The National Strategies
Secondary

Explaining how electric circuits work

Science teaching unit

department for
children, schools and families

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Explaining how electric circuits work

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Contents

Explaining how electric circuits work

Background

This teaching sequence is designed for the early part of Key Stage 3. It links to the Secondary National Strategy Framework for science yearly learning objectives and provides coverage of parts of the QCA Programme of Study for science. The overall aim of the sequence is for pupils to develop a *meaningful understanding* of a scientific model so that they are able to explain the working of electric circuits and can apply their knowledge to a range of simple series and parallel circuits. This aim is addressed through interactive teaching approaches where links between subject matter are explored and established through appropriate talk between teacher and pupils, and amongst pupils.

Teaching design principles

The design of this sequence is based upon a number of key principles. These are listed below:

Working on knowledge

The sequence involves:

- probing, and explicitly working from, pupils' starting ideas about electric circuits;
- introducing and helping pupils understand a scientific electric circuit model;
- using that model to account for observations with a range of simple series and parallel circuits.

Teaching approach

The sequence involves:

- introducing an analogy (the 'rope loop'), which makes links to pupils' existing ideas, to develop the scientific electric circuit model;
- using the same analogy systematically throughout the sequence to support the development and understanding of the scientific electric circuit model;
- differentiating explicitly between the scientific electric circuit model, which is the central teaching goal for this sequence, and the teaching analogy which is used to help pupils achieve that goal;
- providing explicit opportunities for Assessment for Learning (AfL) through a series of diagnostic questions;
- prompting pupils to reflect on their overall progress in learning from the beginning to the end of the sequence.

Mode of interaction

The sequence has been designed to maximise pupils' learning by incorporating various interactions between the teacher and pupils.

It involves:

- using different *modes of interaction* between teacher and pupils according to different teaching purposes;
- providing opportunities for pupil–pupil talk in pairs and small groups.

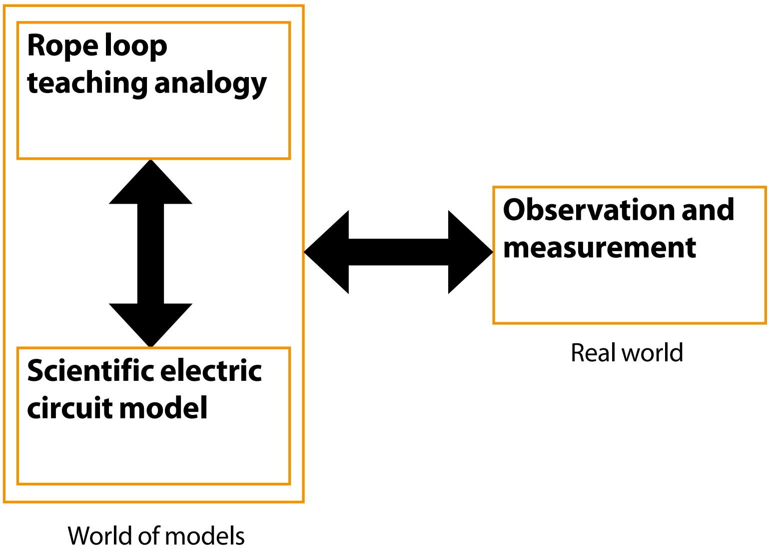
How science works

The sequence involves:

- Developing the general idea of a scientific model as a device for explaining or accounting for a range of phenomena, in this case a range of different electric circuits.

The world of models and the real world

Overall, the teaching approach involves moving between the world of models, including both the scientific electric circuit model and the rope loop teaching analogy, and the real world of observation and measurement.



Pupils' starting points

By the time pupils begin their science lessons in Key Stage 3, they will have experienced some teaching about electric circuits.

Most pupils will:

1. have had the opportunity to build some simple circuits;
2. know that a complete circuit is needed to make a bulb light up;
3. know that adding batteries makes the bulb brighter;
4. know that adding bulbs in series makes them dimmer;
5. have been introduced to circuit diagrams.

What the pupils will NOT have is a coherent understanding of HOW the electric circuit works. The overall aim for this sequence of lessons is therefore to introduce a scientific model that is good enough to explain WHY things happen as circuit components (batteries and bulbs) are changed around.

Explaining how circuits work: Overview

Lift-off activity - Probing pupils' starting ideas: Diagnostic questions

Developing the scientific model - from rope loops to electric circuits: Exploring models.

Developing the scientific model - Rope loops, electric circuits and electric currents: groupwork and diagnostic questions

Explaining that circuit - Electric currents, Bulbs and batteries: diagnostic questions and group activity

Bulbs in parallel: pupil challenge and diagnostic questions

Lift-off activity: 'Probing pupils' starting ideas'

Teaching 'story'

The teaching sequence 'lifts off' with an activity to prompt the pupils to talk through their existing ideas about electric circuits. Pupils discuss their ideas in pairs and make a record of their thoughts.

It would be a good idea for this activity to be completed at the end of the lesson prior to starting the work on electricity. This way the teacher has the opportunity to read through and digest the pupils' ideas before beginning the sequence.

Activity: Thinking and talking about electric circuits

This activity involves the diagnostic question 'Bulb light'.

Teaching objectives

- To encourage pupils to discuss their ideas about how electric circuits work, thereby motivating them to start thinking about the topic.
- To collect Assessment for Learning (AfL) baseline information about the pupils' initial thinking about the subject.

Learning outcomes

By the end of this activity, pupils will be able to:

- identify their own starting ideas about electric circuits.

Mode of interaction

Pairs of pupils discussing and putting forward their ideas about how electric circuits work: INTERACTIVE/DIALOGIC

DIALOGIC HOTSPOT

What happens during this activity

The teacher first of all demonstrates the lighting of a bulb in a simple circuit: no surprises for the pupils here, as the bulb lights.

Pupils then work in pairs on the diagnostic question 'Bulb light' and are encouraged to talk and think through their ideas before writing down their answers, including as much detail as possible. If a pair of pupils disagrees about what is happening in the circuit, ask them to record their ideas separately.

On completion of the answers, each pair of pupils places their sheet in a 'special' envelope, which will be returned at the end of the electricity lessons. The teacher needs to look through the responses so:

> *'Don't stick the envelopes down just yet. I want to read through your ideas then seal the envelopes myself.'*

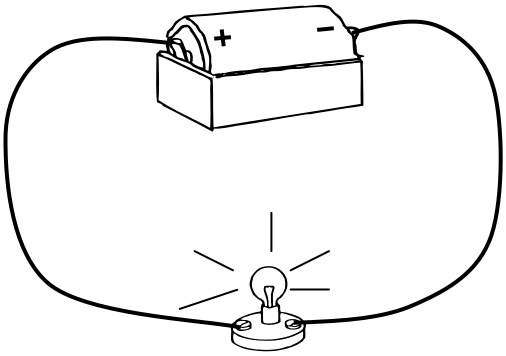
Pupils' responses to 'Bulb light'

Experience shows that there are a limited number of 'alternative conceptions' which are likely to emerge from this activity.

1. **What flows around the circuit:** pupils are likely to have a strong sense of 'something' moving around the circuit and usually refer to this as 'electricity'. In fact, the term 'electricity' has no specific meaning according to the scientific point of view. We can refer correctly to the *electric current* around the circuit or *electric charges* moving around the circuit, but in scientific terms it is meaningless to refer to *electricity* flowing around the circuit. An experienced teacher friend insists that the only time pupils should use the word 'electricity' is when writing down the title for this new section of work.
2. **From the battery:** pupils often believe that the battery acts as the *source* of whatever it is that flows around the circuit. Thus the 'electric current' or 'electric charge' or 'electricity' is *made* in the battery and flows out of the battery and around the circuit to make the bulb light. The correct scientific view is that the charges (or electrons) already exist in the wires and are simply set in motion by the battery, in all parts of the circuit at the same time.
3. **Used up/conserved:** pupils have the intuitive idea that something must be getting 'used up' in an electric circuit. The problem is that many suggest it is the electric current which gets used up. In other words, pupils will argue that, '*the electric current is less after the bulb than it is before it*'. The correct scientific view is that the electric current is conserved, while the battery energy store is gradually depleted as energy is *transferred* at the bulb to the surroundings through heating and lighting.
4. **Clashing currents:** some pupils may argue that the bulb lights when electric currents flow in opposite directions from either side of the battery, to meet and 'clash' in the bulb, thus making it light. In a simple circuit the electric current actually flows in one direction only. An example of how pupils' starting ideas can be gathered is shown in accompanying dvd.

Bulb light

This is a very simple electric circuit.



1. Explain in as much detail as you can (thinking about both battery and bulb) why you think the bulb lights.

2. a) How could you change the circuit to make the bulb brighter?

   b) Explain why this would work

3. If the circuit is left on, why will the battery go FLAT eventually?

Lesson 1: Developing the scientific model – from rope loops to electric circuits

Teaching 'story'

Having had the chance to talk through their ideas about electric circuits with a partner and to write them down (in response to the diagnostic question 'Bulb light'), the pupils are now shown a BIG electric circuit. This BIG circuit is used to challenge the pupils' ideas about electric circuits.

Activity 1.1: A BIG circuit

A BIG circuit consists of a battery and a bulb. The battery, or power supply, is at the front of the classroom, the bulb at the back and the connecting wires run right round the perimeter.

Click here to see a video clip of this

Teaching objectives

- To enable pupils to recognise the questions involved in coming to understand how an electric circuit works.
- To probe pupils' existing ideas about how an electric circuit works.
- To set the target of developing a scientific model to explain how an electric circuit works.

Learning outcomes

By the end of this activity, pupils will be able to:

- recognise their own and others' initial ideas about electric circuits;
- know that the bulb in a BIG circuit lights immediately the circuit is completed.

What to prepare

- A 24W/12V bulb
- Two very long insulated wires
- A 12V power supply.

The BIG circuit consists of a 12-volt power supply and a large bulb (12 volt/24watt) set up with insulated connecting wire running round the perimeter of the room. It is a good idea to tape the wire to the walls of the room and to mark it with 'BIG CIRCUIT' labels all the way around.

Mode of interaction

The teacher works with the pupils through an INTERACTIVE/DIALOGIC approach, encouraging them to suggest their ideas, and making clear their reasons, about what will happen when the BIG circuit is switched on.

DIALOGIC HOTSPOT

What happens during this activity

The BIG circuit is set up around the room. Have the room in darkness to add to the dramatic effect when switching it on, and to ensure that the bulb can be seen easily. The teacher collects the class together and points out the BIG circuit around the room. The questions to be posed now are along the lines of:

> *'What will happen when the switch is closed?'*
> *'Will the bulb light straight away?'*
> *'Why do you think that there will be a short delay?'*
> *'Anybody agree with Julia about that?'*

At this point the teacher is simply collecting ideas with a non-evaluative (INTERACTIVE/DIALOGIC) approach. The teacher also makes links to the pupils' responses to the 'Bulb light' diagnostic question:

> *'So you think that the electricity leaves the battery and then travels all the way round to the bulb… who agrees with that?… who wrote that down on their sheet inside the envelope?'*

Experience has shown that the class is often divided in predicting what will happen when the BIG circuit is completed. Some pupils think that the bulb will light immediately; others predict that there will be a short delay, '*because the electricity has a long way to travel*'.

The teacher, with a pause for dramatic effect, eventually throws the switch. The bulb lights… immediately.

Teaching 'story'

When the BIG circuit is completed, about half of the class will be happy with their correct prediction (the bulb lights immediately); the rest will be left feeling somewhat surprised at what they have seen. It is likely that NEITHER set of pupils will be able to offer an EXPLANATION as to why the bulb lights as soon as the switch is thrown. This is the next teaching step:

What we need to do now is to try to figure out what is happening in the BIG circuit so that the bulb lights straight away. Although we cannot see what is happening inside the wires, scientists have a scientific electric circuit model to explain what is going on. Our aim is to try to understand this model'.

Activity 1.2: The rope loop

The rope loop is a simple but powerful teaching analogy which is used to introduce and develop the scientific model for the electric circuit. The word 'analogy' may or may not be used in class. You may prefer to talk about the 'rope loop picture', which helps understanding of the 'scientific model' of electric circuits.

Click here to see a video clip of this

Teaching objectives

- To introduce the rope loop analogy for a simple electric circuit.
- To use the analogy to start building a scientific electric circuit model.
- To challenge some of the pupils' alternative ideas which have become apparent through the diagnostic question 'Bulb light' and the 'BIG circuit' demonstration.

Learning outcomes

By the end of this activity, pupils will be able to:

- make links between a simple electric circuit and the rope loop analogy;
- explain that charges originate in the wires of a simple circuit;
- explain that the battery provides a push to set the charges in motion;
- explain that the flow of charges is an electric current;
- explain that energy is transferred in a simple circuit where the moving charges encounter resistance, such as that provided by a bulb;
- explain that charges are not 'used up' in the circuit.

What to prepare

A long length of rope is needed, which can be passed in a BIG loop (prompting links to the BIG circuit) around all of the members of the class. Lightweight (4–6 mm diameter) rope used by climbers is ideal. If the rope is too heavy the frictional forces are too big and it is very difficult to get the rope moving across thirty pairs of fingers.

Mode of interaction

The teacher takes an INTERACTIVE/ AUTHORITATIVE approach in introducing the rope loop analogy: asking lots of questions, making links between the rope loop and electric circuit, keeping the pupils involved.

What happens during this activity

The class stands in a BIG circle in the classroom or in some other large space such as the school hall or playground. The rope loop is then passed out around the pupils with each pupil holding it lightly as it passes through their curled fingers. The teacher sets the rope moving, pulling it through with one hand and passing it out with the other. As the rope circulates, the teacher asks one pupil at the other side of the 'circuit' to grip it a little more tightly with their fingers.

It is most effective to engage pupils in this activity with little or no introduction, then at this point to pose the question:

> *'What has this to do with electric circuits?'*

Questions and answers will lead quickly to the following basic ideas:

- The battery is represented by the teacher pulling the rope round with one hand and feeding it out through the other, thereby setting the rope in motion.
- The bulb is represented by the pupil gripping the rope.
- The electric current, or moving charges, are represented by the rope moving around.

Note: At this point a picture needs to be developed of 'something' moving through the wires when the circuit is complete. You might refer to this 'something' as a flow of 'charges', which are atom-sized particles already existing in the wires. You might wish to refer to a flow of 'electrons'.

- Energy is introduced to the rope loop circuit (energy IN) by the teacher and this energy is transferred to the surroundings (energy OUT) through the pupil's hands. In just the same way, the battery is the source of energy for the electric circuit and energy is transferred to the surroundings at the bulb.

  'Now Anita can feel her hands warming up as she grips the rope more tightly. Her hands are providing a friction force against the movement of the rope and this warms them up. Where does the energy come from to heat up Anita's hands? Yes! From me. I am doing all of the work to keep the rope moving. Where does the energy come from in the electric circuit? Yes! From the battery.'

- Energy is transferred in the rope loop circuit where there is a *resistance* to it moving. In just the same way the bulb in an electric circuit provides a *resistance* to the flow of the electric current.

The rope loop can now be used to challenge some of the pupils' initial ideas which have become apparent through the 'Bulb Light' and 'Big Circuit' activities:

Initial ideas	Scientific electric circuit model	Rope loop picture
The charges originate in the battery	The charges do not come from the battery, they originate in the circuit	*'Now look… it's very clear. The rope loop is not coming from me. I'm just making it move around. In the same way the charges are not made in the battery. They are already there in the wires and the battery simply makes them move round. The moving charges make an electric current.'*
The charges travel around the circuit from the battery creating a delay in the BIG circuit	The charges all around the circuit are set in motion virtually instantaneously and all together, there is no delay in charges travelling to the bulb.	*'Just watch! As soon as I pull on the rope, it starts moving all around the circuit. It's just the same in the electric circuit. As soon as the circuit is completed the charges start moving at the same time in all parts. That's why the BIG circuit bulb lights straight away.'*

Initial ideas	Scientific electric circuit model	Rope loop picture
The electric current gets used up while making the bulb work	The electric current does not get used up. The charges flow round and there is an energy transfer at the bulb, but the charges themselves keep going; they are conserved whilst energy is transferred.	*'Now then, what's getting used up here? Is it the electric current? Is it the moving rope? Does the rope suddenly disappear? No, of course not. What's happening here is that I'm getting more tired as my energy levels go down, as I keep the rope moving and Anita's hands are warmed up.'*
Clashing currents	The electric current flows in one direction, continuously around the circuit.	*'Some people thought that the electric current leaves both ends of the battery, but the right idea is that it just moves around in one direction like the rope.'*

Teaching 'story'

We are very keen on the rope loop analogy, especially when used in conjunction with the BIG circuit. Why is this? Firstly, the rope loop analogy fits easily onto the BIG circuit and provides a very clear image of a loop of charges, which originate in the wires and circulate when set in motion by the battery. It becomes clear, with the rope loop in mind, that the bulb in the BIG circuit will light immediately. We are convinced that this simple model of a loop of charges set in motion by the battery and transferring energy at the bulb offers an excellent starting point in the study of electricity. Furthermore, and as will become apparent, the rope loop analogy can be applied to a full range of series and parallel circuits.

Activity 1.3: Diagnostic question: Rope loops and electric circuits

The pupils work individually or in pairs to complete the diagnostic question 'Rope loops and electric circuits'.

Teaching objective

- To check pupils' understanding of the rope loop analogy for the scientific electric circuit model and the relationship between the two.

Learning outcomes

By the end of this activity, pupils will be able to:

- make links between a simple electric circuit and the rope loop analogy;
- explain that charges originate in the wires of a simple circuit;

- explain that the battery provides a push to set the charges in motion;
- explain that the flow of charges is an electric current;
- explain that energy is transferred in a simple circuit where the moving charges encounter resistance;
- explain that charges are not 'used up' in the circuit.

What to prepare

- Copies of the diagnostic question: 'Rope loops and electric circuits'.

Mode of interaction

The sheet might be completed individually or in pairs with the pupils focusing on the correct scientific point of view: INTERACTIVE/AUTHORITATIVE.

What happens during this activity

The pupils work individually or in pairs to complete the diagnostic question 'Rope loops and electric circuits'.

Teaching 'story'

The key idea for the pupils to understand at this point in the lesson sequence is that the electric circuit consists of a loop of charges circulating and transferring energy. The battery provides the 'push' to set the charges in motion and energy is transferred to the surroundings at the bulb.

And with a little more detail for the teacher

As the charges (or electrons) move around the circuit, they are constantly colliding with the fixed array of ions in the wire through which they pass. However, in the bulb the geometry (very small cross-sectional area) and internal structure (the layout of the atoms) of the filament wire combine to make it particularly difficult for the charges to pass through. As the moving charges collide with the fixed ions of the filament, the ions are made to vibrate more and the filament heats up. The filament wire thus provides a high resistance to the passage of the charges.

Rope loops and electric circuits

Fill in the spaces using the following words in the correct places:

BATTERY, BULB, ELECTRIC CURRENT, ENERGY, RESISTANCE

1. The teacher is like the ____________________ in the electric circuit.
2. The rope is like the ____________________ in the electric circuit.
3. The pupil gripping the rope is like the ____________________ in the electric circuit.
4. The teacher provides the ____________________ to keep the rope moving in the same way that the battery provides the energy in the circuit.
5. Just like the pupil's hands gripping the rope, the bulb provides a ____________________ against the flow of the electric current.

Lesson 2: Developing the scientific model – rope loops, electric circuits and electric currents

Teaching 'story'

In this first activity of the lesson the pupils have the opportunity to talk through for themselves how the rope loop picture and corresponding scientific electric circuit model can be applied to three simple circuits.

Activity 2.1: Building and explaining circuits

Here the pupils work in groups of four to build some simple circuits, to observe what happens in terms of bulb brightness, to model what happens with a rope loop and to develop explanations in terms of the scientific electric circuit model.

Teaching objectives

- For pupils to use the rope loop analogy and the scientific electric circuit model to account for the working of three simple circuits.
- For pupils to develop their understanding of the scientific electric circuit model.

Learning outcomes

By the end of this activity, most pupils will be able to:

- explain the working of a 1 battery and 1 bulb circuit in terms of the rope loop analogy and the scientific electric circuit model;
- explain the working of a 2 batteries and 1 bulb circuit in terms of the rope loop analogy and the scientific electric circuit model;
- explain the working of a 1 battery and 2 bulbs circuit in terms of the rope loop analogy and the scientific electric circuit model.

What to prepare

- Electric circuit kit (see worksheet: Building and explaining circuits).
- A rope loop for each group. This is a smaller rope loop to be used by each group of four pupils. The rope loop is used here as a tool to support talking and thinking.
- Worksheet: Building and explaining circuits.

What happens during this activity

This activity involves both groupwork and a plenary session.

Groupwork

The pupils work in groups of four and each group is supplied with components to build the three specified circuits (1 battery/1 bulb; 2 batteries/1 bulb; 1 battery/2 bulbs) and a rope loop. For each circuit, the group is asked to:

- make a note of the brightness of the bulb;
- model the behaviour of the circuit with the rope loop: here the students are extending the application of the rope loop analogy;
- explain the bulb brightness in terms of the scientific electric circuit model.

Mode of interaction

Groupwork
Groups of pupils talk through explanations for the circuits focusing on the correct scientific point of view: INTERACTIVE/AUTHORITATIVE

Plenary

When the groups have finished they report back on their findings. Here the teacher focuses attention on the explanation for the behaviour of each circuit. The pupils should be encouraged to refer to the rope loop analogy and the scientific electric circuit model and to move towards explanations along the lines of:

1 battery and 1 bulb

Bulb: NORMAL

Rope: NORMAL

> *'The battery provides a push to set the charges moving around the circuit. It's just like pulling the rope around. As the charges pass through the bulb there is a greater resistance (just like holding on tightly to the rope) and energy is transferred to the surroundings as the bulb heats up.'*

2 batteries and 1 bulb

Bulb: BRIGHT

Rope: FAST

> *'With 2 batteries there is a bigger push. It's like having 2 people pull the rope around. The rope goes round more quickly and the person's hands are heated up more. It's the same with the circuit, there is a bigger electric current with 2 batteries, as the charges move around more quickly and bulb lights more brightly.'*

1 battery and 2 bulbs

Bulbs: DIM

Rope: SLOW

> *'Having 2 bulbs is just like having 2 people gripping the rope, it slows everything down so that the rope goes round more slowly and the hands are heated up less. It's the same with the electric circuit, with 2 bulbs there is more resistance and a smaller electric current as the charges move around more slowly. So both bulbs are dimmer.'*

Mode of interaction

Whole-class plenary
Presentations by pupils with questions from teacher to establish the correct science point of view: INTERACTIVE/ AUTHORITATIVE.

Resistance

At this point it would be a good idea to say a little more about how a bulb provides resistance in an electric circuit. Many pupils will have little idea about the actual structure of the bulb, which consists of two terminals with a very fine, coiled filament in between. This can be shown with a clear diagram or picture on the whiteboard. It is the fine filament of the bulb which provides the resistance to the flow of charge.

> *'The filament of the bulb is made of very fine wire and it is difficult for the charges to pass through it, just as it is difficult for the rope to pass through the place where it is being gripped. We say that the bulb provides a resistance to the flow of the electric current. The bigger the resistance, the smaller the current.'*

Teaching 'story'

By the end of this plenary session, a strong picture should be emerging of an electric circuit as simply a loop of charge set into motion by the battery and transferring energy at the bulb where there is resistance.

Adding a second battery gives a bigger push, the charges move round more quickly, there is a bigger electric current, and the bulb is brighter. Adding a second bulb gives a bigger resistance, the charges move round more slowly, there is a smaller electric current, and the bulbs are dimmer.

Attention is now turned to measuring electric currents.

Activity 2.2: Measuring electric currents

This activity follows on directly from the preceding activity, which involved building circuits to produce a big electric current (with 2 batteries) and a small electric current (with 2 bulbs). The question now is: 'How can we measure the size of the electric current?'

Teaching objectives

- To introduce the measurement of electric current in terms of the amount of charge passing a point per second.
- To demonstrate how an ammeter is used to measure electric currents.

Learning outcomes

By the end of this activity, pupils will be able to:

- explain how electric currents are measured in terms of the amount of charge passing a point each second;
- identify the ampere (A) as the unit of current;
- use an ammeter to measure an electric current in a simple circuit.

What to prepare

- The demonstration BIG rope loop
- A demonstration electric circuit with power supply (0–12V), bulb (24W, 12V) and demonstration ammeter.

Mode of interaction

**Presentation/Demonstration
Here the teacher takes INTERACTIVE/ AUTHORITATIVE and NON-INTERACTIVE/ AUTHORITATIVE approaches as they introduce the key concept of electric current and demonstrate how to use an ammeter.**

What happens during this activity

This activity starts with the teacher demonstrating ideas with the rope loop and moves on to measuring the electric current in a circuit.

Part 1: Teacher demonstrates with a rope loop

Start with the BIG rope loop. With 2 'batteries' and 1 bulb (2 people pulling and pushing) the rope circulates quickly. With 1 battery and 2 'bulbs' (2 people gripping) the rope is slowed down. There is clearly a difference between these two circuits: in the first the bulb is bright in and the second the bulb is dim. Pose the question:

'Thinking about the rope loop, what might we measure to show the difference between the two cases? Watch the rope travel round. What could we measure to show the difference?'

An obvious measurement to make is:

'How much rope passes any point in the circuit in a fixed interval of time? Look! In the case of the first circuit a LOT of rope passes through each second. In the second circuit the rope slows down and less rope passes through.'

You might use a stop clock to count out 5 second intervals of time and roughly measure how much rope goes past a particular point in the circuit. You could mark off equal lengths with ribbons (yellow) on one of the demonstration ropes to make this as clear as possible.

What can be said about the amount of rope passing any point in the same circuit? The amount of rope passing through must be the same all around the circuit.

*'We're not losing any rope. We're not gaining any rope.
It's moving around at the same speed.'*

This the first move towards the idea of conservation of charge/current. As was pointed out earlier, the idea of the 'current getting used up' is a common misconception which we are addressing here directly.

Part 2: Teacher demonstrates with an electric circuit

The teacher now turns attention back to a simple electric circuit consisting of a power supply and bulb. In an electric circuit we don't measure how much rope is passing, but how much charge is passing. The amount of charge, or number of charges, passing any point in a circuit, each second, is a measure of the electric current.

Electric current = amount of charge passing a point per second.

The instrument used to measure the size of the electric current is called an ammeter. The reading on the ammeter (in ampere) tells us how much charge is passing each second.

The unit of electric current is the **ampere**

The symbol for the ampere is **A**

And with a little more detail for the teacher

When an ammeter is used to measure the size of an electric current, the reading from the meter is in units of ampere.

A steady electric current of 1.0 ampere means that one coulomb of charge is passing per second.

What does this mean? How many electrons make up one coulomb's worth of charge? Since the charge on one electron is 1.6×10^{19} coulomb, then there must be about 6×10^{18} electrons (6 million, million, million!) in one coulomb of charge.

When thinking about electric currents, the picture is thus one of huge numbers of electrons drifting around the circuit at a rather sedate pace!

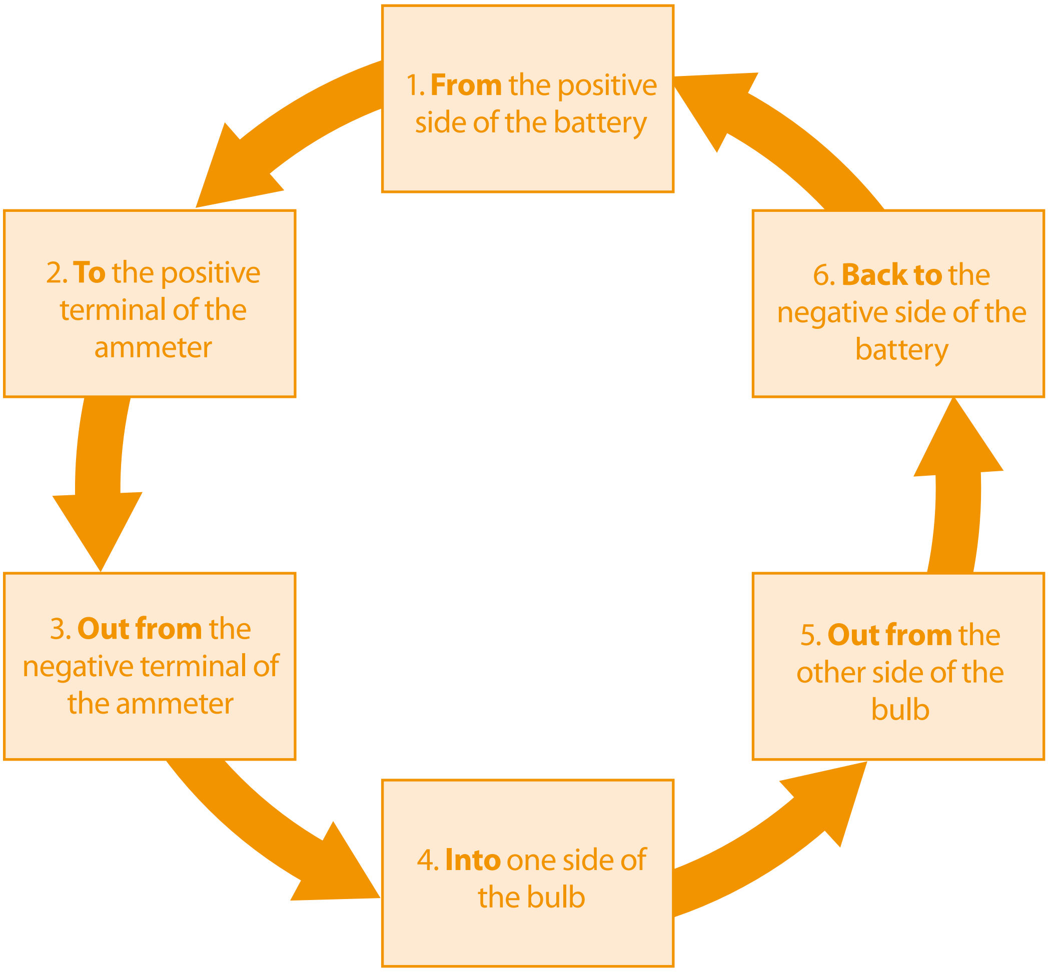
Part 3: The teacher demonstrates the connection of an ammeter

The teacher now demonstrates how the ammeter is connected into an electric circuit to measure the current:

Step 1: Switch off the circuit.

Step 2: Make a gap in the circuit where the current is to be measured.

Step 3: Connect the ammeter into the circuit the 'right way round'. The ammeter has a positive terminal and a negative terminal. The positive terminal of the ammeter must be connected to the positive side of the supply.



Note: Switch on and the ammeter gives us the current reading. Every time you use an ammeter follow this same procedure: make the circuit; make a gap in the circuit; be careful to connect the ammeter the right way round.

Emphasising the point of making a gap in the circuit and placing the ammeter in the gap helps to promote an understanding of electric current measurement. All of the charges flowing around the circuit must pass through the ammeter. *All* of the passing charges are *counted* in the ammeter.

In order that pupils can easily see how the ammeter is connected, this first measurement should be made with a good-sized demonstration meter. After the first reading has been taken, look to another point in the circuit and ask the class to *predict* the reading at this second point. There should be no hesitation that the reading will be the same: if there are any doubts, go back to the rope loop. Ask a pupil to take the second current reading with the ammeter. It is the same as the first.

The current is the same all around this simple circuit.

Conservation of electric currents: they really don't get used up!

The point has already been made that electric currents 'do not get used up'. In a simple circuit with one battery and one bulb, the size of the electric current is the same all around the circuit.

If it is 0.75 ampere before the bulb, it is 0.75 ampere after the bulb,

and 0.75 ampere through the battery and bulb.

In other words, 0.75 coulombs of charge pass each point in the circuit every second. There are no 'side-paths' down which the charges can pass and the charges themselves cannot just 'disappear'.

A bit of history

There is an opportunity here to place this work on electric circuits in a social/historical context with the pupils finding out more about the life and times of **André-Marie Ampère**. Ampère (1775 –1836), was a French physicist who is generally credited as being one of the main discoverers of electromagnetism and, as we have seen, the unit of measurement of electric current, the ampere, is named after him.

Activity 2.3: Diagnostic question: Electric current

The pupils work individually or in pairs to complete the diagnostic question 'Electric current'.

Teaching objective

- To check pupils' understanding that the electric current is the same all around the circuit.

Learning outcomes

By the end of this activity, pupils will be able to:

- recognise that the current is the same all around a simple electric circuit.

What to prepare

- Copies of the diagnostic question: 'Electric current'.

Mode of interaction

The question might be completed individually or in pairs with pupils focusing on the correct science point of view: INTERACTIVE/AUTHORITATIVE.

Correct answer: Box 3 'There is an electric current through one wire to the bulb. It passes through the bulb and back to the battery. The current in the other wire is **the same size.**

Building and explaining circuits

1 battery and 1 bulb

How bright is the bulb? DIM/NORMAL/BRIGHT: ____________________

How does the rope move round? SLOW/NORMAL/FAST: ____________________

Explain why the bulb lights.

____

____

____

2 batteries and 1 bulb

How bright is the bulb? DIM/NORMAL/BRIGHT: ____________________

How does the rope move round? SLOW/NORMAL/FAST: ____________________

Explain why the bulb is bright.

____

____

____

1 battery and 2 bulbs

How bright are the bulbs? DIM/NORMAL/BRIGHT: ____________________

How does the rope move round? SLOW/NORMAL/FAST: ____________________

Explain why the bulbs are dim.

____

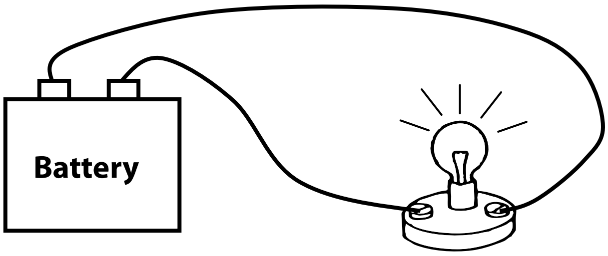
____

____

Electric current

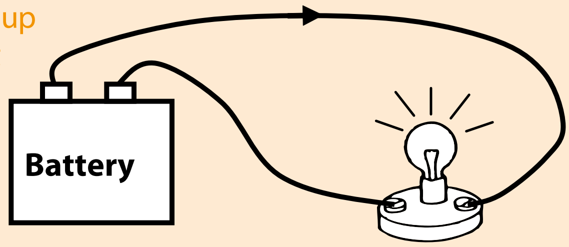
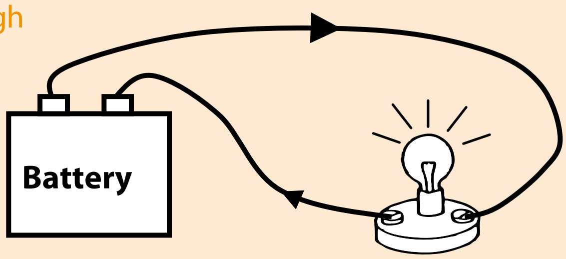
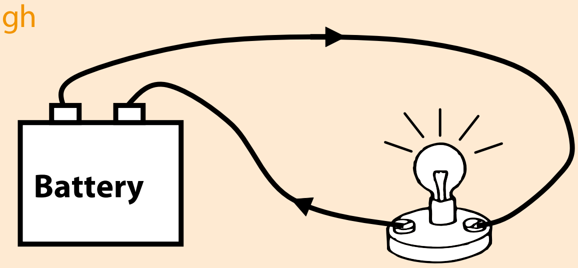
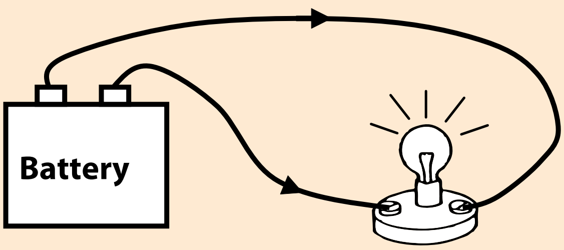
A bulb is connected to a battery.

The bulb is lit.



Which of the following best describes the **electric current** in this circuit?

Tick ONE box

☐	There is an electric current through one wire to the bulb. It is all used up in the bulb. So there is no current in the other wire.	
☐	There is an electric current through one wire to the bulb. **Some** of it is used up in the bulb. So there is a **smaller current** in the other wire.	
☐	There is an electric current through one wire to the bulb. It passes through the bulb and back to the battery. The current in the other wire is **the same size**.	
☐	There are **two** electric currents from the battery to the bulb. They **meet** at the bulb and this is what makes it light.	

Lesson 3: Explain that circuit – electric currents, bulbs and batteries

Teaching 'story'

The pupils now have the opportunity to make some measurements of currents in some simple circuits when the overall push (number of batteries) and total resistance (number of bulbs) are changed. The challenge is then to interpret these measurements in terms of the pupils' developing understanding of the scientific electric circuit model. Some pupils may wish to use a rope loop in thinking through their explanations; others will be happy to focus purely on the scientific model.

The first activity provides practical confirmation that current is conserved in a simple circuit.

Activity 3.1: Same all around!

In this activity pairs of pupils make current measurements to show that the electric current does not get used up in a simple circuit.

Teaching objective

- For pupils to gain practical confirmation that the electric current is conserved in a simple (non-branching) electric circuit.

Learning outcomes

By the end of this activity, pupils will be able to:

- connect an ammeter into a simple circuit;
- explain that the current is the same all around a simple circuit.

What to prepare

- Electric circuit kit plus ammeters

Worksheet: 'Same all around!'

Mode of interaction

Pupils talk in pairs explaining and confirming that the electric current is conserved: INTERACTIVE/ AUTHORITATIVE

What happens in this activity

Pupils work in pairs to make two measurements of electric current. They will need some help in making their first current measurements but this should not take too long. For the purposes of this activity it is much easier for pupils to use digital meters. An important point here is not to use meters which are too sensitive. It is not helpful, for example, to have a pupil claiming that some of the current has been used up because the first reading is 0.74A and the second 0.73A! Avoid this problem if possible by using meters measuring to 0.1A.

Once the pupils have made their readings, stop the class and confirm that the current is the same at both points in the circuit; then move on to the next activity.

Pupils might explain that the current is the same all around this circuit because:

> *'The charges just keep moving around and don't get used up. It's just like the rope moving round. Energy gets transferred but the charges just keep moving.'*

Activity 3.2: Explain that!

In this activity pairs of pupils work on developing explanations for the behaviour of a range of simple circuits.

Teaching objectives

- For the pupils to build 2 sets of circuits and to make observations of bulb brightness and current values.
- For pupils to account for their observations in terms of the scientific electric circuit model.

Learning outcomes

By the end of this activity, pupils will be able to:

- predict bulb brightness for different numbers of batteries and bulbs;
- predict changes in electric current with different numbers of batteries and bulbs.

What to prepare

- Electric circuit kit plus ammeters
- Worksheet: 'Explain that!'

Mode of interaction

Pupils talk in pairs discussing the scientific explanation for each circuit: INTERACTIVE/AUTHORITATIVE

What happens during this activity

Each pair of pupils builds the following circuits, using an ammeter to measure the electric current:

Series A: 1 battery/1 bulb; 2 batteries/1bulb; 3 batteries/1 bulb

Series B: 1 battery/1bulb; 1 battery/2 bulbs; 1 battery/3 bulbs

For each circuit, the pupils:

- note the bulb brightness;
- measure the electric current in 2 places with an ammeter;
- write an explanation to account for the bulb brightness and electric current value.

The pairs of pupils report back on their findings in a plenary session. The science story to develop is as follows:

Series A circuits:

Observations: as more batteries are added the bulb becomes brighter and the current readings larger.

Explanation: as more batteries are added, there is a bigger push and the charges move around more quickly creating a bigger current. The bigger electric current produces a brighter bulb.

Series B circuits:

Observations: as more bulbs are added, the bulbs get less bright and the current readings smaller.

Explanation: as more bulbs are added, there is a bigger resistance in the circuit and the charges move around more slowly creating a smaller electric current. The smaller electric current produces dimmer bulbs.

Activity 3.3: Diagnostic questions

The pupils work individually or in pairs to complete some or all of the diagnostic questions: 'Electric current points'; 'Battery and bulb'; 'Current motor'.

Teaching objective

- To check pupils' understanding of conservation of electric current.

Learning outcomes

By the end of this activity, pupils will be able to:

- predict that the current is the same all around a simple circuit.

Mode of interaction

The diagnostic questions might be completed individually or in pairs with pupils focusing on the correct scientific point of view: INTERACTIVE/ AUTHORITATIVE

Correct answers

Electric current points: 'The electric current is the same at **a** and **b**'. 'The current is **the same** all round the circuit'.

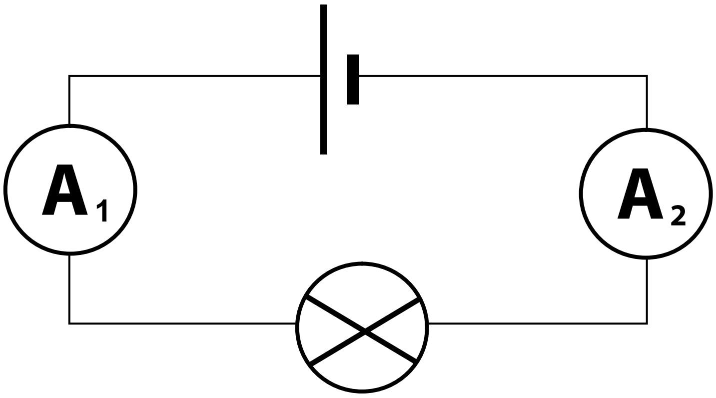
Battery and bulb: 'There is an electric current in wire B **from the bulb to the battery**'. 'The current in wire B is **the same** as in wire A'.

Current motor: 'Exactly 0.4 ampere'. 'The current is **the same** all round the circuit'.

Teaching 'story'

The diagnostic question 'Current motor' raises the issue of whether or not the electric current is conserved in electrical devices other than bulbs: the answer is YES! In the case of the motor the current flows through the coils of the motor to make an electromagnet, but the current itself remains the same all around the circuit.

Same all around!



FOR THIS ACTIVITY YOU NEED JUST ONE AMMETER

Measure current 1 = ______________________ ampere

PREDICT current 2 = ______________________ ampere

Measure current 2 = ______________________ ampere

EXPLAIN in your own words why the current is the same all around this circuit.

I know the current is the same all around this circuit because:

____

____

____

____

____

Explain that!

Set up the following circuits. For each one:

- Write down the brightness of the bulb(s):
  DIM, NORMAL, BRIGHT, VERY BRIGHT
- Measure the electric current.

Circuit 1: 1 battery/1 bulb Brightness: ____________ Current ____________ A	**Circuit 2:** 2 batteries/1 bulb Brightness: ____________ Current ____________ A	**Circuit 3:** 3 batteries/1 bulb Brightness: ____________ Current ____________ A

Circuit 4: 1 battery/ 1 bulb Brightness: ____________ Current ____________ A	**Circuit 5:** 1 battery/2 bulbs Brightness: ____________ Current ____________ A	**Circuit 6:** 1 battery/3 bulbs Brightness: ____________ Current ____________ A

Question 1: Look at your results as you move from **Circuit 1** to **Circuit 3**.

a. What happens to the brightness of the bulb?

b. What happens to the electric current?

c. Explain why this happens.

Question 2: Look at your results as you move from **Circuit 4** to **Circuit 6**.

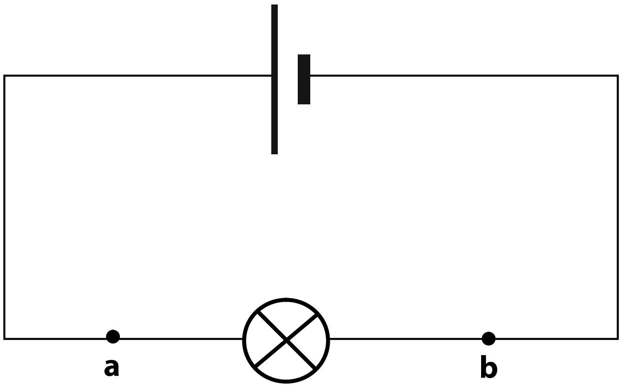
d. What happens to the brightness of the bulbs?

e. What happens to the electric current?

f. Explain why this happens.

Electric current points

In this circuit, the bulb is lit.



(a) What can you say about the electric current at points **a** and **b**?

*Tick **ONE** box*

☐	The electric current at **a** is bigger than at **b**.
☐	The electric current at **b** is bigger than at **a**.
☐	The electric current is the same at **a** and **b**.

(b) How would you explain this?

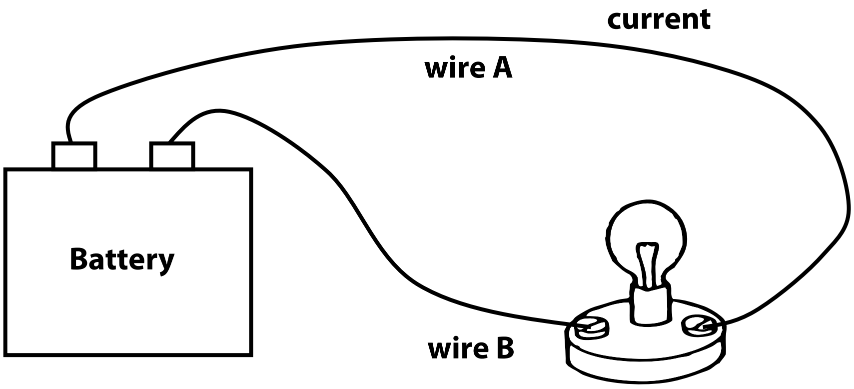
*Tick **ONE** box*

☐	The current is the **same** all round the circuit.
☐	**Some** of the current is used up by the bulb.
☐	**All** of the current is used up by the bulb.

Battery and bulb

A battery is connected to a bulb. The bulb is lit.

There is an electric current in wire A **from the battery to the bulb.**



(a) What can you say about the **electric current** in wire B?

*Tick **ONE** box*

☐	There is an electric current in wire B **from the battery to the bulb**.
☐	There is an electric current in wire B **from the bulb to the battery**.
☐	There is **no** electric current in wire B.

(b) How does the **current** in wire B compare with the **current** in wire A?

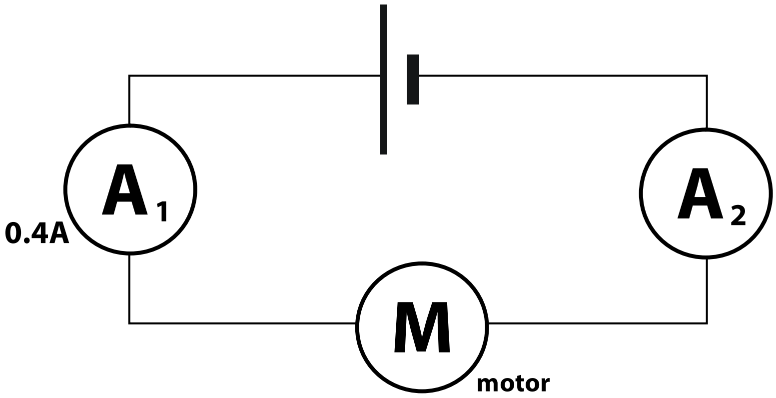
*Tick **ONE** box*

☐	The current in wire B is **bigger** than in wire A.
☐	The current in wire B is **the same** as in wire A.
☐	The current in wire B is **smaller** than in wire A.

Current motor

In this circuit a battery is connected to a motor.

The reading on ammeter A1 is 0.4A.



(a) What will the reading on ammeter A^2 be?

*Tick **ONE** box*

☐	More than 0.4 ampere
☐	Exactly 0.4 ampere
☐	Less than 0.4 ampere, but not zero
☐	Zero

(b) How would you explain this?

*Tick **ONE** box*

☐	**Some** of the current is used up by the motor.
☐	**All** of the current is used up by the motor.
☐	The current is the **same** all round the circuit.

Lesson 4: Bulbs in parallel

Teaching 'story'

This final lesson of the sequence starts with a challenge: how to connect 2 bulbs to two batteries so that both bulbs are brightly lit. In this case connecting the bulbs in series will not suffice, since the bulbs will be of 'normal' brightness. The challenge is for pupils to arrive at the solution of connecting the bulbs in parallel.

Activity 4.1: Equally bright!

In this activity the concept of parallel circuits is introduced.

Click here to see a video clip of this

Teaching objectives

- To prompt pupils to think about parallel circuits.
- To review the fact that bulbs connected in parallel are normally equally bright.
- To use the rope loop analogy to develop an explanation for the working of a parallel circuit in terms of two connected circuit loops.

Learning outcomes

By the end of this activity, pupils will be able to:

- connect bulbs in parallel;
- recognise that bulbs connected in parallel are normally equally bright;
- explain the working of a parallel circuit in terms of two circuit loops (possibly referring to the rope analogy);
- explain that adding a bulb in parallel leads to energy being transferred from the battery at a higher rate; the battery flattens more quickly as two bulbs are illuminated.

What to prepare

- Electric circuit kit
- Rope loops of different sizes.

Mode of interaction

Pupils talk in pairs discussing the problem of finding a solution to the challenge. They are likely to try out a number of different ideas: INTERACTIVE/ DIALOGIC

What happens during this activity

Setting the challenge

The teacher first of all sets the challenge. Start with the simplest circuit:

- 1 battery and 1 bulb: *'Here we have a very familiar circuit. The bulb is of normal brightness. What happens if we add an extra battery?'*
- 2 batteries and 1 bulb: *'That's right, the bulb becomes BRIGHT!'*

  'Now then, the challenge for you is to connect 2 batteries and 2 bulbs so that the bulbs are BRIGHT! Not normal but BRIGHT!'

In addition to getting the circuit to work satisfactorily, the pupils are asked to try to develop an explanation as to how the circuit works. This is tough! Make the rope loops available and encourage the pupils to use them in developing their ideas. As the pairs work on their circuit, move around providing encouragement and helping pupils in the right direction.

Plenary

Give sufficient time for a number of groups to have succeeded with the activity then call the class together to review findings. Ask one of the successful pairs to demonstrate setting up the circuit with the bulbs connected in PARALLEL.

At first appearance, the parallel circuit seems to offer 'something for nothing'! With 2 batteries and 1 bulb, the bulb is BRIGHT. With 2 batteries and 2 bulbs connected in parallel, BOTH bulbs are BRIGHT! How can BOTH bulbs be bright? One way to explain this is to use the rope loops.

To model the parallel circuit with rope loops, you need 2 loops with one being smaller in diameter so that it fits inside the other.

The teacher acts as the battery and starts moving the smaller loop around through 1 bulb (1 pupil gripping). Ask the class how to add a further bulb in parallel. The bigger loop is simply taken so that the teacher is able to pull/push it through (along with the small loop) the gripped hand of a second pupil. The 2 rope loops are thus connected in parallel. Both bulbs are now equally lit as the teacher pulls the rope through the pupils' hands at the same rate. In this case the teacher (the battery) needs to do twice the work in keeping two rope loops circulating and transferring energy at both sets of hands.

With the parallel rope loop set up the teacher (the battery) will run out of energy more quickly and it is exactly the same with the parallel electrical circuit. Here, when the 2 bulbs are connected in parallel to a battery, the battery will run out of energy more quickly as it provides the push to keep both sets of charge circulating through the bulbs. In other words, the battery goes flat more quickly.

The rope loops show very well that a parallel circuit consists of two linked but separate circuits with a single battery providing the push to circulate the charges in each. Furthermore, the electric current passing through the battery is twice that passing through each bulb.

And with a little more detail for the teacher

Adding a second bulb in parallel to the first sets up a second circuit loop in which charges can be set in motion. Not only do we have the loop of charges passing through the first bulb, but we also have a second loop of charges passing through the second bulb. The number of charges passing through the battery each second is thus *doubled*, with half of the charges moving on to pass through the bulb in the first loop, and the other half through the bulb in the second loop.

The battery provides the same push for each of the loops of charges, and so the current is the same in each of the loops as it would be for one battery/one bulb. So each of the bulbs, connected in parallel, is of normal brightness.

Since the battery is providing the push to keep two loops of charges circulating through the resistance of each bulb, it will run out of energy twice as quickly as energy is transferred to the surroundings at both bulbs.

Activity 4.2: Diagnostic questions

Three diagnostic questions and a card sort activity are provided to enable pupils to talk through some of the ideas raised in this sequence of lessons. The pupils work in pairs to complete some or all of:

- 'Remove battery'
- 'What happens to the current?'
- 'Blockbuster'
- 'How bright is that?'

Teaching objective

- To check pupils' understanding of what happens in circuits with different numbers of batteries and bulbs.

Learning outcomes

By the end of this activity, pupils will be able to:

- predict the brightness of bulbs in simple series and parallel circuits;
- predict what happens in simple circuits as the number of batteries and bulbs are changed;
- provide explanations for the working of simple circuits.

What to prepare

- Sets of diagnostic questions and 'How bright is that?' card sorts.

Mode of interaction

The diagnostic questions might be completed individually or in pairs with pupils focusing on the correct scientific point of view:
INTERACTIVE/AUTHORITATIVE

What happens during the activity

For the 'How bright is that?' activity pairs of pupils are given a set of the circuit cards and are asked to: *'Arrange the cards in order so that the bulb(s) in each of the circuits go from the DIMMEST to the BRIGHTEST'*.

The correct order is:

J	C	F H	I	A E	G	D	B

Note that the bulb in circuit J does not light.

Correct answers

Remove battery: 'It gets less, but not zero'. 'One battery exerts a smaller 'push' on the electric charges'.

What happens to the current?: 'It gets less, but not zero'. 'The battery cannot push as big a current through two bulbs'.

Blockbuster: Brightest: C. Dimmest: G. Current biggest: C. Current least: G Same: A, E, I.

Activity 4.3: Open the envelope!

Teaching 'story'

This final activity takes us back to the start of the lessons and to the 'Lift off' activity where each pupil wrote down their ideas in response to the 'Bulb light' question. Now the pupils have the chance to go back to their answers and to gauge how far their thinking has developed.

Teaching objective

- To encourage pupils to reflect on their own learning during the sequence.

Learning outcomes

By the end of this activity, pupils will be able to:

- Recognise how far, and in what ways, their understanding of electric circuits has progressed.

What to prepare

- Sealed envelopes for return to pupils.

Mode of interaction

The 'Bulb light' responses should be reviewed individually first of all and then in discussion with a partner. The discussion is likely to cover a full range of correct and incorrect ideas: INTERACTIVE/DIALOGIC

What happens during the activity

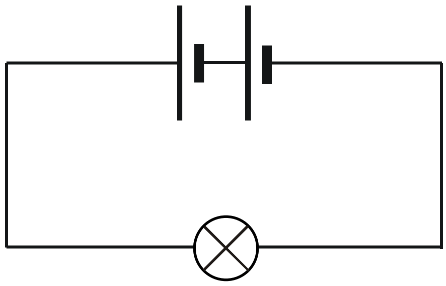
The sealed envelopes are returned to the class and each pupil looks carefully through what they wrote initially and how their ideas have changed. The pupils might be asked to mark their original response in terms of:

- parts which were CORRECT;
- parts which were NOT CORRECT.

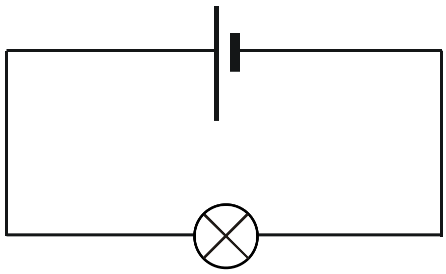
Remove battery

Two batteries are connected to a bulb.

The bulb is lit.



One of the batteries is then removed.



(a) What happens to the current going through the bulb?

*Tick **ONE** box*

☐	*It gets bigger.*
☐	*It stays the same.*
☐	*It gets less, but not zero.*
☐	*It drops to zero.*

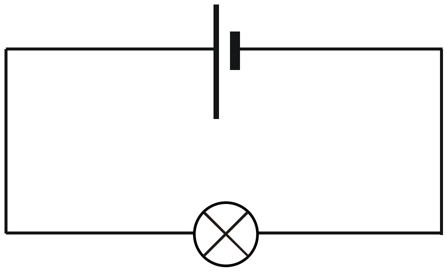
(b) Which of the following is the best explanation for this?

*Tick **ONE** box*

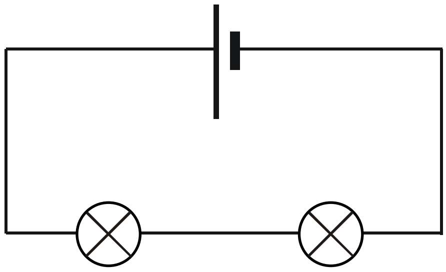
☐	*One battery exerts a smaller 'push' on the electric charges.*
☐	*The bulb always needs the same amount of current to make it light.*
☐	*The resistance in the circuit is less.*

What happens to the current?

This circuit consists of a battery and a bulb. The bulb is lit.



A second identical bulb is added.



(a) What happens to the current in the circuit?

*Tick **ONE** box*

☐	It gets bigger.
☐	It stays the same.
☐	It gets less, but not zero.
☐	It drops to zero.

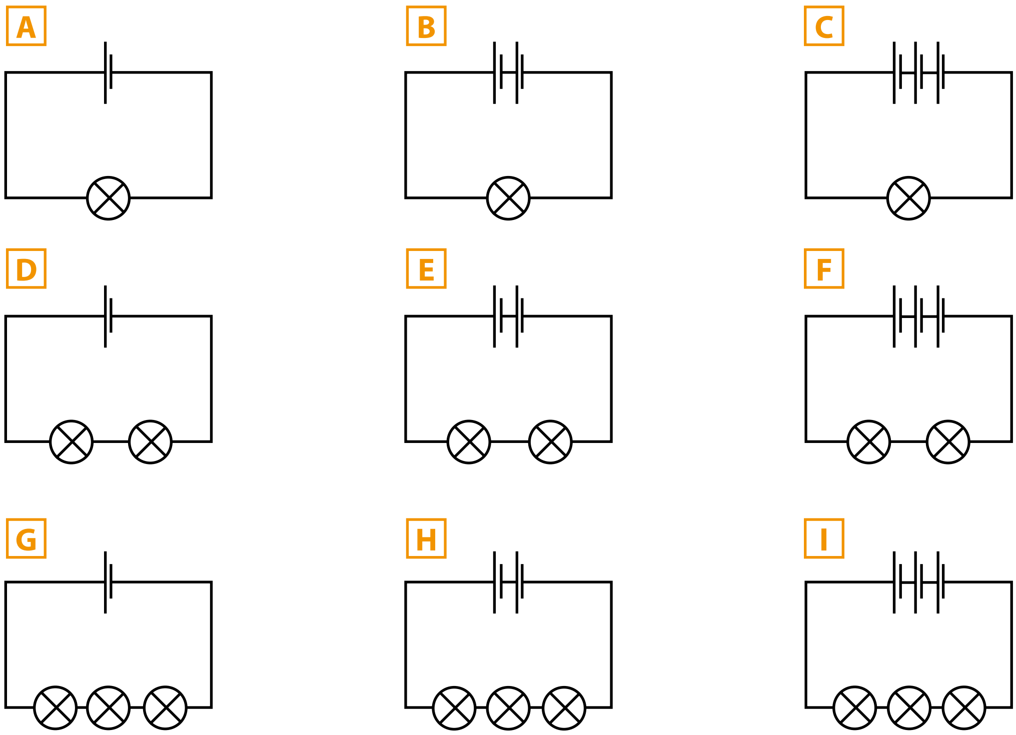
(b) How would you explain this?

*Tick **ONE** box*

☐	The battery is not strong enough to push any current through two bulbs.
☐	The battery cannot push as big a current through two bulbs.
☐	It is the same battery, so it supplies the same current.
☐	The current is shared between the two bulbs, so each gets half.

Blockbuster

Look at these circuits:



In which circuit is each bulb the **BRIGHTEST**?

In which circuit is each bulb **DIMMEST**?

In which circuit is the current **BIGGEST**?

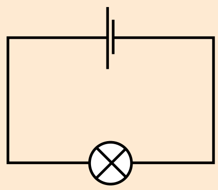
In which circuit is the current the **LEAST**?

In which three circuits are the bulbs the same **BRIGHTNESS** and the currents the **SAME**?

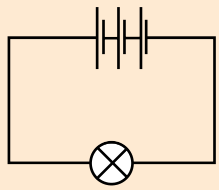
Card sort

Cards: How bright is that?

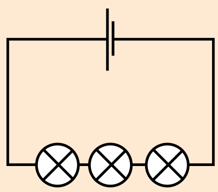
A: 1 battery and 1 bulb



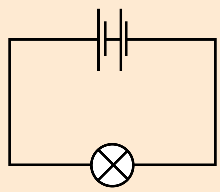
B: 3 batteries and 1 bulb



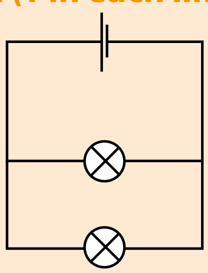
C: 1 battery and 3 bulbs



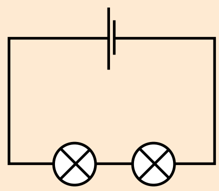
D: 2 batteries and 1 bulb



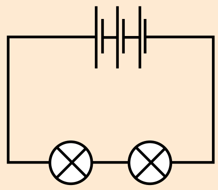
E: 1 battery and 2 bulbs in parallel (1 in each limb)



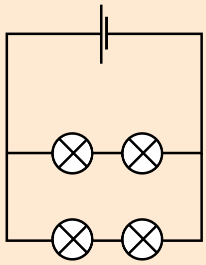
F: 1 battery and 2 bulbs



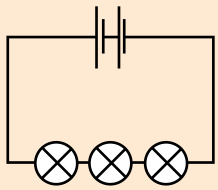
G: 3 batteries and 2 bulbs



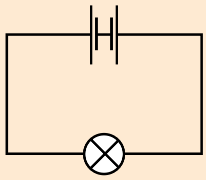
H: 1 battery and 4 bulbs in parallel (2 in each limb)



I: 2 batteries and 3 bulbs



J: 2 batteries (facing each other) and 1 bulb



Audience: Science subject leaders, teachers of science and higher level teaching assistants.

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