# The National Strategies Secondary

# Voltage, energy and power in electric circuits

Science teaching unit

department for children, schools and families

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# Voltage, energy and power in electric circuits

First published in 2008 Ref: 00094-2008DVD-EN

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# Voltage, energy and power in electric circuits

# Background

This teaching sequence bridges Key Stage 3 to Key Stage 4. 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 review their ideas and understanding about electric circuits from Key Stage 3 and to develop a meaningful understanding of the 'new' concepts of voltage and power, and in particular how they relate to ideas about energy.

This work on voltage and power has been planned to build directly on the earlier Key Stage 3 approaches, particularly in that the 'rope loop' analogy is used throughout. We are convinced that the consistent use of a carefully selected analogy provides a sound basis for effective teaching and meaningful learning. At the same time, we recognise that some pupils may not have had the opportunity to work with the rope loop analogy at Key Stage 3. So, for these classes we recommend that an additional lesson (which we refer to as the 'Lift-off' lesson), which focuses on the BIG circuit and the rope loop analogy, be added to the start of this Key Stage 3–4 sequence. This will be valuable in helping to deepen pupils' understanding of electric circuits.

The teaching approaches set out here are planned to be interactive in nature as links between subject matter are explored and established through appropriate discussion 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' existing understanding of electric circuits;
- helping pupils understand a scientific electric circuit model that includes the concepts of current, voltage, resistance, energy and power;
- 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 analogy'), 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.

#### 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 objectives;
- providing opportunities for pupil–pupil discussion in pairs and small groups.

#### How science works

The sequence explicitly addresses two aspects of:

- 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 circuits;
- assessing the quality of data sets.

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#### The world of models and the real world

Overall, the teaching approach taken 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.



World of models

#### **Pupils' starting points**

This sequence of lessons builds on previous work on electricity where it is assumed that 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. know that adding bulbs in parallel makes the bulbs normally bright;
- 6. know that charges, already existing in the wires, circulate in a complete circuit;
- 7. know that energy is transferred when charges pass through a resistance;
- 8. know that charges are conserved;
- 9. know that electric current is a measure of the rate of flow of charge measured in coulomb per second.

These ideas are reviewed in Lesson 1 of this second sequence.

#### **Electrical units**

This is a full listing of the units used in the lesson sequence.

Variable	Unit	Unit symbol
Electric current (I)	ampere	А
Voltage (V)	volt	V
Resistance (R)	ohm	Ω
Energy	joule	J
Power	watt	W
Charge	coulomb	С
Time	second	S

It is a good idea to be consistent in the use of units to encourage good habits in pupils. Thus:

```
NOT: 2.5 amps or 2.5 Amp.....BUT: 2.5 ampere or 2.5A
```

```
NOT: 10 sec or 10 secs.....BUT: 10 second or 10s
```

The rules here are that:

- the unit is expressed in lower case and strictly speaking should be 'singular': 2.5 ampere;
- the unit symbol is written in upper case IF it refers to a person's name, such as V, A, or N.

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# Voltage, energy and power in electric circuits: Overview



# Lift-off activity: Developing the scientific model – from rope loops to electric circuits

#### **Teaching 'story'**

This teaching sequence builds on the ideas developed in '*Explaining how electric circuits work*' (see 'Background', page 1) where the 'rope loop' teaching analogy was introduced. As argued earlier, we are convinced that the consistent use of a carefully selected analogy provides a sound basis for effective teaching and meaningful learning and we therefore return to using the rope loop analogy in this Key Stage 4 sequence. For those classes that are new to the rope loop analogy at Key Stage 4, we have included this additional 'Lift-off' lesson.

The lesson starts with the BIG circuit! This is possibly the BIGGEST circuit that the pupils have ever seen and it is used to challenge their ideas about electric circuits.

#### **Activity 1: The BIG circuit**

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

#### **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, most pupils will:

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

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#### What to prepare

The BIG circuit consists of a 12 volt power supply and a large bulb (12 volt/24 watt) set up with insulated connecting wire running round the perimeter of the classroom. 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.

- A 24W/12V bulb works very well, being big enough for the class to see
- Two very long insulated wires
- A 12V power supply.

#### Mode of interaction



#### 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 the circuit 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 up 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:

'So you think that the electricity leaves the battery and then travels all the way round to the bulb ... who agrees with that?'

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 up 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 up... immediately.

#### **Teaching 'story'**

When the BIG circuit is completed about half of the class will be happy with their correct prediction (the bulb lights up 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 now is to try to understand this model'.

#### **Activity 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 be unfamiliar to some pupils and so will need to be introduced.

#### **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 conceptions which have become apparent through 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 electric 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.

#### Click here to see an example of this

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 basic ideas that:

- The battery is represented by the teacher pulling the rope round and 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 Big Circuit activity:

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 for charges to travel 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 up straight away.'
The electric current gets used up to make 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.'

Initial ideas	Scientific electric circuit model	Rope loop picture
Clashing currents	The electric current flows in one direction, continuously around the circuit	'Some people think 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.'

#### Activity 3: 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 of 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 a 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.

#### **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 grasp 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 \_\_\_\_\_\_ against the flow of the electric current.

# Lesson 1: Explaining how electric circuits work

#### **Teaching 'story'**

The aim of this lesson is to review previously taught ideas about electric circuits and to get pupils building, and talking about, a range of circuits, explaining how they work.

#### **Activity 1.1: Constructing explanations**

In this activity pairs of pupils are presented with various electric circuits and are asked to explain how each one works. The circuits to be considered are:

- 1. one battery and one bulb;
- 2. one battery and two bulbs in series;
- 3. two batteries and one bulb;
- 4. one battery and two bulbs in parallel.

#### **Teaching objectives**

- To engage the pupils in making some simple circuits, to remind themselves what happens in each one, and to measure electric currents with an ammeter.
- To prompt pupils to talk through explanations for each circuit, drawing on the rope loop analogy as necessary.

#### Learning outcomes

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

- describe what happens in some simple electric circuits;
- explain what happens in each circuit, using a simple scientific model of circulating charges, and drawing on the rope loop analogy as necessary.

#### What to prepare

- An electric circuit kit, including an ammeter and at least two identical light bulbs.
- A rope loop for each group. This is a 'mini' rope loop to be used by each pair of pupils. The rope loop is used here as a tool to support talking and thinking.

#### What happens during this activity

#### Groupwork

The pupils work in pairs and each pair is supplied with components to build the four specified circuits along with a rope loop. For each circuit, the pair is asked to:

- make a note of the brightness of the bulb(s);
- make current measurements with the ammeter;
- model the behaviour of the circuit with the rope loop;
- explain the bulb brightness in terms of the scientific circuit model.

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



#### Plenary

When the pairs have finished they report back on their findings. Here the teacher focuses attention on the explanation for the behaviour of each circuit.

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



The pupils shows be encouraged to refer to the rope loop analogy (click here to see an example of this and the scientific circuit model and to move towards explanations along the lines of:

1. 1 BATTERY and 1 BULB		
Bulb	Normal brightness	
Current	Same on either side of the bulb	
Rope	'Normal speed'	
Explain	When the circuit is complete the battery provides a push to set the charges moving. As the charges pass through the filament of the bulb they encounter a resistance and the bulb heats up with energy being transferred to the surroundings. The current measures how many charges pass any point in the circuit each second and is the same on either side of the bulb since the charges are not 'used up'.	

2. 2 BATTERIES and 1 BULB		
Bulb	Bright	
Current	Bigger: with equal readings on either side of the bulb	
Rope	'Fast'	
Explain	The two batteries provide a bigger push which sends the charges around the circuit more quickly producing a bigger electric current. This means that more charges pass through the bulb each second, there is more heating and the bulb is brighter.	

3. 1 BATTERY and 2 BULBS		
Bulbs	Dim	
Current	Smaller: with equal readings on either side of the bulb	
Rope	'Slow'	
Explain	The two bulbs provide an increased resistance which slows down the flow of charge all around the circuit, thereby reducing the electric current. This means that fewer charges pass through the bulb each second, there is less heating and the bulbs are dimmer.	

4. 1 BATTERY and 2 BULBS IN PARALLEL		
Bulbs	Normal brightness	
Current	The current to and from the battery is double that through each bulb	
Rope	Two ropes circulating at 'normal' speed (same as first circuit).	
Explain	The parallel circuit is best thought of as 2 separate circuits each with 1 battery and 1 bulb. The current through the battery is therefore double that through each bulb. This can be visualised in terms of 2 rope loops being set in motion by the 'battery' with each loop passing through its own 'bulb'. The energy from the 'battery' is transferred more quickly as work is done to keep both ropes moving. In other words the battery 'runs flat' more quickly.	

## **Constructing explanations**

#### Circuit 1: 1 battery and 1 bulb

- a. How bright is the bulb? DIM/NORMAL/BRIGHT: \_\_\_\_\_
- b. What are the current readings?

Current at X = \_\_\_\_\_A Current at Y = \_\_\_\_\_A

c. How does the rope move round? (thinking about answer to part a). SLOW/NORMAL/FAST: \_\_\_\_\_\_

d. Explain why the current readings are the same:

#### Circuit 2: 2 batteries and 1 bulb

- a. How bright is the bulb? DIM/NORMAL/BRIGHT: \_\_\_\_\_
- b. What are the current readings?
  - Current at X = \_\_\_\_\_A Current at Y = \_\_\_\_\_A
- c. How does the rope move round? (thinking about answer to part a).

SLOW/NORMAL/FAST: \_\_\_\_

d. Explain why the current readings are bigger than in Circuit 1:

#### Circuit 3: 1 battery and 2 bulbs

- a. How bright are the bulbs?
- DIM/NORMAL/BRIGHT: \_\_\_\_\_
- b. What are the current readings?
  - Current at X = \_\_\_\_\_A Current at Y = \_\_\_\_\_A Current at Z = \_\_\_\_\_A
- c. How does the rope move round? (thinking about answer to part a).

SLOW/NORMAL/FAST: \_\_\_\_\_

d. Explain why the current readings are all the same and smaller than in Circuit A:

#### Circuit 4: 1 battery and 2 bulbs in parallel

a. How bright are the bulbs? DIM/NORMAL/BRIGHT: \_\_\_\_\_

b. What are the current readings?

Current at W = \_\_\_\_\_A Current at X = \_\_\_\_\_A

Current at Y = \_\_\_\_\_A Current at Z = \_\_\_\_\_A

c. How do the ropes move round? (thinking about answer to part a).

#### SLOW/NORMAL/FAST: \_\_\_\_

d. Explain why the current readings at Y and Z are about half those at W and X:

# Lesson 2: Introducing the idea of voltage

#### **Teaching 'story'**

This lesson marks a significant step forward in the unfolding 'story' of electric circuits as the concept of voltage is introduced. First of all, however, the pupils are engaged in a 'warming-up' activity where they have the opportunity to review some of the ideas raised in the previous lesson through working on a selection of diagnostic questions.

#### Activity 2.1: Warming-up activity: Diagnostic questions

A full range of eight diagnostic questions is provided. The teacher selects from these to review ideas and to promote talking.

#### **Teaching objectives**

- To review what happens in simple electric circuits as the number of batteries and bulbs is changed.
- To explain what happens in the circuits as the changes are made.

#### Learning outcomes

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

- predict what will happen in a range of simple electric circuits as changes are made to the numbers of batteries and bulbs;
- explain what happens in those circuits in terms of circulating charges, electric current flow, resistance and energy transfer.

#### What to prepare

The following diagnostic questions are available in paper and electronic form. Sets of the questions might be made on card and laminated.

	Question	Focus/answer
1.	Add battery	Changing batteries: bulb brighter; bigger current, more energy.
2.	Remove battery	Changing batteries: gets less; smaller push.
3.	Add bulb	Changing bulbs: gets less; cannot push as big a current.
4.	Both ammeters	Increasing resistance: $A_1$ gets smaller; $A_2$ gets smaller; current smaller everywhere in circuit.
5.	Two bulbs	Identical bulbs in series: same brightness; energy shared equally; current reduced all round circuit.
6.	Same circuit?	Parallel circuit diagrams: all are correct.
7.	Identical resistors	Parallel circuit: smaller; same; bigger; same.
8.	Ammeter readings	Parallel circuit: A1 0.3A; A2 0.3A; A3 0.5A.

#### What happens during this activity

The teacher selects the diagnostic questions to be worked on. Questions 1-5 might usefully be addressed at this point. The activity might be organised in:

- Pairs: pupils work in pairs on the questions and report back in a plenary.
- Pairs/fours: pupils work in pairs and then join with another pair to come up with a joint/agreed response. The groups of four report back to the plenary.

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



Plenary: the teacher and class talk through the questions and explore the pupils' answers

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



## 1: Add battery

One battery is connected to a bulb. The bulb is lit normally.



## (a) What happens to the bulb?

An extra battery is added.

#### Tick **ONE** box

The bulb stays the same brightness.
The bulb is lit, but not as bright.
The bulb gets brighter.
The bulb is not lit.

#### (b) Which of the following help to explain this?

#### Tick **TWO** boxes

The resistance in the circuit is smaller so the current is bigger.
The extra battery pushes a bigger current around the circuit.
With the extra battery more energy is transferred by the charges.

# 2: 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 through the bulb?

#### Tick **ONE** box

lt 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



# 3: Add bulb

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



#### (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.	
Two bulbs need more current than one on its own.	
The current is shared between the two bulbs, so each gets half.	

## 4: Both ammeters

The resistor in this circuit, R1, has a **small** resistance.

There is a reading on both ammeters.



R<sub>1</sub> – small resistance

It is replaced by resistor  $R_2$  which has a **large** resistance.



R<sub>2</sub> - large resistance

- (a) What happens to the reading on ammeter A1?
- (b) What happens to the reading on ammeter A2?

Tick **ONE** box

#### Tick **ONE** box

lt gets bigger.	lt gets bigger.
It stays the same.	It stays the same.
It gets smaller.	It gets smaller.

#### (c) How would you explain this?

#### Tick **ONE** box

The bigger the resistance, the bigger the current.	
It is the same battery, so it supplies the same current.	
Increasing the resistance makes the current smaller everywhere in the circuit.	
Increasing the resistance makes the current smaller after it. It has no effect on the current before it.	
Increasing the resistance makes the current smaller after it. So the current before it gets bigger.	

## **5: Two bulbs**

The two bulbs in this circuit are identical.



(a) How bright will the bulbs be?

#### Tick **ONE** box

Bulb 1 is lit. Bulb 2 is off.
Bulb 2 is lit. Bulb 1 is off.
Both bulbs are lit. Bulb 1 is brighter than bulb 2.
Both bulbs are lit. Bulb 2 is brighter than bulb 1.
Both bulbs are lit, with the same brightness.

#### (b) How would you explain this?

#### Tick **TWO** boxes

Energy is shared equally between the two bulbs as the charges pass round the circuit.
The first bulb uses up some of the electric current, so there is less left for the other one.
The electric current is shared equally between the two bulbs.
The electric current is reduced all round the circuit.

# 6: Same circuit?

This electric circuit is set up on the bench.



Five pupils are asked to draw its circuit diagram. Their drawings are shown below. For each, put a tick in one box to show if you think it shows the connections in the circuit correctly or not.







correct wrong



f.

d.

\$













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For each of the sentences below, write one of the following in the gap to complete the sentence correctly:

smaller than	the same size as	bigger than
a. The current at <b>c</b> is <b></b>	the cu	rrent at <b>e</b> .
b. The current at <b>d</b> is	the cu	rrent at <b>b</b> .
c. The current at <b>a</b> is	the cu	rrent at <b>b</b> .
d. The current at <b>e</b> is	the cu	rrent at <b>a</b> .

# 8: Ammeter readings

In the circuits below, the readings on some of the ammeters are shown. Write down the readings you would expect to see on the other ammeters. Note that the bulbs are **not** all the same.




### Activity 2.2: What is voltage?

### **Teaching 'story'**

In introducing the concept of voltage, we start with something familiar: that batteries come in different shapes and sizes and are 'measured' in terms of their voltage. The question is: what does the voltage actually tell us? What does it measure?

### **Teaching objective**

• To introduce the concept of voltage.

### **Learning outcomes**

By the end of this lesson the pupils will be able to:

- state that batteries are 'measured' in terms of their voltage;
- explain that the battery voltage relates to the size of 'push' which it gives to the charges in the circuit;
- explain that the voltage actually measures the amount of energy (as supplied by the battery) which each coulomb of charge can transfer as it passes through resistance.

### What to prepare

- A variable voltage supply
- A short length of resistance wire (i.e., wire with high resistance)
- A heat resistant mat
- A demonstration voltmeter.

### Pupils need to know that:

- energy is measured in joule;
- charge is measured in coulomb;
- voltage is measured in volt.

### **Mode of interaction**

The teacher takes a largely INTERACTIVE/AUTHORITATIVE approach in talking about different kinds of batteries with the class and then introducing the concept of voltage.



### What happens during this activity

#### Different batteries, different voltages.

Pupils are likely to be aware that batteries come in all shapes and sizes. Have an assortment of batteries ready and ask the class to predict the voltage of each....

'What might you use this kind of battery in? Yes...a torch. How many volts do you think? OK. Each one of these batteries is marked 1.5 volt. If two are put together in series the voltages add up. What about this one? 9 volt. What about the supply for this kettle? 240 volt.

### Turning up the voltage

The teacher then directs the pupils' attention to a simple circuit consisting of a variable voltage power supply, connecting leads and a short length of resistance wire. The teacher starts on a low voltage and gradually turns up the supply, focussing attention on the short length of resistance wire which gets hotter until it is glowing brightly:

'So let's start with a low voltage here and see what happens as we increase the voltage. Just look! See how the wire is glowing brightly now. That's with 12 volts. It's just like a bulb filament really'.

The question to pursue is what is happening in the circuit as the voltage is gradually increased. The picture to get across is as follows:

- a bigger battery voltage;
- gives a bigger 'push';
- this bigger push drives the charges round the circuit more quickly;
- charges moving more quickly give a bigger electric current;
- as the charges pass through the resistance wire they undergo more energetic collisions producing more heating in the bulb;
- so the bulb is brighter.

This line of reasoning is likely to be familiar from earlier work on circuits and can be consolidated by reference to the rope loop:

- a bigger battery voltage;
- achieved by pulling the rope loop with a bigger force;
- this bigger pull drives the rope round more quickly;
- as the rope passes through the resistance (hand) there is more heating;
- so the hand becomes hotter.

### So what does voltage actually measure?

### **Battery voltage**

A starting point here is that voltages are measured with a voltmeter. Using the same resistance wire circuit the teacher connects a demonstration voltmeter *across* the battery and takes the reading:

'So I can take the voltmeter and connect it across the power supply. It reads 8 volt. This tells me how much energy the supply is providing for the circuit. We know that the higher the voltage, the bigger is the push and the more energy is given to the charges in the circuit.'

'In fact the battery voltage tells me how many joule of energy can be transferred by each coulomb of charge as it passes through the resistance.'

'This 8 volt supply gives 8 joule of energy for each coulomb of charge.

The 1.5 volt battery gives 1.5 joule of energy for each coulomb of charge.

What about the 240 volt supply? Yes, that's right 240 joule of energy for each coulomb.'

The voltmeter reading across the battery is a measure of how much energy (in joule) the battery provides for each coulomb of charge in the circuit.

1 volt = 1 joule per coulomb

1.5 volt = 1.5 joule per coulomb

240 volts = 240 joule per coulomb

#### Voltage across the resistance wire

The teacher now connects the demonstration voltmeter across the resistance wire and takes the reading:

'So now let me take the voltmeter and connect it across the hot wire. It reads 8 volt ... exactly the same reading as before ... but this tells me how much energy is being transferred at the wire. This tells me how much energy is being transferred by each coulomb of charge as it passes through the wire'.

'Why are the two readings the same? What does this tell us? Yes! That's exactly right, the amount of energy being supplied to the circuit by the battery is the same as the amount of energy being transferred in the hot wire. The energy IN is the same as the energy OUT!'

These important new ideas are returned to at the start of the next lesson.

## Lesson 3: Measuring and understanding voltages in simple circuits

### **Teaching 'story'**

In this lesson the pupils have the opportunity to make some voltage measurements of their own and to think through what these measurements actually mean in terms of charges passing and energy being transferred.

Before pupils start making measurements the teacher should review the important new ideas introduced in the previous lesson whilst comparing and contrasting the concepts of current and voltage.

### Activity 3.1: Reviewing current and voltage ideas

This is a teacher-led demonstration to review the concepts of current and voltage.

### **Teaching objectives**

- To review what current measurements mean.
- To review how currents are measured.
- To review what voltage measurements mean.
- To review how voltages are measured.

### Learning outcomes

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

- explain what current and voltage measurements in simple circuits actually mean;
- describe how to make current and voltage measurements.

#### What to prepare

- 10V power supply
- 12V/24W bulb
- 10V voltmeter
- 5A ammeter.

### **Mode of interaction**

Presentation/Demonstration Here the teacher takes an INTERACTIVE/AUTHORITATIVE approach as the pupils demonstrate making current and voltage measurements.



### What happens during this activity

The teacher starts with a simple battery and bulb circuit, makes the bulb light and then asks how to measure the electric current flowing:

'OK, so the bulb has lit up. Now, what do we need to do to measure the electric current that is flowing?'

Students should have little trouble in describing how the ammeter is connected into the circuit and explaining that the reading measures the number of charges flowing past each point per second.

The teacher then takes a voltmeter and asks how it should be connected to measure the voltage across the bulb:

'Who can remember from last lesson, how to connect the voltmeter to measure the voltage across the bulb?'

This time the voltmeter is connected across or in parallel to the bulb. What does the voltage reading tell us?

'OK! The voltmeter reads 10V. Who can remember what this means? What does the voltmeter tell us?

If the voltmeter reading is 10V, this tells us that 10 joule of energy are transferred as each coulomb of charge passes through the filament of the bulb. The voltage value is a measure of the amount of energy transferred for each unit of charge that passes.

### Teaching tip: Careful with your language!

Insist at all times:

Current THROUGH......Voltage ACROSS

It just does not make sense to talk about the 'current across the bulb' or the 'voltage through the bulb'. If pupils get these 'the wrong way round' the chances are that they do not understand the underlying ideas.

### **Activity 3.2: Predicting and measuring voltages**

This is a class activity where pupils work in pairs to make a range of voltage measurements.

### **Teaching objectives**

- For pupils to practice making voltage measurements.
- For pupils to reflect on what the voltage measurements mean.

### Learning outcomes

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

- make voltage measurements in simple circuits;
- explain what the voltage measurements mean.

#### What to prepare

- Variable DC power supply or batteries and holders up to 10V
- 12V/24W bulbs
- 10V voltmeters
- A lemon
- Electrodes: rods of copper, zinc, magnesium
- A solar cell.

### What happens during this activity

The pupils are organised to work in pairs and each pair is given a voltmeter and the worksheet 'Predicting and measuring voltages'. The worksheet sets out a range of circuits for which the class make voltage measurements.

The activity is probably best organised as a circus so that each pupil pair takes their voltmeter 'test-instrument' and makes the required measurements at each station. The order in which the measurements are made does not matter.

### **Mode of interaction**

Groupwork Pairs of pupils talk through predictions for each circuit focusing on the correct scientific point of view: INTERACTIVE/AUTHORITATIVE.



### Plenary

When pairs of pupils have completed making their measurements, the teacher asks the class about their predictions and measured values and whether or not these make sense. The teacher should model careful use of the convention, and pay particular attention to ensure pupils consistently and confidently talk about current through ... and voltage across ...

Plenary Pupils report back to the whole class on their predicted and measured values. The focus here is on the correct scientific point of view as the teacher asks probing questions: INTERACTIVE/AUTHORITATIVE.



### **Predicting and measuring voltages**

a. One battery:	voltage =	volt
-----------------	-----------	------

- b. Two batteries: voltage = .....volt
- c. Three batteries: voltage = .....volt

d. How many batteries would you need to make 12 volts? ......Batteries

2. Circuit A



**Measure** voltage (V) across battery = .....volt

Predict voltage (V1) across bulb =
.....volt

Measure voltage (V1) = .....volt



**Measure** voltage (V) across battery = .....volt

Predict voltage (V2) across bulb =
.....volt

Measure voltage (V2) = .....volt

4. Circuit C



5. Lemon cell

Measure the voltage across the lemon cell with:

COPPER and ZINC electrodes:	voltage =volt
COPPER and MAGNESIUM electrodes:	voltage =volt
COPPER and COPPER electrodes:	voltage =volt

### 6. Solar cell

Measure the voltage across the solar cell with:

Hand covering the cell:	voltage =volt
Hand NOT covering the cell:	voltage =volt
Cell under bright light:	voltage =volt

## Lesson 4: Voltage and current - looking for patterns in data

### **Teaching 'story'**

The idea of voltage has been introduced in terms of bigger battery voltages providing a bigger 'push', leading to a faster flow of charge around a circuit, a bigger electric current and therefore increased energy transfer in any circuit resistance. The question to be addressed now is whether there is any 'pattern' in the way that the electric current increases as the battery voltage is raised.

The overall aim here is to move towards an expression of the relationship between voltage and current which is an expression of Ohm's Law, but there is no need to refer to this outcome at the start of the lesson.

### Activity 4.1: Looking for patterns

### **Teaching objectives**

- To engage the pupils in a practical activity involving the measurement of the current through and the voltage across a resistor.
- To generate pairs of voltage and current values and examine these data for any special relationship.
- To establish graphically that the current through the resistor is directly proportional to the voltage across it.
- To establish that in these cases of direct proportionality the resistor obeys Ohm's Law such that I is proportional to V.
- To explain that resistance is defined as R = V / I.
- To establish that the resistors that are used in this experiment obey Ohm's Law and for them the relationship V= I x R applies.
- To see this as another of those special situations of direct proportionality along with, for example, Hooke's Law.

### Learning outcomes

By the end of this lesson the pupils will be able to:

- explain that as the voltage applied to a resistor is increased the current through the resistor goes up;
- explain that for this particular resistor the graph of voltage/current is linear, so that doubling the voltage doubles the current;
- thus recognise that the current flowing through the resistor is directly proportional to the voltage applied;
- identify that in this particular case Ohm's Law is obeyed and V= I x R.

### What to prepare

- Resistors: 7 watts max, ceramic body wire wound: 10 Ohm, 15 Ohm, 22 Ohm
- Lab pack settings: 0–8 volt.

### What happens in this activity

#### Groupwork

This is a group activity where individual groups collect sets of voltage/current data for a specific resistor. Three different resistances are used and these have been selected so that the current measurements fall within the 0–1A range when voltages of 0–8V are applied.

Depending on the size of the class it might be possible to organise the pupils into six teams of four with two teams working on each resistance value. Since the pupils' measurements will lead to resistance values being calculated later on in the activity, it is best to refer to the resistors as X, Y and Z at this stage:

- 22 Ohm: RESISTOR X, Teams 1 and 2;
- 15 Ohm: RESISTOR Y, Teams 3 and 4;
- 10 Ohm: RESISTOR Z, Teams 5 and 6.

First of all the teacher needs to provide some information about the resistors. It is sufficient to say that:

These electrical components are called resistors. Just like the filaments of light bulbs, they have a resistance which slows down the flow of electric current, but in this case they do not light up! Different resistors are made to have different resistance values:

If the resistance is BIG the current is relatively small.

If the resistance is SMALL the current is relatively big.

The resistors which we are using today come in 3 different values and have therefore been labelled X, Y and Z. We should be able to find out which has the biggest resistance value and which the smallest'.

Each group is given a resistor and directed to take voltage and current readings across the 0–8V range. This is likely to be the first time that the pupils have made current and voltage measurements together. The teacher needs to emphasise:

'Remember! We are interested in what's happening with the RESISTOR. We want to measure the current THROUGH and the voltage ACROSS the resistor'.

### **Mode of Interaction**

Groupwork

Each group discusses how they are making the measurements, focusing on the correct scientific point of view and applying ideas about current and voltage introduced earlier: INTERACTIVE/AUTHORITATIVE.



### For the teacher

There is likely to be a difference between the value of the power pack setting and the voltage measured across the resistor. For example, the power pack might be set at 2 volt but the voltmeter reading across the resistor is 1.8 volt.

The difference of 0.2 volt is due to energy being transferred in the internal resistance of the supply. There is no need to trouble the pupils with these details. For the sake of them making their measurements, it is best to direct them to set the power pack at its different settings (as specified on the worksheet) and to take the voltage measurements across the resistor.

As the groups complete their sets of measurements, it is a good idea to direct them to plot their values onto a single BIG sheet of 'flip chart' graph paper (or on an interactive whiteboard) with the scales on each axis set up in advance.

Draw attention to the importance of taking a reading of the current when the voltage is set at zero.



### Plenary

Once all of the points have been plotted onto the common axes the teacher needs to prompt the class to discuss any observable trends:

Whole-class plenary The talk here is largely: INTERACTIVE/ AUTHORITATIVE and NON-INTERACTIVE/AUTHORITATIVE as the teacher takes the lead in interpreting the pupils' graphs and moving towards the scientific pattern of proportionality.



### 1. Looking closely at the sets of points

'OK, so these are our 6 sets of points. What can you say about those sets?'

'Alright, the pairs of values from the two groups with resistor X pretty well overlap ... and the same is true for Y and Z ... which we might have expected ... but the plots for X and Y and Z are certainly different'.

'Yes ... all of the points go up. As the voltage goes up the current goes up, which again is what we expected'.

'The points seem to follow a straight line? Yes they do, don't they. Let's lay this rule onto the paper and draw in three lines'.

### 2. The differences between the lines

Attention now turns to the differences between the lines.

'So what can anybody say about the differences between the lines? And what does that tell us about how the three resistors are different?'

It is helpful to look at the current values produced for the same voltage across the resistors. Thus along the line PQ (fixed voltage) currents of A, B and C, respectively, are produced in resistors X, Y and Z.

'What does this tell us about the resistances of X, Y and Z? When you applied the same voltage to each a BIG current was produced in Z but only a SMALL current in X'

### 3. Relative resistances

This kind of discussion leads to the idea that, relative to each other:

- X has a BIG resistance, allowing only a small current to pass;
- Y has a MEDIUM resistance;
- Z has a SMALL resistance, allowing a big current to pass.

### 4. Resistances and slopes

This pattern of behaviour can be linked to the slopes of the graphs:

'So, just by looking at the graph lines, what feature of the graphs tells us about the resistance? How is the line for X different from that of Z?'

'Yes, that's right!'

'If the slope of the graph is steep or BIG, that means that the resistance is big. A given voltage produces only a small current'.

- X has a BIG resistance and a plot with a steep (BIG) gradient;
- Z has a SMALL resistance and a plot with a gentle (SMALL) gradient.

The final step is actually to find the resistance for each of the three resistors by calculating the gradient for each line. Thus for resistor X:

Gradient = y step/x step

= voltage/current

= OP/OA

### 5. A general equation

In general terms:

Resistance = voltage/current

$$R = V/I$$

$$V = I \times R$$

I = V/R

Having reached this algebraic expression of the relationship between the voltage across a resistor, the resistance of the resistor and the current through the resistor, the pupils can now return to their results table on their 'Looking for patterns' worksheet and calculate the resistance values in their final column.

Pupils might also try using this equation to solve some simple problems.

```
For example:
Suppose a 6 volt battery is connected to a 10 ohm resistor. What current will flow through the resistor?
V = 1 x R
So, 1 = V/R
1 = 6/10 = 0.6 ampere
What does this current value mean in terms of the amount of charge passing through the resistor?
0.6 coulomb of charge passes through the resistor each second.
```

# Looking for patterns in voltage and current measurements



### **Results table**

Power pack setting	Current reading (ampere)	Voltage reading (volt)	Resistance (ohm)
0			
1			
2			
3			
4			
5			
6			
7			
8			

## Lesson 5: Ideas about science and the 'Mystery circuit'

### **Teaching 'story'**

In this lesson the pupils have the opportunity to apply the linked concepts of current/voltage/resistance in two separate contexts. The first activity 'Gold-Bling' involves raising some aspects of 'How science works' and in particular assessing the quality of sets of data. The second activity involves the students in talking and thinking through a slightly unusual 'Mystery Circuit'.

### **Activity 5.1: Gold-Bling**

This activity is set in the world of designer jewellery and the teaching and learning focus is on assessing the quality of data sets. In outline, a designer jeweller uses gold wire in making earrings and brooches and wants to have this wire tested to verify that it is of the correct high quality. The jeweller therefore sends two gold wire samples away to a testing laboratory where the wire is tested by electrical resistance measurements, using exactly the same technique of applying voltages and measuring currents as worked on in the previous lesson. The measurements are compared with those for a standard sample of the high quality gold.

Initial sets of voltage/current/resistance data come back from the laboratory. These consist of single sets of measurements of voltage and current (taken at 0.6V and 1.4V) which lead to opposing conclusions (see tables below: Testing Laboratory Initial Results). One set of measurements suggests that sample A is high quality gold, the other suggests sample B. This disagreement points to the need for fuller sets of data before any firm conclusion can be drawn.

In this way the activity brings out the need to have access to measurements across a wide range of values before any firm conclusions can be drawn from a set of data, and to consider outlier values and means in comparing data sets.

### **Teaching objectives**

- To introduce pupils to key concepts, and associated terminology for assessing the quality of data sets in the context of electricity.
- To probe and develop pupils' ability to assess the quality of data.

### Learning outcomes

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

- recognise the need for measurements taken across a wide range of values;
- recognise the importance of identifying anomalous measurements ('outliers');
- know that the mean can be used to provide a 'best estimate' of a set of data;
- recognise the need to consider the range of values, in addition to the mean, when comparing two sets of data.

### **Teacher's note**

The data sets provided are for ohmic conductors. Specifically, as the current increases, the temperature of the wire (and hence the resistance) does not increase significantly. Some students may suggest that the resistance measurements change as the current changes because the materials do not follow Ohm's Law, but the data do not support this. All wire samples are assumed to have the same length and cross-sectional area.

### What happens during this activity

For this activity the class is taken into the world of 'designer jewellery'. The teacher's first job is to set the scene:

'You are a jewellery designer and suspect that some of the gold wire which you use in making earrings and brooches might not be of the required high quality. You decide to have samples from two different batches of wire tested at a local laboratory. Sample A is taken from one batch of wire and sample B from a different batch of wire.

The laboratory tests the wire samples by connecting them up to a battery and measuring the voltage across them and the current through them. From these voltage and current figures, it is possible to calculate the resistance and to compare the values with those for standard high quality gold. All the wire samples have the same length and cross-sectional area.

The initial results for the two wire samples, A and B, have just come back from the laboratory.

In your group, use the results for wires A and B and the manufacturer's data for standard high quality gold to decide whether each sample is made from the required gold'.

### **Groupwork 1**

### What to prepare

The pupils work in groups of 3 or 4 and each group is given 2 cards:

- 'Manufacturer's data for standard high quality GOLD';
- 'Testing Laboratory Initial Results'.

The Testing Laboratory Results come in two forms, labelled Group 1 and Group 2. Tell the class that these are the INITIAL results from the laboratory. The FULL tests have not yet been carried out:

'So these are the results from the testing lab. They have not had time to carry out the full testing ... but let's see what we have here'.

Half the class are given the Group 1 results, half the Group 2 results.

When the pupil groups compare the Testing Laboratory Initial Results with the Manufacturer's Data for GOLD, they are likely to arrive quickly at the following conclusions:

Group 1 Results: Sample A is gold (measurements made at 1.4V)

Group 2 Results: Sample B is gold (measurements made at 0.6V).

### **GROUP 1 Testing Laboratory Initial Results**

Sample	Voltage (volts)	Current (millamps)	Resistance (ohms)
Α	1.4	149	9.4
В	1.4	151	9.3

### **GROUP 2 Testing Laboratory Initial Results**

Sample	Voltage (volts)	Current (millamps)	Resistance (ohms)
Α	0.6	63	9.5
В	0.6	64	9.4

Voltage (volts)	Current (millamps)	Resistance (ohms)
0.2	22	9.0
0.4	43	9.4
0.6	64	9.4
0.8	89	9.0
1.0	106	9.4
1.2	132	9.1
1.4	149	9.4
1.6	174	9.2
1.8	194	9.3
2.0	220	9.1

### Manufacturer's Data for Standard High Quality Gold

### **Plenary 1**

The teacher asks for feedback from the groups.

### **Plenary**

Pupils report back to the whole class on their conclusions about the gold samples. The teacher first encourages the pupils to express their ideas through an INTERACTIVE/DIALOGIC approach. This becomes more AUTHORITATIVE as the need to take a wider range of readings is established.



Group 1 is likely to claim that Sample A is high quality gold, whilst Group 2 is also likely to claim that Sample B is high quality gold.

'How is it possible to get these different results? Half of you say A and half B, yet these are the findings from the same laboratory'.

The point will emerge that the Group 1 results were taken at 1.4 V whilst the Group 2 results were taken at 0.6V. Ask the class what is needed to get a more definite answer to the question:

'So we have a problem here ... what is needed if we are to get a more definite idea about which of the samples is high quality gold?'

The discussion is likely to lead to the idea that 'more' readings are needed: current and resistance values are only available at two voltages, a wider range of readings is needed. A further important point concerns the precision of the measurements being made. For example at 0.6V, the difference in measured current is only 64 - 63 = 1mA. Can we be sure about this difference? Refer back to the pupils' own practical work:

'Think back to your own measurements! How precise were they? Could you be sure to within 1mA?'

Next the groups are told that FULL data sets, for samples A and B, are now available from the Testing Lab and that these sets consist of measurements made over a wider range. The groups must now return to deciding which sample is the standard high quality gold. All groups now have the same data sets.

### **Groupwork 2**

Allow the groups time to talk through their own ideas about the data before providing support with suggestions here and there.

### What to prepare

The pupils work in the same groups and each group works with 3 cards:

- 'Manufacturer's data for standard high quality GOLD'
- 'Testing laboratory's data for Sample A'
- 'Testing laboratory's data for Sample B'.

### Testing Laboratory's Data for Sample A

Voltage (volts)	Current (milliamps)	Resistance (ohms)
0.2	21	9.6
0.4	43	9.4
0.6	63	9.5
0.8	82	9.7
1.0	102	9.8
1.2	124	9.7
1.4	149	9.4
1.6	188	8.5
1.8	191	9.4
2.0	208	9.6

### Testing Laboratory's Data for Sample B

Voltage (volts)	Current (milliamps)	Resistance (ohms)
0.2	22	9.3
0.4	39	10.2
0.6	64	9.4
0.8	88	9.1
1.0	108	9.3
1.2	130	9.2
1.4	151	9.3
1.6	176	9.1
1.8	189	9.5
2.0	217	9.2

Given the variation in resistance values across the range of voltages, one approach for pupils to take in analysing the data sets is to calculate the mean value for each sample (A and B) and to compare this with the mean for the standard high quality gold. Some groups may suggest plotting graphs for the samples, following on from the approach of the previous lesson, but here we already have the resistance values.

However, within the data sets for Samples A and B there are two clear outliers (values which do not fit the expected pattern). The anomalous results are:

Sample A 1.6V 188mA 8.5 ohms

Sample B 0.4V 39mA 10.2 ohms

If these outliers are removed from each of the data sets, the calculated means are:

Mean for Sample A  $86.1 \div 9 = 9.6$  ohms excluding outlier

Mean for Sample B  $83.4 \div 9 = 9.3$  ohms excluding outlier

These means can then be compared with the mean from the Manufacturer's Data for standard high quality gold:

### Mean for Manufacturer's Data 92.3 ÷ 10 = 9.2 ohms

These means are represented below. The vertical lines indicate the range of values within each data set.



Standard gold data

Sample A

Sample B

Groups of pupils who focus on the mean value (excluding the two outliers) are likely to conclude that Sample B is more likely to be high quality gold than Sample A, since the mean value for Sample B is closer to the mean value for standard high quality gold.

Some groups may also take account of the range of values within each set of data. These groups would also conclude that Sample B is more likely to be high quality gold than Sample A. However these groups would support this conclusion with the additional reasoning that few of the measurements for Sample A lie within the range of measurements for standard high quality gold, whereas all but one measurement for sample B lies within the range of measurements for standard high quality gold.

Some pupils may focus on the mode (the most common value) when comparing the sets of data:

- mode for Manufacturer's data = 9.4;
- mode for Sample A = 9.4;
- mode for Sample B = 9.3.

Pupils using such reasoning would conclude inappropriately that Sample A was high quality gold.

#### **Plenary session 2**

The teacher asks for feedback from the groups

Plenary session Pupils report back to the whole class on their conclusions about the gold samples. The teacher first encourages the pupils to express their ideas through an INTERACTIVE/DIALOGIC approach. This becomes more AUTHORITATIVE as the teacher consolidates ideas about outliers and mean values.



The teacher reviews the decisions made by groups and the reasons for these decisions. Concepts of outlier, mean value and range are explored. The outcome is that the data suggest that Sample B is more likely to be high quality gold than Sample A. Note that this is contrary to what half of the groups are likely to have concluded on the basis of the single measurement values at the beginning of the activity. This emphasises the need to use a range of measurements to establish a valid conclusion.

### Activity 5.2: The 'mystery circuit'

### **Teaching 'story'**

This activity is an interactive demonstration which is designed to encourage pupils to talk and think about a slightly unusual circuit.

The 'mystery' circuit consists of a power supply and two bulbs in series. The mystery aspect comes from the fact that the bulbs are NOT of the same rating (there is a difference in the power of the two bulbs) so that when the circuit is completed one bulb lights whilst the other does not. How can that be? How can we explain this?

### **Teaching objectives**

• To confront pupils with a novel circuit which challenges their existing understanding of electric circuits.

### **Learning outcomes**

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

• explain the working of a series circuit in which there are two bulbs of unequal resistance.

### What to prepare

- A 12 V DC power supply
- One 12V 24W bulb: The BIG bulb (for example a car headlamp bulb)
- One 12V 5W bulb: The SMALL bulb (for example a torch bulb).

### **Mode of interaction**

The teacher works with the pupils through an INTERACTIVE/DIALOGIC approach encouraging them to put forward their ideas about what is happening in the 'MYSTERY CIRCUIT'. After time for consideration of a range of ideas the teacher moves towards the correct solution through an INTERACTIVE/ AUTHORITATIVE APPROACH



### What happens during this activity

The teacher gathers the class around a demonstration table and shows the class the two bulbs. The two bulbs are clearly different in appearance. The question is:

'What do you think will happen if I connect the two bulbs in series to the power supply?'

It is likely that a range of answers will be forthcoming including the idea that:

'Both bulbs will light but will be pretty dim'

The teacher connects up the circuit and switches on the supply. The SMALL (12V 5W) bulb lights, whilst the BIG (12V 24W) bulb shows no sign of lighting.

#### 'How can this be?'

The teacher encourages the class to offer suggestions to explain what is happening here. For some pupils this circuit might shake their belief that the current must be the same all around:

'Perhaps the small bulb uses up all of the current so that the big bulb is left with nothing'

It is certainly worth checking that there is a current flowing all around the circuit. Our own measurements indicate a current of 0.4A in all parts.

'So how come the big bulb does not light?'

At this point it might be helpful to get the rope loop out and to encourage the pupils to use it to work through their ideas. The answer to move towards is that it's all a matter of RESISTANCE:

- there is a current flowing all around the circuit, just like the rope loop moving around;
- however, the bulbs are not the same;
- one has a relatively big resistance. The SMALL 12V 5W bulb has a resistance of about 30 ohm under normal operating conditions;
- the other has a relatively small resistance. The BIG 12V 24W bulb has a resistance of about 6 ohm under normal operating conditions;
- more energy is therefore transferred in the higher resistance bulb (12V 5W) as the current passes through it. Some energy is being transferred in the other bulb (12V 24W) but not enough to heat it up.

Use the rope loop in developing this explanation. Two pupils grip the rope to simulate the two bulbs. Pupil 1 (SMALL bulb: big resistance) grips more tightly than pupil 2 (BIG bulb: small resistance). Pupil 1 will soon notice that their hands are warming up! Pupil 2 feels little heating at all.

Will it make any difference if the battery is turned round and the current flows in the opposite direction? Try this with the rope. No difference! More heating occurs at the bigger resistance regardless of the direction of the current or the relative positions of the bulbs. The diagnostic question 'Bright and dim' probes this point.

### **Bright and dim**

In this circuit, the two bulbs are **not** identical.

Bulb 1 is **bright** and bulb 2 is **dim**.





The battery is now turned round, like this:

### (a) How bright will the bulbs be now?

### Tick **ONE** box:



.....

## Lesson 6: Introducing the concept of power

### **Teaching 'story'**

In this final lesson of the sequence the concept of electrical power is introduced. This builds upon and brings together the earlier work on current and voltage and as such provides a satisfying conclusion to this developing 'scientific story'. There is also the opportunity to make links to the pupils' experiences of using electrical appliances outside school.

### Activity 6.1: On your marks, get set, BOIL!

This is an interactive demonstration, which is intended to promote thinking and discussion about the concept of electrical power. We start with a competition between... two kettles! Which one heats water faster?

### **Teaching objectives**

- To engage the pupils in thinking about electrical appliances which 'work' at different rates.
- To introduce informally the concept of electrical power, which is measured in watt.

### Learning outcomes

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

- recognise that different electrical appliances work at different rates;
- explain that electrical appliances which 'work quickly' have a high power rating and vice versa;
- state that the power of an electrical appliance is measured in watt.

### What to prepare

- 2 domestic kettles of different power rating: maybe 1kW and 2kW
- 2 spotlights.

### **Mode of interaction**

The teacher works with the pupils through an INTERACTIVE/DIALOGIC approach encouraging them to put forward their ideas about which kettle might heat the water more quickly and why. Through a more INTERACTIVE/ AUTHORITATIVE approach, the pupils should also be encouraged to talk through how a fair test might be set up.



### What happens during this activity

The teacher starts by announcing that the class will be witness to a very special race or competition in the lesson. The competition is between ... two kettles!

'Have you ever noticed how SLOW some kettles are in heating water ... especially when you want a QUICK cup of tea or coffee? Well, we're going to have a BIG competition this morning to see which kettle is quickest at heating water'.

Discussion with the class will lead to specifying what is needed to make this a FAIR competition: same volume of water in each kettle; same starting temperature of water; clear specification of the end of the test: when the water reaches boiling point. The pupils should also be encouraged to put forward their ideas about which kettle will be the winner and, more importantly 'WHY?'

One teaching colleague sets up this 'competition' with due ceremony: in the red corner ... in the blue corner ... and with a darkened laboratory and a spotlight on each contender (kettle).

'The aim here is to find out which kettle heats the water more quickly. Who's going for the red kettle? Hands up! And the blue one? 3-2-1 and here we go!'

### Plenary

The kettle race provides vivid proof of one electrical appliance 'working' quicker than another. The winning kettle is more powerful than the other.

'Does anybody know in what units we measure the power of appliances such as kettles?'

Yes, that's right the power of the kettle is measured in watts. Just as you'd expect, if the power of the kettle is high it boils the water quickly. If the power is LOW it boils the water SLOWLY'.

The stage is now set to consider in more detail what is meant by electrical power.

### Activity 6.2: What do we ask for when we buy bulbs?

In this activity the teacher introduces, working from first principles, the concept of electrical power.

### **Teaching objectives**

- To introduce the concept of electrical power in terms of energy (joule) transferred per second.
- To show that the power of an electrical appliance can be calculated as follows: Power (watt) = voltage (volt) x current (ampere).

### Learning outcomes

By the end of this lesson the pupils will be able to:

- define electrical power in terms of energy transferred per second;
- calculate electrical power in terms of: Power (watt) = voltage (volt) x current (ampere).

#### What to prepare

- 12V power supply
- 12V/24W bulb.

### **Mode of interaction**

The talk here is largely INTERACTIVE/ AUTHORITATIVE and NON-INTERACTIVE/AUTHORITATIVE as the teacher takes the lead in guiding the class through to the concept of electrical power and how this can be calculated..



### What happens during this activity

Kettles are not the only things that differ in their electrical power. Pupils are likely to know, for example, that we select and buy light bulbs according to their power in watt.

'Who has ever been to the shop to buy a light bulb. Suppose you said, 'I want a light bulb'. What would the assistant ask?'

'Yes, that's right! What power of bulb? How many watts?'

'What's the difference between a 60W bulb and a 100W bulb? Yes, the 100W bulb is much brighter. It has a bigger power'.

Attention is now turned to a particular bulb (rated at 12V/24W). The teacher sets the bulb up in a simple circuit, switches on the 12 volt supply and enlists the help of pupils in measuring the current through the bulb and the voltage across the bulb. The measurements indicate, in round numbers:

Voltage across bulb = 12V

Current through bulb = 2 A

'Now let's think hard about what these measurements mean... remembering some of the ideas we've been working on in the last few lessons'.

A current of 2A is passing through the bulb. 'What does this mean?'

2 coulomb of charge pass through the bulb each second.

There is a voltage of 12V across the bulb. What does this mean?'

12 joule of energy are transferred as each coulomb of charge passes through the bulb.

### **Teaching 'story'**

This is an important 'corner' of the teaching, where the challenge is to help pupils visualise what is happening inside the filament of the bulb. The pupils should be able to 'see' 2C of charge arriving every second, with each coulomb transferring 12J of energy as it passes through. This leads directly to the conclusion that 24J of energy are being transferred each second in the filament of the bulb. This is the power output of the bulb.

'So you need to picture this in your own head':

'2 coulomb of charge pass through every second, and each coulomb of charge transfers 12 joule of energy'

### So: 24 joule of energy are transferred in the bulb every second

This quantity, the amount of energy transferred by the bulb each second, is called the electrical power of the bulb. In general terms:

### Power (watts) = energy transferred per second (joules/second)

The electrical power is calculated by multiplying together the current through the appliance and the voltage across it:

### Power (watts) = voltage (volt) x current (ampere)

For the bulb example set out above:

Voltage across bulb = 12 volt

Current through bulb = 2 ampere

Power of bulb = 12 volt x 2 ampere

### Power of bulb = 24 watt.

## Activity 6.3: Saving money: knowing the power of electrical appliances

This is a card sort activity which focuses on the range of power ratings of different electrical appliances.

### **Teaching 'story'**

The idea of electrical power provides an interesting and important link to the everyday usage of electrical appliances. At the very least, it is useful for pupils to have a sense of what kinds of devices have a relatively high power rating and are therefore expensive to run.

### **Teaching objectives**

- To make the link between power ratings and everyday electrical appliances.
- To emphasise the point that appliances with a high power rating transfer energy at a high rate and therefore drive up the electricity bill.

### **Learning outcomes**

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

- list electrical appliances according to power rating;
- make the connection between high power and high operating costs.

### What to prepare

Sets of cards for the sorting exercise: appliance cards and power rating cards.

### **Mode of interaction**

As the pupils work in pairs on the card sort activity they should be encouraged to swop ideas through an INTERACTIVE/ DIALOGIC approach. The plenary session gives further opportunities for pupils to state their points of view, and to draw on their experiences of using electrical appliances at home, through a DIALOGIC approach. The challenge for the teacher is to draw these ideas together with an AUTHORITATIVE final summary.



### What happens in this activity

Pupils work in groups of two or four and are given two sets of cards. One set of cards shows different electrical appliances and the other set possible power ratings. The challenge for the pupils is to match the picture of the appliance to the correct power rating:

Appliance	Power Rating (watt)
1. Cooker: fully used rings and oven(s)	12,000W
2. Immersion heater	5,000W (5kW)
3. Washing machine	3, 000 W
4. Twenty tube lie-down sun bed	2,300W
5. Fan heater	2, 000W (2kW)
6. Dishwasher	1,500W
7. Computer system	1,200W
8. Microwave cooker	900W
9. TV (32 inch) switched on	250W
10. Hair tongs	175W
11. Electric blanket	80W
12. MP3 player	50W
13. TV on STANDBY	15W
14. Energy efficient bulb	11W

It works well if the pairs are directed to sort the cards along a 'POWER SCALE' moving from the appliance with the smallest power rating to the one with the largest:



'So, the idea is that you have to match the appliance to the power rating and to set them out in a long line from the appliance with the smallest power to the one with the biggest power. I'll be really interested to see if any groups can get the order exactly right!'

### **Plenary**

In talking through this activity with the class a number of important points can be made:

- the appliances are grouped on the 'power scale' with all of the BIG heating devices at one end;
- there is a considerable difference between the power consumption of a TV in normal use and on standby. BUT, on standby the TV is still transferring 15 joule of energy each second (the actual standby power rating varies between TV sets and can be as high as 30W!). This represents a steady trickle of energy which is transferred with no useful outcome, apart from heating up the room;
- the difference in power ratings between energy efficient bulbs (maybe 11W) and normal filament bulbs (maybe 100W) is striking ... for an equivalent lighting effect.

A fundamentally important point to emphasise is that household electricity bills are based on the amount of ENERGY transferred by all of the appliances in the house over a given period of time (maybe 3 months). Pupils may well have seen the electricity meter which clocks up the amount of energy transferred.

In making comparisons between the costs of using different electrical appliances the key figures are the power ratings. For example:

- the immersion heater operates at 5,000W;
- it transfers 5,000 joule of energy each second;

whilst:

- the TV operates at 250W;
- it transfers 250 joule of energy each second.

so:

- the immersion heater transfers energy 200 times more quickly than the TV;
- the immersion heater makes the electricity meter turn 200 times more quickly;
- the immersion heater consumes money 200 times more quickly.

It is clear that if you want to save money by reducing the electricity bill the appliances to think about first are those with a high power rating. In the case outlined above, turning off the TV is not going to help save much money!
### **Teaching 'story'**

The discussions on 'Saving money' from the previous activity nicely set the scene for work in subsequent lessons on the efficiency of electrical appliances. An obvious starting point lies with a comparison of 'conventional' and 'energy efficient' light bulbs.

### **Activity 6.4: Review: Diagnostic questions**

Three diagnostic questions are provided. The teacher selects from these to review ideas and to promote discussion.

### **Teaching objectives**

• To review the terms/ concepts used during the sequence.

#### Learning outcomes

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

• differentiate between charge, current, voltage, energy, power.

#### What to prepare

The following diagnostic questions are available. Sets of the questions might be made on card and laminated.

	Question	Focus/answer
1.	Best word	Review of terms/concepts: an electric current; electric charge; voltage; energy; power output.
2.	Make a match	Probing meanings: B, D, A.
3.	Who do you agree with?	Two different bulbs in series: agree; disagree; agree.



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## 72 The National Strategies | Secondary Voltage, energy and power in electric circuits



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## **Best word**

In this circuit, a bulb is connected to a battery. The bulb is lit. Below are several sentences about this circuit. Each has a word missing.



For each sentence, choose **the best word** to fill the gap.

Tick one box to show the word you have chosen.

(a) When the bulb lights up, there is going through it.		electricity
		an electric current
		energy
		voltage
(b) While the circuit is complete,		electric charge
flows all of the way around it.		energy
		electricity
		voltage
(c) This flow is caused by the		power
across the terminals of the battery.		electric charge
		voltage
		electricity
(d) While the circuit is switched on, is constantly being transferred from the battery to the bulb and out into the surroundings.		electric charge
		electric current
		energy
		electricity
(e) The amount of energy transferred per second		electric charge
		electric current
		energy
		power output

# Make a match

- A. 1 joule per second
- B. 1 coulomb per second
- C. 1 coulomb per joule
- D. 1 joule per coulomb

Match one of the above to each of the three units listed below:

- a) 1 ampere is the same as: .....
- b) 1 volt is the same as: .....
- c) 1 watt is the same as: .....

# Who do you agree with?

Ben, Tanya and Jane are talking about an electric circuit in which two bulbs are connected in series to a battery. One of the bulbs is BRIGHT but the other is much DIMMER in comparison.



Examine each of the following statements in turn and decide whether you AGREE or DISAGREE with it:

(a) **Tanya:** Well, the bright bulb has a bigger power output than the dim one.

.....AGREE

.....DISAGREE

(b) Ben: I reckon the electric current through the brighter bulb must be bigger.

.....AGREE

.....DISAGREE

(c) **Jane:** I think that the battery voltage is shared between the bulbs and the dimmer one has a smaller voltage drop across it

......DISAGREE ......DISAGREE

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

Date of issue: 02-2008

### Ref: 00094-2008DVD-EN

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