Collins

Cambridge IGCSE™

Physics

TEACHER'S GUIDE

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P4.2 Electrical quantities

Introduction

In this topic students learn about the electrical quantities: charge, current, electromotive force, potential difference and resistance. They learn about electrical energy. This is essential knowledge for Topic 4.3 'Electric circuits'.

Links to other topics

Topics	Essential background knowledge	Useful links
1 Motion, forces and energy		1.7 Energy, work and power
4 Electricity and magnetism	4.1 Simple phenomena of magnetism	4.3 Electric circuits 4.4 Electrical safety 4.5 Electromagnetic effects

Topic overview

P4.2a	**Electric charge** In this learning episode students see experiments that demonstrate simple electrostatic effects. They learn how to use the word 'charge' and why there is a need for two types. They learn an explanation for charge in terms of electrons.
P4.2b	**Current** In this learning episode students are introduced to current as the rate of flow of charge.
P4.2c	**Electromotive force and potential difference** In this learning episode students are introduced to electromotive force. They also learn about potential difference.
P4.2d	**Resistance** In this learning episode students are introduced to resistance. They learn how resistance is measured and the effects of the length and cross-sectional area of a conductor on its resistance.
P4.2e	**Electrical energy and electrical power** This learning episode introduces energy transfers and calculations in electrical circuits.
P4.2f	**Consolidation and summary** This learning episode provides an opportunity for a quick recap on the ideas encountered in the topic as well as time for the students to answer the end of topic questions in the Student Book.

Note on circuit construction

Students regularly struggle with constructing working circuits. There are a number of approaches that can be used to support students with this. Producing 'circuit mats' showing the circuit drawn out 'life size', that students place their components on before connecting can help. Having a correctly wired circuit which students can go and look at to check their circuits can also help. Another challenge is that the teacher may end up 'trouble shooting' electric circuits. Use 'test circuits' at the side of the laboratory to help avoid this. These 'test circuits' are simple bulb – battery circuits that are known to function correctly. A key component is then removed e.g. cell, bulb, wire. Students can then connect the component that they think is 'broken' into the appropriate circuit. If the bulb lights, their component is working correctly, if the bulb does not light, then the component is faulty and should be put to one side for your technician to deal with. Students can then sort out their circuits with much less recourse to the teacher.

Career Links

An understanding of current and potential difference is used in many careers in electrical generation and distribution. Possible careers which require use of ammeters and voltmeters (often as multimeters) include engineering maintenance technician and electronics engineering technician.

Learning episode P4.2a Electric charge

Learning objectives

- State that there are positive and negative charges
- State that positive charges repel other positive charges, negative charges repel other negative charges, but positive charges attract negative charges
- Recall and use a simple electron model to explain the difference between electrical conductors and insulators and give typical examples
- Describe simple experiments to show the production of electrostatic charges by friction and to show the detection of electrostatic charges
- Explain that charging of solids by friction involves only a transfer of negative charge (electrons)
- Describe an experiment to distinguish between electrical conductors and insulators
- Supplement State that charge is measured in coulombs
- Supplement Describe an electric field as a region in which an electric charge experiences a force
- Supplement State that the direction of an electric field at a point is the direction of the force on a positive charge at that point
- Supplement Describe simple electric field patterns, including the direction of the field:
  (a) around a point charge
  (b) around a charged conducting sphere
  (c) between two oppositely charged parallel conducting plates
  end effects will **not** be examined

Common misconceptions

Students need to appreciate the particular use of the word 'charge' to explain static electricity. For many, charging has to do with energy transfer, as in charging a mobile phone. The idea of 'charge' as an attribute of matter similar to mass that is responsible for forces is a difficult one to learn when the word already means something else.

Resources

Student Book pages 238–245

Worksheet P4.2a Friction charging

P4.2a tech notes

Resources for demonstrations and a class practical (see Technician's notes, following)

Approach

Introduce the learning episode

Inflate a balloon. Small 'water balloons' work well for this, but need to be inflated using a balloon pump. Rub the balloon against your hair (or a student's hair – choose straight hair without gel) or a jumper. Notice the interaction between the balloon and the hair. Introduce the idea of electron transfer to explain what is going on.

You could use a Van de Graaff generator to set up some large sparks. Explain that the sparks are caused by rapid heating of the air as electrons jump from one sphere to the other (see tech notes).

SAFETY INFORMATION: Standard safety precautions apply when using electrostatic generators. Please refer to the latest health and safety advice.

Develop the learning episode

Discuss the section ‘Electric charge’ on page 238 of the Student Book. Give students examples of different charges and ask if they will attract or repel.

Discuss the section ‘Conductors and insulators’ on page 239 of the Student Book. Use the simple model of a metal shown in Fig. 4.10 to explain the difference between electrical conductors and insulators. Use Table 4.1 on page 240 to emphasise the difference in electron movement.

Move on to discuss charging by friction. At this point students should carry out the practical given on worksheet P4.2a.

Students dry one end of each polymer strip, and then pull that end through the cloth so it becomes charged.

One strip will be balanced on the evaporating dish so that forces of attraction or repulsion between it and the other strips can be observed.

Discuss the section ‘Charge as the loss or gain of electrons’ on pages 240–241 of the Student Book. The fact that charged objects attract neutral ones can be a barrier to understanding, particularly in practical work. It is best if students find this out early on, but there is no need at this stage for them to understand why it happens in terms of polarisation.

Demonstrate simple electrostatic experiments by charging balloons as follows. Tell students that they need to note down any observations as you do the demonstration.

Inflate each balloon. Take the first one and, holding it at the tied end, briskly rub a cloth over the other end. Suspend the balloon by a thread from a clamp stand. Repeat with the second balloon so that you have two charged balloons, each hanging from a separate clamp stand. (Keep the balloons the same distance from each other on the bench at this point.)

Now bring the two balloons towards each other by moving the stands together. If all is well, they should repel each other, suggesting a rule: **similarly charged objects repel**.

Charge the cellulose acetate strip and polythene strip in turn and hold close to one of the balloons.

The attraction to one of the strips suggests that there is more than one type of charge, leading to another rule: **differently charged objects attract**.

The demonstration works best if the equipment is dry. Liberal use of a hair dryer may help.

Move on to summarise the students’ observations and link these with the section ‘Charge as the loss or gain of electrons on pages 240–241 of the Student Book. Students need to learn that electrons have negative charge, so removing them from a neutral atom leaves the atom with positive charge.

Supplement Introduce the unit of charge as coulombs (C) on page 242 of the Student Book.

Supplement Students should answer the questions on page 242 of the Student Book in pairs.

Supplement Discuss the section ‘Attraction and repulsion’ on pages 242–243 in the Student Book. Remind them that they have met field lines previously when studying magnetism. Use Fig. 4.17 to explain the earlier observations about like charges repelling and unlike charges attracting.

Supplement Extend the discussion to include simple electric field patterns using pages 243–244 of the Student Book.

Students should work through the developing practical skills feature on page 244 of the Student Book with a partner.

Finish the learning episode

Use the Van de Graaff generator to charge a metallised plastic ball on a nylon thread (see tech notes). Note the reaction of the ball to strips of charged cellulose acetate and charged polythene. Ask the class to deduce the charge on the dome of the generator.

SAFETY INFORMATION: Standard safety precautions apply when using electrostatic generators. Please refer to the latest health and safety advice.

Students could make notes on the Science in Context feature on page 243 of the Student Book as part of their homework (this is beyond the requirements of the syllabus but may allow students to explore the content more deeply).

Technician's notes

Be sure to check the latest safety notes on these resources before proceeding.

The following resources are needed for the demonstrations in the introduction and at the end of the activity:

rubber balloon (Small 'water balloons' work particularly well, but must be inflated using a balloon pump)
Van de Graaff generator
metal sphere on insulating handle
lead to connect sphere to base of generator
strips of cellulose acetate and strips of polythene

SAFETY INFORMATION: General safety precautions apply when using electrostatic generators.It is important for the safety of the demonstrator that the base of the generator is properly earthed. No student or member of staff should have electrical items in their pockets, metal in their body or a pacemaker.

The following resources are needed for the class practical P4.2a.1, per group:

woollen cloth
two strips of cellulose acetate, two strips of polythene and one strip of wood
hair dryer
small evaporating dish

The experiment works best if the materials are dry.

The following resources are needed for the demonstration on charging balloons in the main part of the activity:

pair of rubber balloons and thread to suspend the balloons
pair of clamp stands from which to suspend balloons
cellulose acetate strip and polythene strip
woollen cloth and hair dryer

The demonstration works best if the equipment is dry. Liberal use of a hair dryer may help.

Answers

Page 240

1. A electrons

2. negatively charged

3. Supplement 1.0 x 10^{12} electrons

4. The key idea is friction – the particles in the storm clouds rub against each other, and so electrons are transferred between them. As a result, the clouds become charged.

Developing practical skills, page 242

1. Any suitable suggestion – e.g. place a large protractor directly behind the stream of water, lined up so that the undeflected stream follows the zero line. Method should mention taking measurements from directly in front to avoid parallax errors.
2. Any suitable suggestion – e.g. place a beaker below the stream and measure the volume of water collected over a set time. The volume collected should remain constant when the measurement is repeated if the stream is at a constant flow.
3. The independent variable is the ‘amount’ of charge on the rod, the dependent variable is the angle of deflection (of the water stream).
4. In this case, the student cannot say exactly what the charge on the rod is in coulombs. All the student can do is compare the strength of the effects produced by different charges – i.e. the charge on the rod *relative* to the other rods.
5. The distance of the rod from the stream will also affect the angle of deflection – it is a variable that needs to be controlled and kept constant. At the moment, the method does not make it clear how close the student means to bring it or how she will measure it.

Developing practical skills, page 245

Reduce the risks of generating sparks which can cause shocks, or worse, explosions. Only insulators can be charged through friction – metal cannot be charged.

Worksheet P4.2a Friction charging

Apparatus

polythene strips

cellulose acetate strips

woollen cloth

evaporating dish

wooden strip

hair dryer

Method

1. Place the evaporating dish upside down on the table.
2. Balance the wooden strip on the dish so that it can rotate freely.
3. Hold the polythene strip at one end. Dry the other end with the hair dryer.
4. Pull the dry end of the strip briskly through the cloth. Do it several times. This should give the end a **negative** charge.
5. Hold the charged polythene close to the **neutral** wooden strip. There should be a force pulling them together.
6. Replace the wooden strip on the dish with the charged polythene strip. Make sure you know which end is charged.
7. Charge the other polythene strip. Hold it close to the charged end of the strip on the dish. If all is well, the strips should repel each other.
8. Charge the cellulose acetate strip and hold it close to the charged polythene strip. They should attract each other, showing that the cellulose acetate strip has a **positive** charge.
9. Replace the polythene strip on the dish with the charged cellulose acetate strip.
10. Charge the second cellulose acetate strip and hold it close to the one on the dish. They should repel each other, showing that they both have a positive charge.
11. Place the neutral wooden strip back on the dish. Check that it is attracted to the charged cellulose acetate strip.

Interpreting and evaluating data

12. Why do the strips in step 7 repel each other?
13. Explain what happens, in terms of electron transfer, when the polythene strip is rubbed with the cloth.

Learning episode P4.2b Current

Learning objectives

- Know that electric current is related to the flow of charge
- Describe the use of ammeters (analogue and digital) with different ranges
- Describe electrical conduction in metals in terms of the movement of free electrons
- Know the difference between direct current (d.c.) and alternating current (a.c.)
- Supplement Define electric current as the charge passing a point per unit time
- Supplement Recall and use the equation $I = \frac{Q}{t}$
- Supplement State that conventional current is from positive to negative and the flow of free electrons is from negative to positive

Common misconceptions

Students find it difficult to grasp that batteries and Van de Graaff generators do essentially the same job. They may also be confused about the difference between the direction of conventional current (arbitrarily chosen by Benjamin Franklin before electrons were discovered) and that of electron flow in a metallic conductor.

Resources

Student Book pages 245–248

P4.2b tech notes

Resources for class demonstration (see Technician's notes, following)

Approach

Introduce the learning episode

Place a wig of long hair on the dome of a Van de Graaff generator. Charge up the dome and use class questioning or encourage the students to apply their learning from the previous lesson to explain why the hairs stand on end (see tech notes).

SAFETY INFORMATION: Standard safety precautions apply when using electrostatic generators. Please refer to the latest health and safety advice.

Develop the learning episode

Discuss the section headed 'Electric Current' on pages 245–246 of the Student Book.

Carry out the following demonstration to show that charge can be made to flow when a circuit is completed. Connect the dome of the Van de Graaff generator in series with a neon lamp, a microammeter and the base of the generator. Switch on the generator. Note that the lamp glows (perhaps faintly) and the microammeter indicates a current.

Make sure that students understand what the role of the microammeter is in the circuit.

Set up a simple circuit with a bulb. Demonstrate how to use digital and analogue ammeters to measure the current in the circuit. When using an analogue ammeter, make sure students understand the purpose of the backing mirror and using parallax to increase the accuracy of the reading. Students may not have met electric circuits in their previous study, so reassure them that they will study circuits and build their own in the next section of the course.

Supplement Point out that electrons flow in the direction of negative current – early scientists assumed that positive charge flowed through metals! Then replace the generator with a high voltage supply and repeat the experiment. Make sure that students understand the difference between the flow of electrons and the direction of conventional current.

Discuss alternating current (a.c.) and direct current (d.c.) using the section headed 'Alternating current and direct current' on pages 247–248 of the Student Book. Students could sketch the nature of each current (as shown in Fig. 4.26 and Fig. 4.27) and then annotate their diagram with information from the Student Book.

Supplement Introduce the definition of electric current as the charge passing a point in a circuit per unit time. You may need to remind students about charge from the previous learning episode. Ask students to work through the example given on page 247. You may wish to give them other questions to try to ensure that they can correctly use the equation $I = \frac{Q}{t}$.

Supplement Use Fig. 4.29 to discuss the difference between conventional current and electron flow.

Supplement Students could then answer the questions on page 248 of the Student Book in pairs.

Finish the learning episode

Ask students to write down two things that they have learned in the learning episode and one thing that surprised them. Take feedback and discuss responses.

Technician's notes

Be sure to check the latest safety notes on these resources before proceeding.

The following resources are needed for the static wig demonstration:

Van de Graaff generator
wig of long hair to place on dome

It is important for the safety of the operator that the base of the Van de Graaff generator is properly earthed.

A wig made from strips of paper is effective.

The following resources are needed for the static circuits demonstration:

Van de Graaff generator
neon lamp
microammeter (1 μA resolution)
high voltage supply
leads (preferably with transparent insulation so that the metal core is visible)

Subdued lighting makes it easier for students to see the glow of the neon lamp.

A scalamp or light-spot galvanometer works best, but you have to be careful to work down through the ranges from the least sensitive to the most sensitive in order to avoid overloading it.

Be careful when dealing with high voltage supplies – always use the output with the built-in safety resistor.

The following resources are needed for the ammeter demonstration:

simple circuit consisting of a cell and a lamp.
digital ammeter
analogue ammeter

Answers

Supplement Page 248

1. a) 15 C
   b) 20 C
   c) 92 C
   d) 45 C
2. 0.50 A
3. 120 s

Learning episode P4.2c Electromotive force and potential difference

Learning objectives

- Define electromotive force (e.m.f.) as the electrical work done by a source in moving a unit charge around a complete circuit
- Know that the e.m.f. is measured in volts (V)
- Supplement Recall and use the equation for e.m.f. $E = \frac{W}{Q}$
- Define potential difference (p.d.) as the work done by a unit charge passing through a component
- Know that the p.d. between two points is measured in volts (V)
- Supplement Recall and use the equation for p.d. $V = \frac{W}{Q}$
- Describe the use of voltmeters (analogue and digital) with different ranges

Common misconceptions

Students often confuse the terms cell and battery (two or more cells) because battery is used commonly to describe what appears to be a single component. Students also struggle to distinguish between electromotive force and potential difference, especially as both are measured in volts, and potential difference has the symbol *V*. Try to always use the correct terms for e.m.f. and p.d. when discussing electric circuits e.g. ask, ‘What is the e.m.f. of the cell?’ rather than, ‘How many volts can the cell produce?’.

Resources

Student Book pages 248–250

P4.2c tech notes

Resources for class demonstration (see Technician’s notes, following)

Approach

Introduce the learning episode

Ask students to work in pairs to write down what a cell does. Take feedback. Explain that in this learning episode they are going to learn about the function of a cell in an electrical circuit.

Develop the learning episode

Discuss the section ‘Electromotive force’ on page 248 of the Student Book. Emphasise that the e.m.f. can be thought of as the energy transferred into a circuit.

Supplement Introduce the equation used to calculate e.m.f. You may need to remind students about the concepts of work done and charge. Give students some example questions to allow them to calculate the different quantities.

Discuss the section ‘Potential difference’ on page 249 of the Student Book using the concept of energy transfer to explain the difference between e.m.f. and p.d.

Supplement Introduce the equation to calculate potential difference. Provide students with some example calculations to practice.

Show the students a voltmeter and set up the circuits shown on page 250 of the Student Book. Note that they have not yet met circuit symbols in this course, and they will have the opportunity to build circuits for themselves in the next topic.

Stress that the voltmeter goes in parallel with the component, whereas the ammeter goes in series. (Again, students will meet the terms ‘parallel’ and ‘series’ in more detail in the next topic.) Show that the sum of the potential differences across each identical lamp is the same as the potential difference across the cell in the first circuit.

Finish the learning episode

Discuss the main points of the learning episode and check that students have achieved the learning objectives.

Technician's notes

Be sure to check the latest safety notes on these resources before proceeding.

The following resources are needed for the potential difference demonstration:

three voltmeters and one ammeter
two lamps
cell and connecting leads

Learning episode P4.2d Resistance

Learning objectives

- Recall and use the equation for resistance, $R = \frac{V}{I}$
- Describe an experiment to determine resistance using a voltmeter and an ammeter and do the appropriate calculations
- State, qualitatively, the relationship of the resistance of a metallic wire to its length and to its cross-sectional area
- **Supplement** Sketch and explain the current-voltage graphs for a resistor of constant resistance, a filament lamp and a diode
- **Supplement** Recall and use the following relationship for a metallic electrical conductor: (a) resistance is directly proportional to length (b) resistance is inversely proportional to cross-section area

Common misconceptions

As soon as physics becomes quantitative it becomes much more difficult for many students. Voltmeters and ammeters look very similar, so students often confuse current with potential difference.

Some uncertainty at this point is perfectly normal. As long as the correct language is used and misconceptions are corrected every time they come up, students should get things straight in their heads by the end of the topic.

Resources

Student Book pages 250–257

Worksheet P4.2d.1 Current–potential difference graph for a resistor

Worksheet P4.2d.2 Current–potential difference graph for a bulb

P4.2d.1 tech notes

Resources for the class demonstration and practical (see Technician's notes, following)

Approach

Introduce the learning episode

Show students how to assemble the circuit that they will be using in their practical work. You could display the circuit diagram on the screen and invite students to help you to assemble the circuit on the bench. Introduce the idea that all circuit components will provide a resistance to current moving through them. Some components provide a lot of resistance, and others less resistance.

Develop the learning episode

Introduce the quantitative aspects of resistance at this point. Make sure that students can rearrange the equation to make R the subject.

Students can do the worked examples on page 251 of the Student Book without the solutions at first. After a given time, compare their answers to the given solutions and discuss any differences. They should then answer the questions on page 251.

Discuss the section 'Determining resistance' on pages 251–252 of the Student Book before students carry out the practical in worksheet P4.2d.1 Students will assemble a circuit to measure the current in the resistor at a variety of potential differences across it. They will use their results to calculate the resistance of the resistor and draw a graph to show how the current depends on the p.d.

Students may need some help assembling the circuit because this is the first time they have done it. They may need help with evaluating their results because they don't fully appreciate how the uncertainty of their values for p.d. and current affect their calculated values for resistance. This is especially true for low values of current, where errors may easily reach 25%. The graph shows this clearly.

Students can work through the developing practical skills feature on pages 253–254 of the Student Book in pairs.

Supplement Discuss the current-voltage graphs for other components using section 'current-voltage graphs' on pages 252–253 of the Student Book. If time allows, students could carry out the practical in worksheet P4.2d.2 to obtain the current-voltage graphs for a bulb. Discuss why the resistance of the bulb changes with increasing current.

Supplement Assemble the circuit that students used for the resistor practical work. Show that the readings remain unchanged if the resistor is swapped over in the circuit. Explain how this is shown on the current−potential difference graph. Replace the resistor with a diode connected in the forward direction. Show that swapping over the diode results in different values for current and potential difference.

Students should read the section 'Resistance of a metallic wire' on page 253 of the Student Book and make notes to answer the following two questions: (a) how does the length of a wire affect its resistance? (b) how does the cross-sectional area of a wire affect its resistance?

Supplement Study the worked example on page 255 of the Student Book by setting students the problem to attempt in pairs (without the solution). After a given time, bring the class back together to compare students' solutions with the given answer.

Students should answer the questions on page 256.

Finish the learning episode

You could discuss the Science in Context feature on pages 256–257 of the Student Book (this is beyond the requirements of the syllabus but may allow students to explore the content more deeply).

Technician's notes

Be sure to check the latest safety notes on these resources before proceeding.

The following resources are needed for the class practical P4.2d.1, per group:

3 V battery pack
ammeter (0−1 A); voltmeter (0−10 V)
12 Ω resistor (1 W rating at least); variable resistor (0−100 Ω)
4 mm connecting leads

You could use digital meters if they are available.

The following resources are needed for the class practical P4.2d.2, per group:

3 V battery pack
ammeter (0−1 A); voltmeter (0−10 V)
variable resistor (0−100 Ω)
bulb
4 mm connecting leads

The following resources are needed for the demonstration during the activity:

all resources used for class practical
diode (rated at 1 A, for example 1N4000 series diode)

Answers

Page 251

1. 10 V

2. (a) 6.0 Ω (b) Supplement 5.0 C (c) 7.5 Ω The resistance of the lamp has increased.

Developing practical skills, pages 253–254

1. The method involves a comparison between the voltmeter reading and the ammeter reading. These will change in proportion so the absolute values do not matter, the ratio will remain constant.
2. A zero error is where the meter has an incorrect reading when it should in fact read zero. To check the ammeter and voltmeter, the student should connect together the terminals of each meter – if the reading is not zero then the scale on the meter will need to be adjusted.
3. graph drawn; best-fit line should be a straight line through the origin.
4. Resistance is given by the gradient of the line drawn on the graph. The triangle used for the calculation should be clear on the graph and should be of a good size – generally a triangle spreading over at least two-thirds of the graph line would be taken as the minimum acceptable.
5. Calculating the resistance from each pair of readings and then taking a mean would give equal importance to the particular values measured. When drawing the best-fit line on the graph you can make a finer judgement about the value of each data point, weighting the line towards the more general pattern.
6. Heating effects can be reduced by actions such as carrying out the experiment at lower supply voltages and only completing the circuit for short periods of time when measurements are actually being made.

Page 256

1. Length of the wire; cross-sectional area of the wire

2. Resistance would increase

3. Supplement 2.0 Ω

4. Supplement 6.0 Ω

Science in context, page 257

Possible advantage:

- High power production for the same wind speed
- Fewer turbines required for a specific power output

Worksheet P4.2d.1 Current–potential difference graph for a resistor

Apparatus

battery

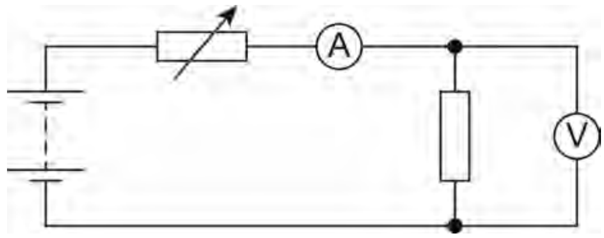
voltmeter

ammeter

fixed resistor

variable resistor

leads



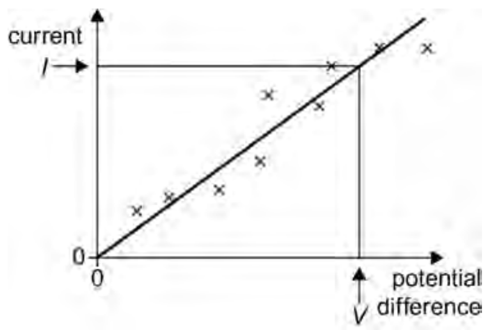
Method

1. Connect the variable resistor, ammeter and fixed resistor in series with the battery.
2. Alter the variable resistor. If all is well, the ammeter reading should change from about 0.03 A to about 0.25 A.
3. Connect the voltmeter in parallel with the fixed resistor.
4. Alter the variable resistor. If all is well, the voltmeter reading should go up and down as the ammeter reading goes up and down.
5. Measure the current in the fixed resistor for 10 different values of potential difference across it. Try to cover the whole range of values evenly.
6. Enter your results in a table like this.

Potential difference/V	Current/A	Resistance/Ω

Interpreting and evaluating data

7. Use your results to plot a current–potential difference graph.
8. Draw a line of best fit though the points.
9. Use your line of best fit to read off a single pair of values for current *I* and potential difference *V*.
10. Use your values for *I* and *V* to calculate a value for the resistance $R = \frac{V}{I}$

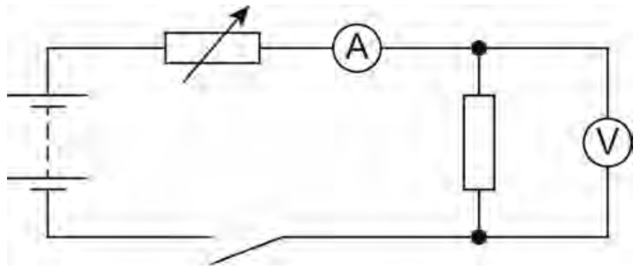


11. What do you notice about the graph?
12. Find the gradient of the graph.
13. Use the rule $\text{resistance} = \frac{\text{potential difference}}{\text{current}}$ to fill in the last column of the table.
14. Do the results agree with the idea of resistance being the same for all values of potential difference? Use your data to justify your answer.

Worksheet P4.2d.2 Current–potential difference (voltage) graph for a bulb

Apparatus

battery
voltmeter
ammeter
bulb
switch
variable resistor
leads



Method

1. Connect the variable resistor, ammeter, switch and bulb in series with the battery.
2. Close the switch and alter the variable resistor. If all is well, the ammeter reading should change from about 0.03 A to about 0.25 A.
3. Connect the voltmeter in parallel with the fixed resistor.
4. Close the switch and alter the variable resistor. If all is well, the voltmeter reading should go up and down as the ammeter reading goes up and down.
5. Now wait for a few minutes to allow the bulb to cool down.
6. Measure the current in the fixed resistor for 10 different values of potential difference across it. Try to cover the whole range of values evenly. Open the switch between each reading.

   Enter your results in a table like this.

Potential difference/V	**Current/A**	**Resistance/Ω**

Interpreting and evaluating data

7. Use your results to plot a current–potential difference graph.

   Draw a line of best fit though the points. This will be a curve.
8. Use your line of best fit to read off a pair of values for current *I* and potential difference *V* at two different values for potential difference. Calculate the resistance of the bulb at these two values for potential difference.

Evaluating methods

9. Suggest why a switch is used to measure the current-potential difference graph for a bulb, but not for a fixed resistor.

Learning episode P4.2e Electrical energy and electrical power

Learning objectives

- Understand that electric circuits transfer energy from a source of electrical energy, such as an electrical cell or mains supply, to the circuit components and then into the surroundings
- Recall and use the equation for electrical power $P = IV$
- Recall and use the equation for electrical energy $E = IVt$
- Define the kilowatt-hour (kW h) and calculate the cost of using electrical appliances where the energy unit is the kW h

Common misconceptions

Students will not yet be used to dealing with mixed units in science, so will need to be made aware of the need to express values in basic units (W, J or s) before putting them into a formula.

Resources

Student Book pages 257–260

Worksheet P4.2e Kettle power

P4.2e.1 tech notes

Resources for demonstration (see Technician's notes, following)

Approach

Introduce the learning episode

Arrange a circus (display) of different mains electrical appliances around the room. Give students ten minutes to find out the power rating (W or kW) of each appliance from its base plate. If the appliances are not available, then provide photographs of base plates for students to use instead.

SAFETY INFORMATION: It is safer to turn off the mains supply to the room while students are handling the appliances.

Develop the learning episode

Using the section on 'electrical energy and electrical power' on pages 257–258 of the Student Book as a guide, explain the significance of the power rating, and do an energy transfer calculation, involving a power rating in kW and a time in minutes or hours, to emphasise the need to get quantities into base units before doing calculations.

Study the worked examples on page 258 of the Student Book by setting students the problem to attempt in pairs (without the solution). After a given time, bring the class back together to compare students' solutions with the given answer. Some students may find these questions challenging because they will not only need to be able to transpose the formula $E = IVt = Pt$ to do these questions but also deal with conversions of power and time to basic units. You may need to provide additional support to students. Students should then answer the questions on page 258 of the Student Book.

Discuss the cost of electricity in your region, and how electricity bills are calculated. Using the section 'the kilowatt-hour' on page 259, show students how the kilowatt-hour is derived. Study the worked example on page 259 using the process described previously.

Students should complete the questions on page 260 of the Student Book.

Finish the learning episode

Carry out the kettle demonstration, which provides the measurements needed to do worksheet P4.2e. You use a kettle to boil a known mass of water.

SAFETY INFORMATION: Boiling water is scalding, and appropriate care should be taken.

Encourage students to help with taking measurements, but do not let them take measurements of the temperature of the boiling water: this is too dangerous. The measurements you need to calculate the heating power of the kettle are the: mass of empty kettle, mass of kettle + water, mass of water abd the temperature rise of the water. From these measurements students can calculate the power rating of the kettle. They can use worksheet P4.2e to carry out the calculation.

Ask students to write down two things that they did well in the learning episode and one thing that they feel they could improve. Discuss responses and deal with any issues that arise.

Technician's notes

Be sure to check the latest safety notes on these resources before proceeding.

The following resources are needed for the demonstrations in the introduction:

A range of mains electrical appliances with base plates that show their power ratings (could include kettle, TV, kitchen blender, hair dryer, desk lamp, computer)

SAFETY INFORMATION: All mains appliances should be school property and have been inspected and tested according to the normal employer's routine.

It is safer to turn off the mains supply to the room while students are handling the appliances.

The appliances should be set out as a circus – at different places around the room. Students go to each appliance in turn.

Place a potato in the oven to cook and use a stop clock to measure how long it takes.

The following resources are needed for the kettle demonstration (worksheet P4.2e.1):

plastic kettle (white if possible); stop clock; scales; thermometer

SAFETY INFORMATION: Boiling water is scalding, and appropriate care should be taken.

Students should be encouraged to help with measurement taking, but no measurements of the temperature of the boiling water should be made, as this is too hazardous.

Answers

Page 258

1. 220 W
2. 10 V
3. 2160 J
4. 3.33 A
5. 12 V

Page 260

1. 0.1 kW h; 1.8 pence
2. 6 kW h; 108 pence
3. lamp uses 0.48 kW h; heater uses 0.48 kW h. Would both cost the same.

Worksheet P4.2e Kettle power

1. Complete these calculations to find the heating power of the kettle.

Mass of empty kettle = ______ kg

Mass of kettle + water = ______ kg

Mass of water = ______ kg

Initial temperature of water = ______ °C

Final temperature of water = ______ °C

Temperature rise of water = 100 °C − ______ °C = ______°C

Energy transferred (J) = mass (kg) × temperature rise (°C) × 4200 J /kg °C

Energy transferred = ______ kg × ______ °C × 4200 J / kg °C = ______ J

Time taken = ______ s

Power rating = $\frac{\text{energy transfer (J)}}{\text{time taken (s)}} = \frac{\_\_\_\_\_\_\text{ J}}{\text{s}}$ = __________ W

Kettle power rating = ______ kW

2. Why do you think the measurement of the power rating does not agree with the rating on the kettle?

Learning episode P4.2f Consolidation and summary

Learning aims

- Review the learning points of the topic summarised in the end of topic checklist
- Test understanding of the topic content by answering the end of topic questions

Resources

Student Book pages 261–264

Approach

Introduce the learning episode

Ask students to work with a partner to make a list of key words from this topic. They could then work together to produce a spider diagram showing how the different concepts are linked. They could compare their list with the list of key terms given on page 261 of the Student Book. Discuss the checklist on pages 261–262 and ask questions to see how much of the content students are comfortable with. Students could make flashcards of the key content and then use the flashcards to quiz each other on the information.

Develop the learning episode

Ask students to work individually through the end of topic questions on pages 263–264 of the Student Book without looking at the text. As they work, walk around the classroom observing their answers and questioning them as necessary to find out which questions are causing difficulties.

Finish the learning episode

After a set period, ask the students to stop working and discuss any areas of difficulty you observed as you walked round the class. Students should complete any unanswered questions for homework, but you should stress that they should attempt the questions without looking at the text, so that they can see how much they have remembered.

Answers

End of topic questions mark scheme

The marks available for a question can often indicate the level of detail you need to provide in your answer.

Question	Correct answer	Marks
1 a)	Electrons are rubbed off the surface of the plastic onto the cloth. Static electricity is produced by removing electrons from one insulator to another. An excess of electrons leads to a negative charge.	1 mark 1 mark
1 b)	The positively charged rod induces a negative charge on the surface of the paper near to the rod. Opposite charges then attract.	1 mark 1 mark
2	The passenger is charged by friction as her clothes rub against the seat covers. The car is also charged by friction with the road and the air. Touching metal allows the charge to flow to earth.	1 mark 1 mark
Supplement 3 a)	current = charge / time = 10 C / 30 s = 0.33 A	1 mark 1 mark
Supplement 3 b) i)	charge = current × time = 10 A × 1 s = 10 C	1 mark 1 mark
Supplement 3 b) ii)	charge = current × time = 10 A × 60 × 60 = 36 000 C	1 mark 1 mark
4 a)	$V = IR = 2 \times 12$ = 24 V	1 mark 1 mark
4 b)	$V = IR = 0.1 \times 200$ = 20 V	1 mark 1 mark
4 c)	$I = V / R = 12 / 100$ = 0.12 A	1 mark 1 mark
4 d)	$I = V / R = 230 / 10$ = 23 A	1 mark 1 mark
4 e)	$R = V / I = 6 / 0.1$ = 60 Ω	1 mark 1 mark
4 f)	$R = V / I = 230 / 10$ = 23 Ω	1 mark 1 mark
Supplement 5 a)	energy used each second = *mgh* mass per second = 360 kg/60 s = 6 kg = 6 kg × 10 m/s^2 × 10 m 600 J/s = 600 W	1 mark 1 mark 1 mark 1 mark

Question	**Correct answer**	**Marks**
Supplement 5 b)	current = power / voltage = 600 W / 12 V = 50 A	1 mark 1 mark 1 mark
Supplement 5 c)	current = power / voltage = 600 W / 220 V = 2.7 A	1 mark 1 mark 1 mark
Supplement 5 d)	A lower current means that you can use a thinner connecting wire, simpler switches and have less energy loss in the wires. 220 V is a safety hazard near the water and will require careful protection for the motor and operator.	1 mark 1 mark
Supplement 6 a)	I = P / V = 1400 W / 230 V = 6.09 A	1 mark 1 mark 1 mark
Supplement 6 b)	1400 W = 1.4 kW and 30 mins = 0.5 hours energy usage = 1.4 x 0.5 = 0.7 kW h	1 mark 1 mark 1 mark
Supplement 6 c)	cost = 0.7kW h x 18p = 12.6 pence	1 mark 1 mark
Supplement 7 a)	Q = I t = 0.1 A x 20 s = 2.0 C	 1 mark 1 mark
Supplement 7 b)	Work done = energy transferred = I V t = 0. A x 1.5 V x 20 s = 3 J	 1 mark 1 mark
	Total:	48 marks

