7. Sketch a distance–time graph for two horses moving across a 500 m field. One horse trots steadily across the field in 4 minutes. The other accelerates to a gallop, stops for 1 minute to eat grass and then gallops the rest of the way, reaching the far side after 3 minutes. [4]

8. Which of these statements is true about your weight and mass on a planet that has twice the gravitational field strength of Earth? [1]

   a) Weight is the same, mass is double.
   b) Weight and mass are both the same.
   c) Weight and mass are both double.
   d) Weight is double, mass is the same.

9. In which of these locations would the gravitational field be the strongest? [1]

   a) On the surface of a red giant star.
   b) On the Moon as it orbits the Earth's surface.
   c) At the edge of the Earth's atmosphere.
   d) On the Earth's surface.

10. Which of these statements would be true for a rocket taking off from a launch pad and accelerating towards space? [1]

   a) The forces on it are balanced.
   b) There will be a resultant force acting upwards.
   c) Whilst it's travelling vertically upwards it will not experience air resistance.
   d) Once it gets into orbit around the Earth, gravity will no longer act on it.

EXTEND. Questions 11–13

See how well you can understand and explain new ideas and evidence.

11. Which of these defines what the strength of the gravitational field on the surface of a planet depends on? [1]

   a) The mass and radius of the planet.
   b) The mass of the planet and its distance from the Sun.
   c) The shape and radius of the planet.
   d) The rotation speed of the planet.

12. Draw a diagram to show what would happen to a satellite if the Earth's gravity were suddenly turned off. [1]

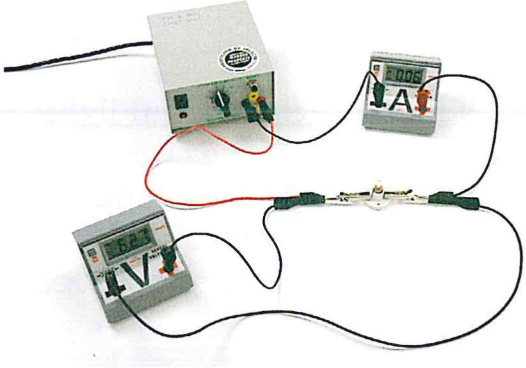
13. Scientists believe that there is a massive black hole at the centre of our galaxy, with a mass 30 billion times that of the Sun. Explain what evidence could suggest its existence.

   If a spacecraft set off in a straight line at a constant speed towards the black hole, what additional evidence would indicate the presence of the black hole?

   What challenges would the spacecraft face? [4]

In this chapter you will find out

Explaining electric circuits



- Components in an electric circuit provide opposition to the current, known as resistance, and transfer energy to the surroundings.
- Components in circuits can be arranged in series or in parallel. These arrangements have different effects on the voltage and current, and provide different applications.
- The current, voltage and resistance are related to each other.
- Models are a good way of explaining what happens in a circuit.

Current

- Current is a movement of electrons and is the same everywhere in a series circuit.
- Current depends on the 'push' given by the battery, known as the voltage.
- Current divides between loops in a parallel circuit and combines when loops meet.

Potential difference

- Voltage, or 'potential difference', is the amount of energy per unit of charge transferred through the electrical pathway.
- In a series circuit, voltage is shared between each component. In a parallel circuit, voltage is the same across each loop.

Electrostatic force

- Around a charged object, the electric field affects other charged objects, causing them to be attracted or repelled.
- The field strength decreases with distance.

Using models to explain current

Current is the rate of flow of charge (electrons) in the circuit, and is given the symbol *I*. It is measured by an **ammeter** in **amperes** (symbol A), after the French scientist André-Marie Ampère.

Models and analogies are often used to explain complex phenomena like current. One analogy is to compare electric current to water flowing in a stream. The charges are the water particles, and the current is the flowing stream.

Another analogy used to represent current is that of a convoy of coal trucks. The trucks represent the charged particles, the movement of the trucks represents the current, and the coal they carry represents the energy they transfer.

FIGURE 1.2.1c: In the analogies pictured in the photos, what represents the charge and what represents the current?

4. Using first the water analogy and then the coal-truck analogy, draw diagrams to show the difference between a low current and a high current.
5. Which analogy is better at explaining that current transfers energy to different components? Explain your answer.

Scientific explanation of current

When the battery is connected, the electrons in all parts of the wires within the circuit move at the same time, in the same direction and at the same rate. This movement constitutes the current. In this way, no matter where the components are in the circuit, they will all conduct at the same time – there is no delay because all the electrons in the circuit move simultaneously.

Current is not used up in the circuit. It has the same value before and after each component in the circuit.

6. Explain the strengths and limitations of the two analogies above, in light of the scientific explanation for current.
7. Explain why current is not used up in a circuit.

Did you know...?

A current of 1 amp means there are 6 250 000 000 000 000 000 electrons flowing past a point every second!

Know this vocabulary

component
electrical conductor
electrons
electrical insulator
current
ammeter
ampere

Figure 1.2.2c shows how the voltmeter must be connected *across* a component (here a bulb) to measure the difference in potential across the component. Voltage is also known as **potential difference**.

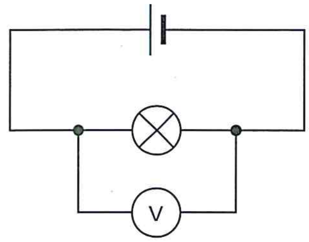


FIGURE 1.2.2c: Measuring the voltage across a bulb.

3. In which of the circuits in Figure 1.2.2b will the light bulb be the brighter? Explain your answer.
4. What might happen to a motor if it were connected to the 230 V mains electric supply rather than to a 12 V battery?

Using analogies to explain voltage

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

A high waterfall is also like a large voltage. It will transfer a lot of energy to the water (charge), making the river flow very fast (a large current). The difference in height makes the river flow. In a circuit, the difference in charge across the battery provides the push for the current.

FIGURE 1.2.2d: The difference in height makes the water move.

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

Did you know...?

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

Know this vocabulary

voltage
volt
voltmeter
potential difference

As the electrons move, they will collide with other particles in the metal structure. This is the cause of resistance in most ordinary metals. It is why even the best electrical conductors, like platinum, will have some resistance.

In an insulator, the electrons are more tightly bound to atoms than in a conductor; far fewer electrons are free to move and so there is insignificant current.

2. As an analogy of a circuit with resistance, 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.

Working out resistance

Resistance is measured with the unit **ohms** (Ω) and is represented by *R*. All the components in a circuit will have their own resistance. It is possible to investigate the relationship between voltage (*V*) across and current (*I*) through a component, as shown in Figure 1.2.3c.

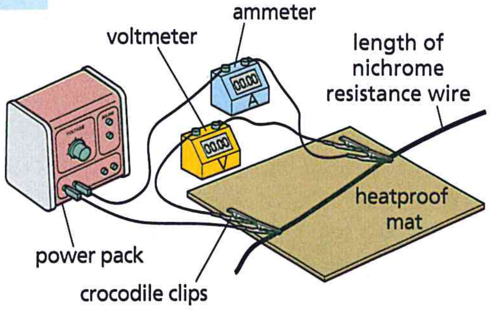


FIGURE 1.2.3c: As the voltage supplied is changed using the power pack, the current is measured using the ammeter. The resistance of the length of nichrome wire between the crocodile clips can then be determined.

The definition of resistance is:

$$\textbf{resistance} = \frac{\textbf{voltage}}{\textbf{current}} \qquad R = \frac{V}{I}$$

As resistance can be calculated from potential difference and current, we can use this to find out what the resistance of a component is. A team of students is investigating this to see if the resistance of a component stays the same.

Figure 1.2.3d shows the circuit they set up. The rectangle is the resistance – that's what they're trying to find the value of. They altered the settings on the power pack so that there was a range of voltages. Their results are shown in Table 1.2.3.

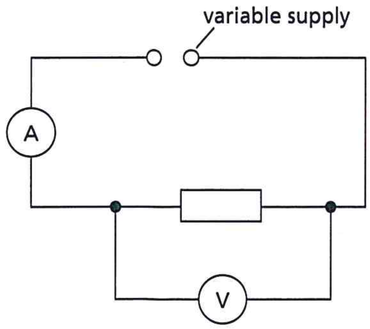


FIGURE 1.2.3d: Circuit to determine resistance.

TABLE 1.2.3: Investigation results.

Potential difference/V	Current/A
0.9	0.03
1.9	0.07
3.1	0.10
3.9	0.12
5.0	0.15
6.1	0.19

4. What calculation needs to be done on each pair of readings to find the resistance?
5. a) Calculate the resistance for each pair of readings.
   b) What do you notice about the values?

Know this vocabulary

resistance
free electron
ohm

- The full voltage is supplied to each loop.
- The current from the battery is divided between the loops.

Figure 1.2.4d shows a parallel circuit with two light bulbs.

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 loops 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, because the potential difference across each is the same (equal to the battery voltage).

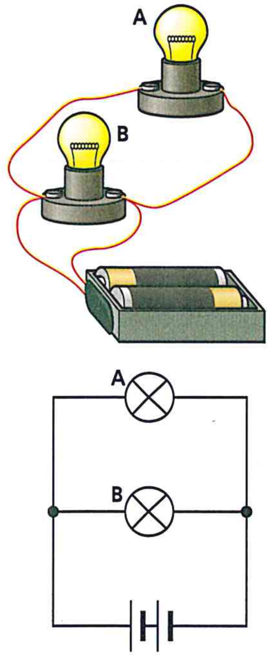


FIGURE 1.2.4d: What happens to bulb A in this parallel circuit if bulb B 'blows'?

3. What would happen to the components in a series circuit if one of the bulbs stopped working?
4. 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.
5. a) Draw a parallel circuit with four bulbs.
   b) Explain how this is different from a series circuit with four bulbs.

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 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 loop 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. There is the same current in each branch of the circuit, so the bulbs light up with the same brightness as in the single-bulb circuit. The energy stored in the battery will decrease twice as quickly and the battery will run out faster than in a series circuit.

6. 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.

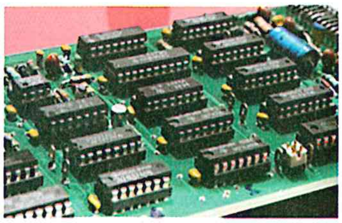


FIGURE 1.2.4e

Know this vocabulary

series circuit
parallel circuit

Selecting series or parallel circuits, according to application

Each type of circuit has advantages and disadvantages. These are summarised in Table 1.2.5.

	Advantages	Disadvantages
Series circuits	Simple to set up. Shares the voltage between the components, which is useful if the components need a lower voltage than the supply voltage.	If one component fails, the whole circuit stops working. If more components are added, each gets less voltage and so might not work as well.
Parallel circuits	If a component in one of the loops fails, the other loops keep functioning. Each loop gets the same voltage, so adding more loops doesn't mean other loops suffer a voltage drop.	More complicated to set up. Adding more loops doesn't reduce the voltage, so if components need a lower voltage they won't work.

TABLE 1.2.5

We can therefore decide which type of circuit to use in each situation.

3. Which kind of circuit would you use to supply 20 bulbs, each rated at 12 V, with a power of 240 V?

4. Which kind of circuit would you use for emergency lighting in a restaurant, running from a 12 V supply and powering 12 V bulbs?

Did you know...?

A wiring system that consists of wires arranged in complete loops around a building is called a ring main.

Mains supply is a supply of electricity to a building at the standard voltage for that area (230 V in the UK).

Household circuits

Figure 1.2.5c shows how the household electricity supply is connected in the UK. It is an arrangement known as the domestic **ring main**.

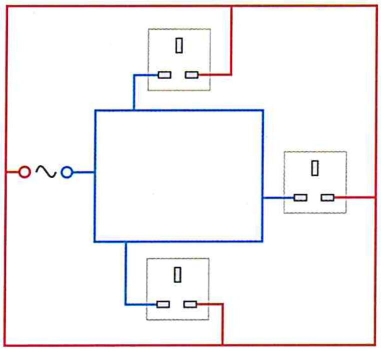


FIGURE 1.2.5c: Arrangement of sockets in a domestic ring main.

All the plug sockets in the ring main are connected in parallel, for the following reasons:

- If one of the electrical appliances should stop working, other appliances are not affected.
- The **mains supply** of 230 V is applied across all the sockets.
- Switches can be used to turn the current on and off within each branch.

5. Suggest disadvantages with this arrangement.

FIGURE 1.2.5d: Each socket has 230 V applied to it.

Know this vocabulary

ring main

mains supply

When two objects of the same material become charged they **repel** each other.

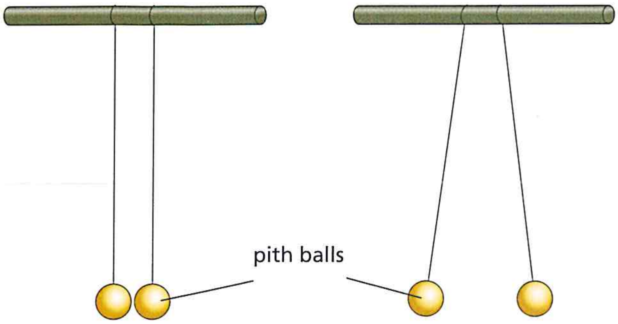


FIGURE 1.2.6c: Repulsion between two identical charged objects.

4. What could small pieces of dust and paper experience when a charged object is brought close?
5. How could you find out if two charged combs repel each other?

Factors affecting field strength

If you push a supermarket trolley you are applying a **contact force** because you are in contact with the object. Electrostatic force, however, like gravity, is a **non-contact force**. If we have an object with a static charge it produces an electric field. Fields are an important idea in science.

A charged balloon will produce an electric field – an area around the balloon in which anything affected by the charge will be subject to a force. If we were to use the charged balloon to attract bits of tissue paper, it would work only if the bits were within the field.

The strength of the field will depend on two things:

- the strength of the charge on the balloon;
- the distance between the balloon and the bits of paper.

6. What evidence supports the idea that static electricity exerts a non-contact force?
7. How could you show that the field around the balloon got weaker as the distance from the balloon increased?
8. There's another non-contact force we've met already, as well as electrostatic. What is it?
9. Some people don't like getting shocks from static charge. Suggest how they could reduce the likelihood of getting them.

Did you know...?

Some items of clothing become charged so easily that when you take them off, the cloth crackles and sparks as the charge escapes. This occurs in dry weather, and a dark room is needed to see the effect.

Know this vocabulary

charge
static electricity
field
attract
repel
contact force
non-contact force

Other materials behave differently. A polythene rod, for example, gains electrons when rubbed with a cloth. It becomes negatively charged and the cloth, which has lost electrons, becomes positively charged.

5. Describe what happens to a cloth when it is rubbed on a nylon rod.
6. Explain how different materials behave differently when rubbed with a cloth.

Charging by electron transfer

There are two types of static charge – negative and positive. Both types are produced in the same way – by transferring electrons. When something is charged up by friction, one material is rubbed against another. This results in some negatively charged electrons being transferred from one to the other.

Did you know...?

A Van de Graaff generator produces electricity by friction. The ones used in schools can produce 100 000 volts. Bigger Van de Graaff generators can exceed two million volts.

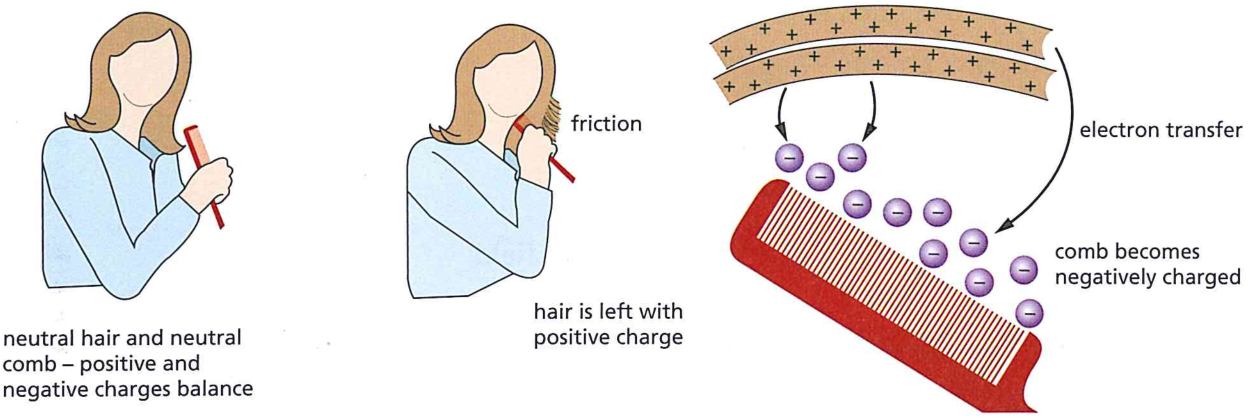


FIGURE 1.2.7c: Electrons are transferred when you comb your hair with a plastic comb.

This means that one material has lost electrons and doesn't have enough to balance out its positively charged protons. This material now has a positive charge. The other material has gained excess electrons so it has a negative charge.

For example, if you brush your hair vigorously with some types of plastic comb or brush, your hair becomes charged and so does the comb. In this case, electrons are being transferred from your hair to the comb. This means your hair is lacking electrons and has a positive charge. The comb has gained electrons and has a negative charge.

7. How can you tell that your hair has become charged?
8. How could you show that the comb has also become charged?
9. Neither your hair nor the comb will stay charged permanently. Using the idea of electron transfer, suggest what you think happens.

Know this vocabulary

electron
proton
charged up
negatively charged
positively charged

4. Describe how charged particles move when an object is put in an electric field.
5. Draw a labelled diagram, similar to Figure 1.2.8b, to show how a positively charged rod can attract a trickle of water.
6. Suggest why a metal rod is unlikely to be able to attract a trickle of water.

Loss of charge

Static charge depends on electrons being unable to flow into or out of an object. If a charged polythene rod is connected to a conductor, such as a wire, electrons will flow away from the rod. The rod loses its charge and becomes neutral.

Air is not a good conductor, but it can transfer some electrons, so charged objects gradually lose their charge. In wet weather, the water vapour in the air can transfer more electrons so charge is lost more quickly.

When a Van de Graaff generator is turned on, the globe becomes positively charged. If the charge builds up enough, the air can start to conduct. Sparks will jump across the gap to anything in good contact with the ground.

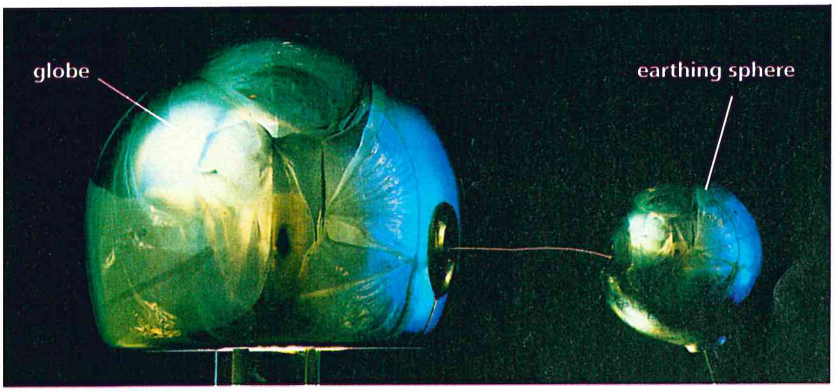


FIGURE 1.2.8c: A Van de Graaff generator and earthing sphere.

7. Explain why experiments with static electricity give better effects in dry weather.
8. a) Explain why, if someone is charged up by a Van de Graaff generator, their hairs rise up and spread out.
   b) Explain the process of discharging the globe of a Van de Graaff generator.
9. Suggest ways of avoiding getting electrostatic shocks in everyday life.

Did you know...?

An electrostatic field exists around a charged object in three dimensions – above and below it as well as on all sides.

Know this vocabulary

electric field
repel
attract

☐ Describe the relationship between current, voltage and resistance in a qualitative way.	☐ Use data to identify a pattern between current, voltage and resistance.	☐ Use data and the mathematical relationship between current, voltage and resistance to carry out calculations.
☐ Describe the effect that a charged object has on other charged objects.	☐ Explain what is meant by an electrostatic field.	☐ Suggest how objects may become electrostatically charged.
☐ Know the two types of static charge.	☐ Explain how electron transfer can result in either type of charge.	☐ Explain the operation of a circuit using the idea of electrons moving from the negative to the positive terminals of a power supply.
☐ Describe how friction between objects may cause electrostatic charge through the transfer of electrons.	☐ Explain various examples of electrostatic charge; use ideas of electron transfer to explain different effects.	☐ Explain why some electrostatic charge mechanisms are more effective than others.

EXTEND. Questions 7–8

See how well you can understand and explain new ideas and evidence.

7. Table 1.2.10 gives some data from an investigation comparing the different lengths of the same wire. The values of resistance have been calculated using $V/I = R$.

Plot a graph of the resistance against the length of the wire.

TABLE 1.2.10

Length of wire (cm)	Average voltage (V)	Average current (A)	Average resistance (Ω)
10	0.47	0.23	2.0
20	0.59	0.17	3.5
30	0.64	0.13	4.9
40	0.69	0.11	6.3
50	0.72	0.09	8.0
60	0.76	0.07	10.9
70	0.82	0.06	13.7

8. Jo is asked to construct a circuit with a battery and two parallel loops, each containing two bulbs in series. [4]

a) Draw the circuit diagram.

b) If the total resistance in the circuit is 20 ohms and the voltage supplied by the battery is 5 V, how much current will flow out of the battery?

c) Show on your diagram where an ammeter could be put in the circuit to check this.

d) Explain what will happen to the other bulbs if one of the bulbs should blow.