The difference in height nakes the river flow. In a circuit, the difference in charge cross the battery provides the push for the current. This is why voltage is also known as **potential difference**.

FIGURE 2.6.12e: The difference in height makes the water move.

5. Compare a circuit with a 12V battery and one light bulb with one that has a 1.5V cell and one light bulb. Use the two analogies in this topic to explain how they will be different.
6. Explain one limitation for each of the analogies outlined.

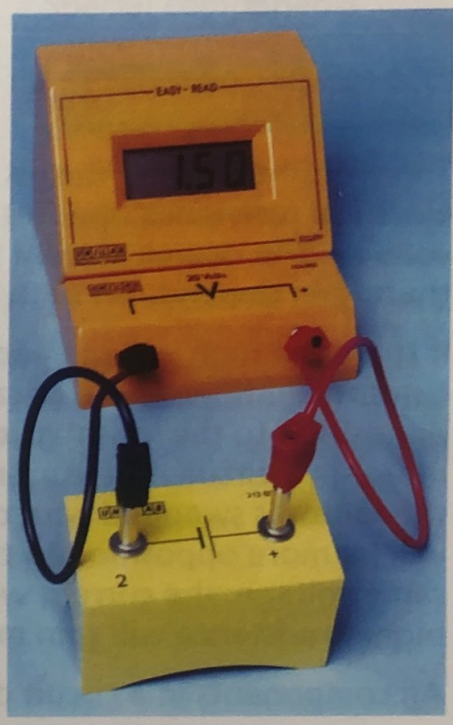


FIGURE 2.6.12d: A voltmeter connected to measure the voltage of a cell

Key vocabulary

voltage

volt

voltmeter

potential difference

Explaining resistance

We are learning how to:

- Explain what resistance is and how it affects the circuit.
- Investigate and identify the relationship between voltage and current.

All materials offer some opposition to the flow of current – we call this 'resistance'. The amount of resistance can vary widely, even in different metals. Why are some metals, like gold, better at conducting electricity than other metals, like tin?

What is resistance?

The word 'resistance' means to oppose. In electric circuits, electrical **resistance** opposes the 'push' provided by the voltage. The overall current flowing through the circuit, therefore, depends on both the voltage and the resistance.

If there is a high voltage and a low resistance, then a large current will flow. This is because there is not very much opposition to the 'push' given by the voltage. Imagine a motor in a circuit. The current through it causes it to spin. If the motor is swapped with one of higher resistance, there will be more opposition to the flow of charge and, for the same voltage, the current will be smaller. The motor with a higher resistance will spin more slowly.

All components in a circuit provide some resistance.

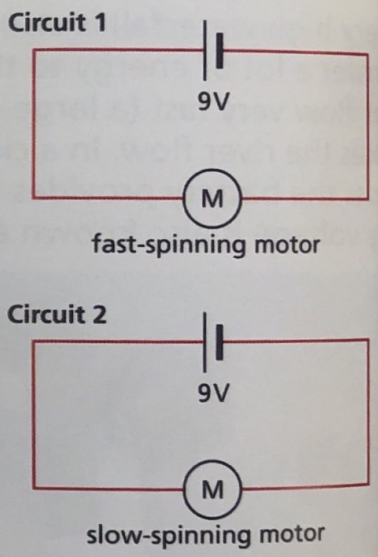


FIGURE 2.6.13a: The resistance in circuit 1 is low, so there is a bigger current; what can you say about circuit 2?

1. A buzzer is an electrical device that transfers the energy of an electric current to sound energy.
   - **a)** A circuit, A, has a 6V battery and a buzzer. Another circuit, B, has a 6V battery and a buzzer with higher resistance. In which circuit will the buzzer be louder?
   - **b)** Explain your answer to a) using ideas about resistance and current.

Conductors and insulators

Resistance depends on the type of material an object is made from. Materials that are very good conductors of electric current have a very low resistance. Electrical insulators have a very high resistance, and do not allow current to flow easily.

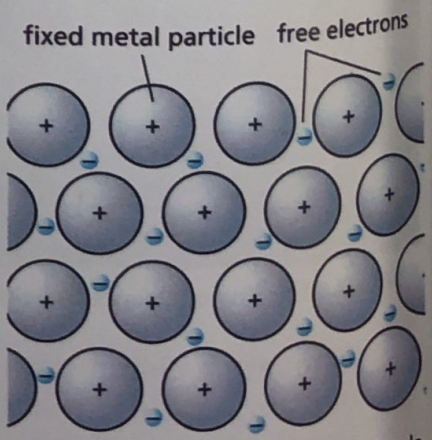


FIGURE 2.6.13b: Conduction in metals depends on free electrons

ll metals conduct electricity well because they have many **ree electrons** that can move when a voltage is applied.

s the electrons move, they will collide with other atoms. his is the cause of resistance in most ordinary metals. It is hy even the best electrical conductors, like platinum, will ave some resistance.

an insulator, the electrons are more tightly bound than in conductor; far fewer electrons flow and so there is much ss current.

2. As an analogy, think of an obstacle race. Which parts of a circuit do the obstacles represent? Which parts of the circuit do the people represent?
3. What would happen to a light bulb if the copper wires in a circuit were replaced with platinum? Explain your answer.

Did you know...?

Special components called resistors, with high resistance, are often made from nichrome or tungsten. They are used deliberately to transfer electrical energy to light and heat in the surroundings.

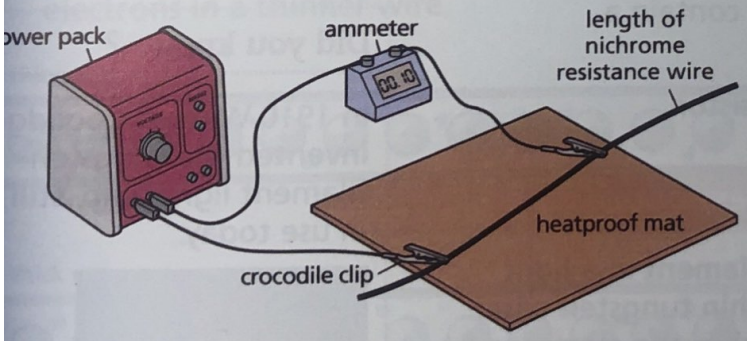
Working out resistance

esistance is measured with the unit **ohms** (Ω) and is epresented by *R*. All the components in a circuit will ave their own resistance. It is possible to investigate the elationship between voltage (*V*) and current (*I*) across a mponent, as shown in Figure 2.6.13c.

he definition of resistance is:

$$\text{resistance} = \frac{\text{voltage}}{\text{current}}$$

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



GURE 2.6.13c: As the voltage supplied is changed using the power pack, the rrent is measured using the ammeter. The resistance of the length of nichrome re between the crocodile clips can then be determined.

4. What is the resistance of the circuit shown in Figure 2.6.13d?
5. Give two ways you might increase the resistance of the circuit. Explain your answers.

Key vocabulary

resistance

free electron

ohm

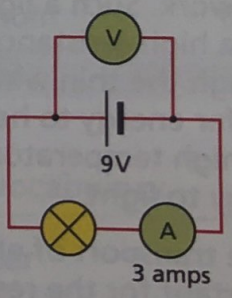


FIGURE 2.6.13d

Investigating factors affecting resistance

We are learning how to:

- Describe some uses of resistance.
- Investigate and explain factors affecting resistance.

Wires of different resistance have different purposes. High-resistance wires are used in light bulbs, whereas in some electronic applications it is essential that there is minimal electrical resistance. There are different ways in which the properties of a circuit may be changed.

Types of resistor

Increasing the resistance in a circuit reduces the amount of current passing. If too much current passes through a laptop computer, for example, it can cause damage to the circuits. Components called fixed **resistors** are used in circuits to enable a specific amount of current to pass through the components.

Other types of resistors, called **variable resistors**, allow you to change the amount of current flowing through a circuit by turning a knob or using a slider. Dimmer-light switches use this type of resistor to control the current and hence vary the brightness of the bulb.

1. Name at least one appliance that may contain a variable resistor and one that may contain a fixed resistor.
2. Give one advantage of a variable resistor.

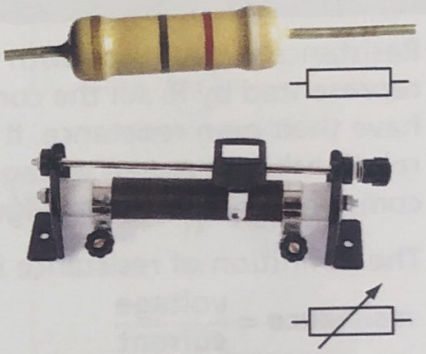


FIGURE 2.6.14a: Fixed resistor (top) and variable resistor (bottom)

Advantages and disadvantages of resistance

Resistance is the property that makes a **filament** in a light bulb work. Such a light bulb uses a very thin tungsten wire, with a high resistance. As the voltage pushes the electrons through the thin wire, there are collisions with atoms that transfer energy to heat. The tungsten wire heats up to a very high temperature and begins to glow, transferring energy to light.

In the transport of electricity across long distances, it is important for the resistance to be kept as low as possible to avoid energy losses through heating. The properties of the transporting cables enable this to be achieved.

Did you know...?

In 1910 William Coolidge invented the tungsten filament light bulb, still in use today.

FIGURE 2.6.14b: An early tungsten filament light bulb

3. Do electric heaters need a high or a low resistance in order to work? Explain your answer.
4. Mains household electricity has a voltage of 230 V. A hairdryer needs 15 A to work and another needs 12 A. Suggest one difference in the circuits of the two hairdryers.

Explaining how factors affect resistance

There are three main factors affecting the resistance of a wire:

- The *material* that the wire is made from. Table 2.6.14 lists the resistance values of some materials, for the same length and cross-sectional area. This value depends on the number of free electrons that are available in the material.
- The *length* of the wire. In a longer wire, the electrons meet with more opposition because there are more atoms to collide with during their flow. Large resistors, such as those used in electric cookers or heaters, use long lengths of wire made from nichrome – long lengths are often coiled.

  In a variable resistor, the length of the wire included in the circuit can be changed. This idea is used in the volume control of radios and televisions.
- The *thickness* of the wire. In a thin wire it is harder for the electrons to push their way through so they experience more resistance. Also, there are fewer 'free' electrons in a thinner wire.

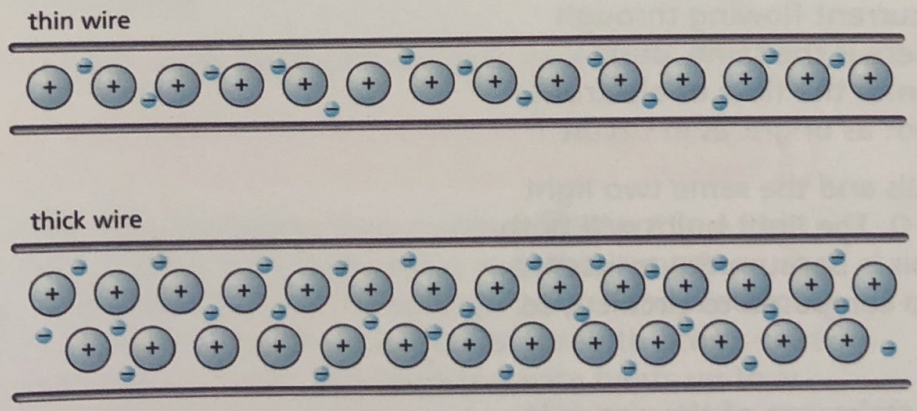


FIGURE 2.6.14d: Comparing thick and thin wires

5. Explain how the volume of a radio can be changed using a variable resistor.
6. Describe the type of wire you would choose in an overhead power cable.

FIGURE 2.6.14c: How does turning the knob affect the circuit inside the radio?

TABLE 2.6.14: Comparing the resistance of different materials

Material	Resistance value ($\Omega \times 10^{-8}$ m)
aluminium	2.82
copper	1.72
gold	2.44
nichrome	150
silver	1.59
tungsten	5.6
iron	9.71
platinum	0.11
rubber	100 000

Key vocabulary

resistor

variable resistor

filament

Explaining circuits using models

We are learning how to:

- Describe how the voltage, current and resistance are related in different circuits.
- Use a model to explain the relationship between voltage, current and resistance.

You have learned about what voltage, current and resistance are. Now you will see how they interact in a circuit. The 'rope model' is a useful analogy – it explains most features of current, voltage and resistance in circuits.

Relating voltage, current and resistance

The size of the voltage and the size of the resistance both determine how much current flows. Look at the three different circuits in Figure 2.6.15a.

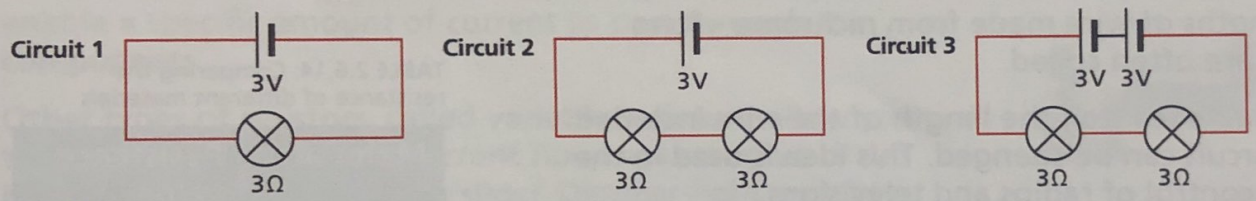


FIGURE 2.6.15a

In circuit 1, there is a voltage of 3 V and one light bulb of resistance 3 Ω.

In circuit 2, there are two identical light bulbs in series, providing twice as much resistance, but supplied with the same voltage as in circuit 1. The current flowing through the circuit is now less, because there is the same 'push' (voltage) but twice the opposition to the flow of electrons (resistance). The light bulbs are not as bright as in circuit 1.

In circuit 3, there are now two cells and the same two light bulbs, each with a resistance of 3 Ω. The light bulbs will both be just as bright as in circuit 1. This is because the resistance and the voltage are both doubled compared to circuit 1, so the current will be the same.

1. What is the voltage and the resistance of the circuit in Figure 2.6.15b?
2. Explain whether the light bulbs in Figure 2.6.15b are dimmer or brighter than in:

   a) circuit 1 **b)** circuit 2 **c)** circuit 3

   of Figure 2.6.15a.

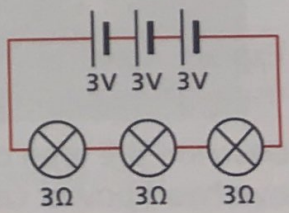


FIGURE 2.6.15b

Describing series and parallel circuits

We are learning how to:

- Understand how voltage and current vary in a series circuit.
- Understand how voltage and current vary in a parallel circuit.

The way in which components are arranged in a circuit can affect how well they work and how useful they are. The two arrangements are called series and parallel.

Series circuits

In a **series circuit**:

- All the components are connected, one after the other, in a complete loop of conducting wire.
- There are no **branches** in the circuit.
- There is only one path that the current can take.
- The voltage is shared between the components.

Figure 2.6.16a shows a series circuit with two light bulbs.

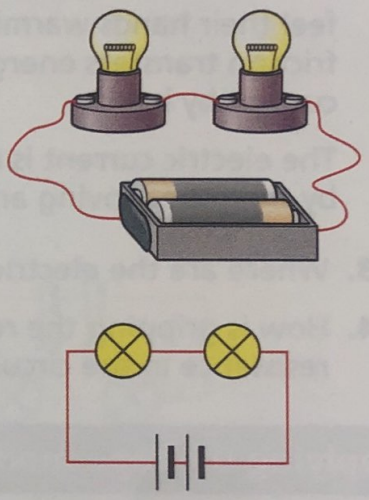


FIGURE 2.6.16a: How can you tell that the components in this circuit are connected in series?

1. What would happen to the components in a series circuit if one of the bulbs stopped working?
2. **a)** Draw a circuit diagram showing a motor, a light bulb and a buzzer in a series circuit.

   b) What would happen to the current in your circuit if the motor stopped working?
3. Draw two circuits – one with just one bulb, and the other with three identical bulbs in series. Both circuits should have just one cell of the same voltage. Compare:

   a) the voltage in each circuit

   b) the current in each circuit

   c) the brightness of the bulbs in each circuit.

Parallel circuits

In a **parallel circuit**:

- Each component is connected separately in its own loop between the two terminals of a cell or battery.

- There are different branches for the current to follow.
- The full voltage is supplied to each loop.
- The current from the battery is divided between the loops.

A parallel circuit is rather like separate series circuits connected to the same energy source.

The different components are connected by different wires. Therefore, if a bulb blows or is disconnected from one parallel wire, the components in the other branches keep working because they are still connected to the battery in a complete circuit.

If more bulbs are added in parallel, all the bulbs light up with the same brightness as before. There could be a hundred bulbs in parallel, all equally bright, and just as bright as if there were just one bulb. The battery, however, will not last as long!

4. a) Draw a parallel circuit with four bulbs.

b) Explain how this is different from a series circuit with four bulbs.

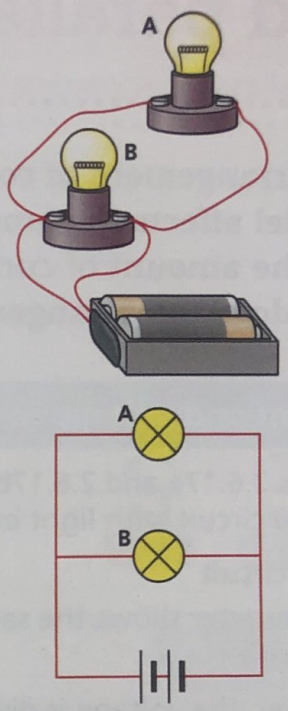


FIGURE 2.6.16b: What happens to bulb A in this parallel circuit if bulb B 'blows'?

Explaining series and parallel circuits

When two light bulbs are connected in series, the resistance in the circuit is increased compared to that with one light bulb. The thin (filament) wire in each light bulb has a high resistance. The increased resistance opposes the flow of current, so fewer electrons pass per second, transferring less energy. The light bulbs are therefore not as bright as in a circuit with the same voltage but only one bulb.

However, when two light bulbs are connected in parallel, each branch behaves like a separate circuit. The resistance in each branch is the same as if there were just one light bulb in the whole circuit. The same energy is transferred to each branch from the battery, so the bulbs light up with the same brightness as in the single-bulb circuit. The battery is, however, transferring twice the amount of energy to the bulbs and will run out faster than when in a series circuit.

5. Explain the advantages and disadvantages of arranging components in series or in parallel.

Did you know...?

Most circuits used are combinations of series and parallel parts. These are called series–parallel circuits.

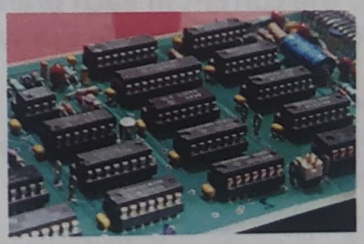


FIGURE 2.6.16c

Key vocabulary

series circuit

branch

parallel circuit