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OCR
Oxford Cambridge and RSA

GCSE (9–1)

Delivery Guide

TWENTY FIRST CENTURY SCIENCE PHYSICS B

J259

For first teaching in 2016

Electric circuits

Version 1

Can also be used for teaching:
GCSE (9–1) TWENTY FIRST CENTURY COMBINED SCIENCE B

www.ocr.org.uk/physics

GCSE (9 –1)

TWENTY FIRST CENTURY SCIENCE PHYSICS B

Delivery guides are designed to represent a body of knowledge about teaching a particular topic and contain:

- Content: A clear outline of the content covered by the delivery guide;
- Thinking Conceptually: Expert guidance on the key concepts involved, common difficulties students may have, approaches to teaching that can help students understand these concepts and how this topic links conceptually to other areas of the subject;
- Thinking Contextually: A range of suggested teaching activities using a variety of themes so that different activities can be selected which best suit particular classes, learning styles or teaching approaches.

If you have any feedback on this Delivery Guide or suggestions for other resources you would like OCR to develop, please email resources.feedback@ocr.org.uk

QUALIFICATION AWAITING ACCREDITATION

'These draft qualifications have not yet been accredited by Ofqual. They are published (along with specimen assessment materials, summary brochures and sample resources) to enable teachers to have early sight of our proposed approach.

Further changes may be required and no assurance can be given at this time that the proposed qualifications will be made available in their current form, or that they will be accredited in time for first teaching in 2016 and first award in 2018.

Subtopic 4 – What determines the rate of energy transfer in a circuit?

Subtopic 5 – What are magnetic fields?

Subtopic 6 – How do electric motors work?

Subtopic 7 – What is the process inside an electric generator?

The images used throughout this guide have been provided to help aid learners' understanding and learning in this topic area.

A brief description is provided below each image.

P3.1.1	Describe the production of static electricity, and sparking, by rubbing surfaces, and evidence that charged objects exert forces of attraction or repulsion on one another when not in contact
P3.1.2	Explain how transfer of electrons between objects can explain the phenomenon of static electricity
P3.1.3	Explain the concept of an electric field and how it helps to explain the phenomenon of static electricity

Sufficient build up of charge causes air to lose its resistance, and discharges occur.

General approaches:

Most learners will have personal experience of static electricity; this is an opportunity to explain phenomena that are already to some extent familiar and link them to the more complicated concepts introduced later on. It is useful at this early stage to ground the concept of charge as representing in some sense an actual number of things; a number of 'missing' or 'extra' electrons, in the case of most static electricity; a number of electrons being moved around a circuit in the case of later subtopics. The idea that things with charge experience forces of attraction and repulsion should be familiar from what learners already know about basic magnetism, and the understanding that charge can be dissipated, or evened out, with a transfer of charged particles - usually electrons – should be easy enough to communicate. This topic relies on some understanding of ideas dealt with in later chapters, though, so some introduction of the atomic model, with small light negatively charged electrons on the edge of atoms and large positively charged nuclei at the centre, might help in terms of understanding just why electrons are so much easier to move, and therefore more likely to do so when there's an attractive or repulsive force, than protons.

Common misconceptions or difficulties learners may have:

It is possible for learners to confuse the idea of an amount of charge with the concept of positive and negative charge. A negative charge is not in reality 'less' charge; it's just an amount of one of the two types of charge. While positive and negative charges will cancel each other when summed, like positive and negative numbers, it is sometimes necessary to reiterate the point that the names 'positive and negative' are arbitrary, and simply represent two opposite kinds of thing. More advanced learners might appreciate the information that quarks have three kinds of charge, named after colours. The direction of field lines can also be confusing, since they are given as flowing from positive to negative charges, whereas we know that electrons flow in the opposite direction, but this can be explained by pointing out that the field lines represent the direction of force experienced by a positive charge, and that, in order to see the lines for a negative charge, we can simply reverse the arrows. In reality, as long as it's clear that the attractive and repulsive forces are mutual, it should also be easy to explain that the direction of the arrows makes so little difference for our purposes as to be negligible.

Conceptual links to other areas of the specification – useful ways to approach this topic to set learners up for topics later in the course:

Although later parts of this chapter are quite specialised, the introductory ideas are connected to almost all the other major areas of the physics course. The electromagnetic field is the field in which EM radiation (chapter 1) propagates; the ways in which electric current can be generated relate directly to issues of energy consumption (chapter 2) and climate change (1.2); The attractive and repulsive forces of electric and magnetic fields are examples of the way forces act on matter (chapter 4), and the idea of electron exchange connects to the subject of particle models and atomic structures, which connects centrally with the subjects of chapters 5 and 6.

There are also connections with other areas of the science curriculum; learners may find out more about the structure of the atom in chemistry, and indeed may discover the existence of ion exchange in biology.

When discussing the attraction of materials with a strong charge imbalance to those that are balanced, you can emphasise that it's the difference between charges that creates the attractive force; this early mention of the idea that a difference creates an attractive force can be expanded upon when discussing potential difference and voltage in following subtopics of this chapter.

Approaches to teaching the content:

There are several simple and well-known experiments and activities that can demonstrate the behaviour of static electricity, and the concepts underlying it are fundamental to much of our understanding of physics, so it is worth encouraging learners to think in terms of the exchange of charged particles experiencing forces when conducting them. Later on in the chapter, the equations will start to proliferate and it will become harder to visualise the physics of what's happening, so it's important at this early stage to ground learners in basic concepts such as charge and field strength, as well as the idea that the mechanism for the exchange of charge and dissipation of potential difference is the exchange of charged particles.

Note: several of the resources in this chapter use Java; although there have been security concerns with Java, it by all accounts should be safe if it's kept updated regularly. If you are still unsure, it can help to disable your computer's internet connection while using the software, and disable Java when you reconnect the computer.

Electric field lines demonstrated.

Activity 1

Electric fields experiment

Nuffield Foundation
http://www.nuffieldfoundation.org/practical-physics/electric-fields

A simple experiment to show electric field patterns using semolina and castor oil.

A relatively straightforward demonstration of semolina seeds exhibiting similar behaviour under the influence of electric fields as you would see in iron filings in a magnetic field. In this case, the fact that the phenomenon is not magnetism can be demonstrated by trying magnets instead of electrical connections.

Activity 2

John Travoltage, and Balloons And Static Electricity

PHET – University of Colorado Boulder
http://phet.colorado.edu/en/simulation/john-travoltage

Rubbing John's foot on the carpet and moving his finger near the doorknob gives him an electric shock, and the flow of charges can be traced.

This is extremely simple, but potentially amusing to some learners.

Activity 3

Balloons And Static Electricity

PHET – University of Colorado Boulder
http://phet.colorado.edu/en/simulation/balloons-and-static-electricity

Rubbing balloons causes attractive forces to operate on the balloon.

A far better simplification of static electricity in common objects in a familiar context. Learners can observe that the balloons are repelled by each other, attracted to the jumper and mildly attracted to the wall; charge distribution and polarisation are simply described.

Activity 4

Electromagnetism - Electrostatic Force: The Four Fundamental Forces of Physics #4a

SciShow
https://www.youtube.com/watch?v=GMnsZuEE_m8

Part one of a pair of videos linking electrostatics and magnetism, and observing some interesting links to other parts of the curriculum.

The fact that all energy exchange between particles is done by photons might confuse some learners, but it does link with various ideas introduced in chapter 1, such as the absorption and emission of EM radiation at different frequencies (and thus with different energies) by matter.

Activity 5

The Birth of a Lightning Bolt

YouTube
https://www.youtube.com/watch?v=6MUYsIjTKvk

A short documentary video about the filming in ultra high speed of a flash of lightning.

There are some aspects of the behaviour of the lightning that may surprise some learners.

Activity 6

Kelvin Water Dropper

Maglab
https://nationalmaglab.org/education/magnet-academy/watch-play/interactive/kelvin-water-dropper

A simple interactive model of Kelvin's water dropper, which amplifies electrostatic charge differences between two vessels to the point where there is a discharge.

In addition to its ingenuity, this can be a useful demonstration of the transfer of mechanical energy (the pumping of the water) into electrical potential energy.

Activity 7

Electric Field Of Dreams

PHET – University of Colorado Boulder
http://phet.colorado.edu/en/simulation/efield

A Java applet featuring a small square in which particles of different charges and masses can be placed and their interactions observed. A field of user-defined strength and direction can be applied across the whole area.

This is particularly interesting if you play with large variations in mass and charge between particles. The fact that more massive particles seem to 'resist' the field because of their larger kinetic energy can be related to the increased resistance of most conductors when heated in the next subtopic.

Activity 8

Electric Field Hockey

PHET – University of Colorado Boulder
https://phet.colorado.edu/en/simulation/electric-hockey

A Java game in which the object is to guide a charged 'puck' into a goal using other charges placed around the field to attract and repel it. Two harder levels introduce obstacles that the puck may not collide with.

There are several similar games online, including http://www.physicsclassroom.com/Physics-Interactives/Static-Electricity/Put-the-Charge-in-the-Goal/Put-the-Charge-in-the-Goal-Interactive and http://www.pbslearningmedia.org/resource/npe11.sci.phys.matter.charges/electric-charges-interact/; This one is helpful because of the ability to show field lines and trace the puck's path, and also because it connects directly to the previous visualisation.

Activity 9

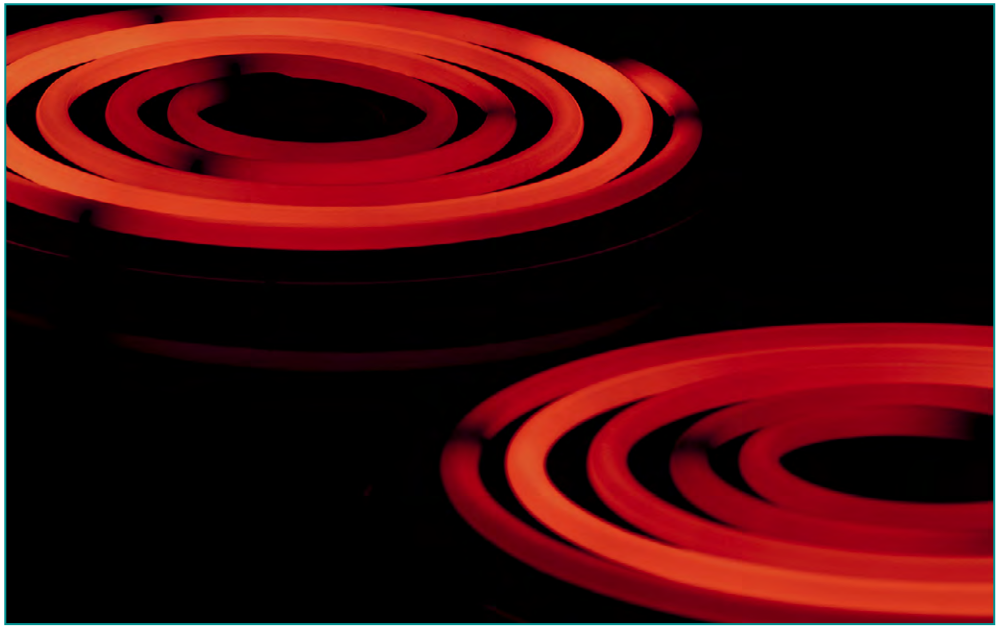
Gas Station Fire, Static Electricity Starts a Flash Fire

YouTube
https://www.youtube.com/watch?v=tuZxFL9cGkI

A short piece of security camera footage in which a spark from a driver's jumper at a petrol station causes a fire.

In fact, we are rather more likely to cause dangerous sparks with static electricity at petrol stations than with electronic devices.

P3.2.1		Recall that current is a rate of flow of charge, that for a charge to flow, a source of potential difference and a closed circuit are needed and that a current has the same value at any point in a single closed loop
P3.2.2		Recall and use the relationship between quantity of charge, current and time charge (C) = current (A) x time (s)
P3.2.3		Recall that current (I) depends on both resistance (R) and potential difference (V) and the units in which these quantities are measured
P3.2.4	a)	Recall and apply the relationship between I, R, and V, to calculate the currents, potential differences and resistances in d.c. series circuits, potential difference (V) = current (A) x resistance (Ω)
	b)	Recall and apply the relationship between I, R, and V, to calculate the currents, potential differences and resistances in d.c. series circuits, potential difference (V) = current (A) x resistance (Ω) PAG7
P3.2.5		Recall that for some components the value of R remains constant (fixed resistors) but that in others it can change as the current changes (e.g. heating elements, lamp filaments)
P3.2.6	a)	Use graphs to explore whether circuit elements are linear or non linear and relate the curves produced to their function and properties M4c, M4d, M4e
	b)	Describe experiments to investigate the I-V characteristics of circuit elements. To include: lamps, diodes, LDRs and thermistors. Be able to draw circuit diagrams for the circuits used PAG6
P3.2.7		Represent circuits with the conventions of positive and negative terminals, and the symbols that represent common circuit elements, including filament lamps, diodes, LDRs and thermistors



Passing a high current through a conductor heats it up.

General approaches:

As the chapter progresses, learners will be required to become familiar with a number of equations describing relationships between quantities: energy, charge, power, current, resistance, potential difference and so on. It is useful at this early stage to remind learners that most of these are simply definitions of the terms themselves expressed in different ways, and that they all relate to energy, charge and time. Developing the ability to manipulate simple algebraic relationships is crucial at this stage, and reminders that the current represents the charge (and therefore the aggregate number of electrons passing any point) per second, should be useful. Although resistance is a harder concept to resolve mathematically, it seems many learners find it easier to understand intuitively than ideas such as potential difference; it's not too hard to imagine that a higher resistance simply means you have to push/pull harder (with a higher voltage) to get more charge through per second (current); many analogies are usable.

Common misconceptions or difficulties learners may have:

Encouraging learners to manipulate the equations in this subtopic may allow them to produce nonsensical results; learners may discover that, if they imagine a circuit having no resistance and work out the current, it is infinite. Grounding them in the concept that current is an actual flow of charged particles and reminding them that all wires have some resistance, even though it can often be negligible as far as our calculations are concerned, should help explain why this doesn't happen, as well as being an opportunity to remind learners of the dangers of short circuits.

The energy in the voltage of a circuit is of course work done; it is the amount of energy being transferred by the flow of charge. This may confuse learners who notice that electrical potential and potential difference are different things measured in the same units, but should be easy for learners to accept; the name 'potential difference' can be explained as being the difference in potentials between charges at different points in the circuit instead of simply the measure of the potential at one point, just as the difference between the speeds of two trains on a track would be measured in the same units as the speeds of the cars.

The fact that conventional current moves in the opposite direction from the actual direction in which charges flow in circuits may bother some learners, but, as before, it should be pointed out that as far as the examples we will be considering in this chapter are concerned (particularly when magnetism is introduced), there is no effective difference between positive charge flowing in one direction in a circuit and negative charge flowing in the other.

Conceptual links to other areas of the specification – useful ways to approach this topic to set learners up for topics later in the course:

This subtopic is the beginning of much that will underlie the more complicated concepts explored later in the chapter. By emphasising that potential difference in a circuit represents energy over charge and that current is charge over time, the relationship between power, voltage and current introduced in later subtopics can be suggested. It is also useful if learners get used to the relationship between measurements in simple circuits so that the behaviour of more complex ones later on can be interpreted more easily; learners can see, for instance, that a drop in current without a drop in voltage means an increased resistance, without necessarily having to do the sums, which will be useful when dealing with parallel circuits in subtopic 3. Discussions of various models of electric current and voltage can be an opportunity to discuss the merits of various models with learners, and to explore ideas of critical thinking in IaS1.

Approaches to teaching the content:

There are various analogies for voltage and current in circuits, all of which eventually fall down. There are gravitational analogies (as explored in one or two of the resources), which can be useful but which don't take account of the repulsion of like charges, water pump analogies, in which the mechanism by which the water is pumped can make it easy to confuse voltage and current, and various others. As mentioned above, this can be a valuable opportunity to discuss the idea of using analogies and models to describe concepts, but of course the concepts need to be grasped fully before that can happen, so it is important to make sure learners are able not just to remember the equations but also to understand the relationships they represent, otherwise the maths later on will become unnecessarily confusing. There are few activities demonstrating this subtopic that do not simply involve making circuits and observing their behaviour, since building analogical models of electric circuits is usually harder than building the circuits themselves, so I have concentrated on explanations and attempts to give learners some kind of 'feel' for what is actually going on.

Activity 1

Ohm's Law - Ohm's Law, Circuits, Resistance - PhET

PHET – University of Colorado Boulder
http://phet.colorado.edu/en/simulation/ohms-law

A simple activity in which voltage and resistance can be manipulated in a circuit to change current.

This is extremely simple, but can be helpful in grounding learners in the concept of the relationship between volts, amps and Ohms.

Activity 2

Does Volts or Amps Kill You? Voltage, Current and Resistance

RimstarOrg
https://www.youtube.com/watch?v=9iKD7vuq-rY

A short video about the relative dangers of different amounts of current and voltage on humans.

Despite the poor grammar of the title (more literate learners may enjoy pointing out that either 'does" should be "do" or "Volts" and "Amps" should be "voltage" and "current") and the incorrect spelling of "respiratory" in the onscreen text, this is an informative video, that connects to the idea of resistance changing with different currents and voltages as well as connecting to the idea that substances can have different resistances under different conditions.

Activity 3

Electric circuits || A battery (cell)

Durham University
https://community.dur.ac.uk/p.m.johnson/electric_circuits/02_battery.htm

A partly interactive presentation about cells and DC circuits.

This presentation, featuring several sequential pages, some of which have slightly interactive graphics, is quite in-depth, and makes some useful gravitational analogies as well as describing the processes of current flow more accurately than many descriptions.

Activity 4

Electric Potential: Visualizing Voltage with 3D animations

YouTube
https://www.youtube.com/watch?v=-Rb9guSEeVE

A video in which potential and potential difference are visualised using a gravitational analogy and CGI.

As useful as this model is in many ways, more able learners can have fun pointing out the flaws in the analogy and the presentation; questions and criticisms of the video's shortcomings can be encouraged in terms of exploring the limits of analogies.

Activity 5

Temperature effects on resistance

Learnabout Electronics
http://www.learnabout-electronics.org/Resistors/resistors_01a.php

A short explanation of resistance changes due to temperature in different materials.

This is part of a series of short texts on resistance and conduction which interested learners can be encouraged to explore.

Activity 6

How to Make a Lemon Battery

SciShow
https://www.youtube.com/watch?v=GhbuhT1GDpI

A short video showing how to make a lemon battery and exploding some myths about the experiment.

Again, more able learners may be interested in the statement "the electricity is not in the lemon". Of course, as with all ways of generating electric currents, a form of energy is being converted into electrical energy, and in this case it is chemical potential energy.

Activity 7

Ohm's Law using emojis

YouTube
https://www.youtube.com/watch?v=NqZZ-S74EFA

A short video using emojis to represent charged particles and current flow.

Another attempt to describe the concepts introduced in this subtopic in a way that helps learners visualise the processes involved.

The potential difference between two sections of canal.

P3.3.1	Relate the potential difference between two points in the circuit to the work done on, or by, a given amount of charge as it moves between these points potential difference (V) = work done (energy transferred) (J) / charge (C) M1c, M3b, M3c, M3d
P3.3.2	a) Describe the difference between series and parallel circuits: to include ideas about how the current through each component and the potential difference across each component is affected by a change in resistance of a component b) Describe how to practically investigate the brightness of bulbs in series and parallel circuits. Be able to draw circuit diagrams for the circuits used PAG7
P3.3.3	Explain, why, if two resistors are in series the net resistance is increased, whereas with two in parallel the net resistance is decreased qualitative explanation only
P3.3.4	Solve problems for circuits which include resistors in series, using the concept of equivalent resistance M1c, M3b, M3c, M3d
P3.3.5	Explain the design and use of d.c. series circuits for measurement and testing purposes including exploring the effect of : a) changing current in filament lamps, diodes, thermistors and LDRs b) changing light intensity on an LDR c) changing temperature of a thermistor (ntc only)

General approaches:

This tends to be the point at which learners who are not confident with the basic meanings of the terms being used struggle. It can be easy to get relationships mixed up and inverted, so remembering that voltage can be seen as energy per amount of charge and so on is important. As the calculations become more complicated, learners should begin to become familiar with the results of changing variables in circuits. As with the last subtopic, there is no substitute for experience, both in manipulating and using the equations and in using circuits or models thereof. The fact that the results of calculations can be verified with experiment should help reinforce the concepts.

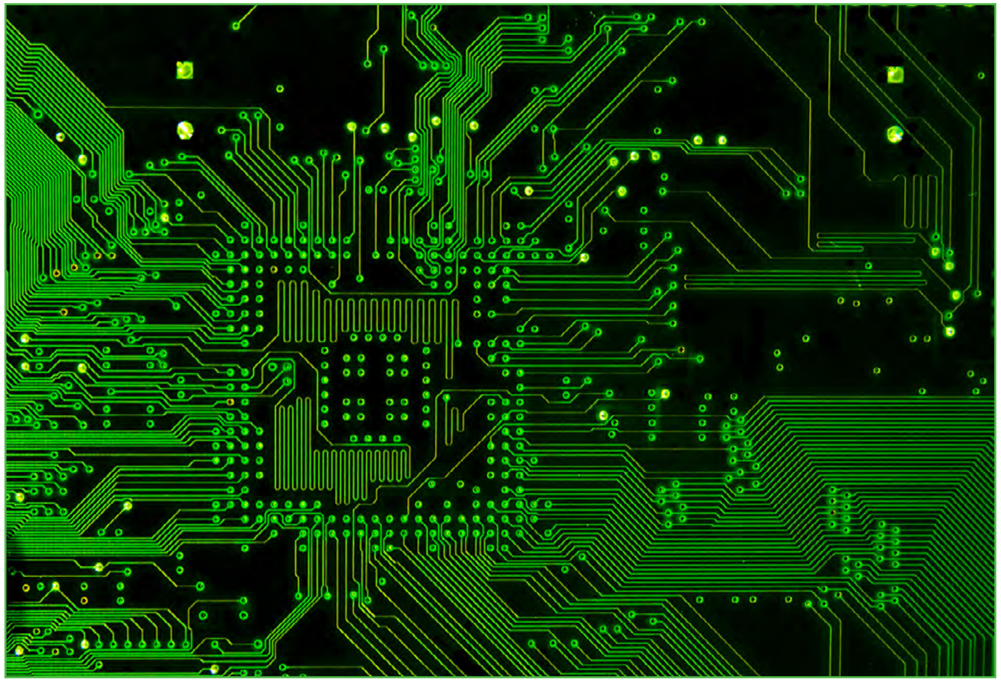
Common misconceptions or difficulties learners may have:

When we talk about voltages and currents dividing and adding across different types of circuit, and especially when we begin to introduce equations using reciprocals for resistors in parallel, learners can become confused; the process of deriving the larger equations from smaller and more manageable steps should not be rushed; learners will need to understand how the conclusions about the behaviour of series and parallel circuits behave are reached and what they mean. The idea that adding a resistor in parallel reduces the overall resistance may surprise some learners, but of course you are not adding resistance to the circuit; you are adding a branch to the circuit, which cannot stop charge flowing through the original resistor and therefore cannot increase the overall resistance of the circuit.

The behaviour of cells or batteries in parallel may also confuse some learners, who can wonder why an increase in the amount of potential energy available doesn't affect the current or voltage across the circuit; the explanation that each cell adds a certain amount of electrical potential to each charge that goes through it and that therefore the cells in parallel merely divide the charges flowing through the circuit instead of adding more potential energy to each one can be difficult. The idea that the extra energy provided by having more batteries/cells is translated into a longer battery life often helps.

Conceptual links to other areas of the specification – useful ways to approach this topic to set learners up for topics later in the course:

The relationships between terms and an understanding of the behaviour of branching currents are central to the following subtopics. In particular, the equations defining voltage and current will end up allowing us to derive the relationship between power, voltage and current from the definition of power in terms of energy and time given in subtopic 4. Again, the limitations and drawbacks of using analogies can be discussed, relating to topics in IaS1.



The movement of charged particles can achieve more impressive feats than you might imagine.

Approaches to teaching the content:

At this stage, analogies for concepts become increasingly unwieldy, and it is worth grounding learners in the reality of the phenomena being modelled from time to time and reinforcing new concepts with practical experimental examples as often as possible. Later on in the chapter, variables will become harder to quantify and experimental error will increase, so an understanding of the practical reliability of the principles involved under controlled conditions at this stage is extremely useful.

One hopes these lights are connected in parallel.

Activity 1

Circuit Construction Kit (DC Only), Virtual Lab - Circuits, Light Bulbs, Batteries - PhET

PHET – University of Colorado Boulder
http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc-virtual-lab

A flexible Java application modelling a circuit. Users can investigate the effects of combining different components in various ways.

This is relatively easy to use, and is particularly useful in allowing learners to experiment with circuits that would be unsafe in practice, while allowing learners to test successful ideas on real circuits afterwards.

Activity 2

Circuit Builder Interactive

Physics Classroom
http://www.physicsclassroom.com/Physics-Interactives/Electric-Circuits/Circuit-Builder/Circuit-Builder-Interactive

Another circuit simulator; a little simpler, but also easier to use.

Although this only allows limited scope, it is rather simpler and quicker than the previous application, and might be preferred for demonstrating simpler concepts.

Activity 3

Electric Circuits: Basics of the voltage and current laws

YouTube

https://www.youtube.com/watch?v=m4jzgqZu-4s

A follow-on visualisation video from those in the previous subtopic, in which a continuation of the gravitational analogy using CGI is used to explore the behaviour of circuits.

Again, more able learners can point out the advantages and disadvantages of the models being used. This video does contain some useful reminders of important ideas, and reminds learners that conventional current and electron flow are in opposite directions.

Activity 4

Series and Parallel Circuits: A Water Analogy

YouTube

https://www.youtube.com/watch?v=7_7NO2Np5-s

A video featuring an experiment to model the behaviour of resistors in series and in parallel using water.

This analogy is so obviously stretched that it can seem miraculous that it works at all, but of course it is extremely crude. The point is to provide a variety of analogies in order to reinforce some basic concepts.

Activity 5

Bitesize - GCSE Physics - Electrical circuits, AC and DC - Activity

BBC
http://www.bbc.co.uk/education/guides/zddp34j/activity

A partly interactive presentation about series and parallel circuits.

This contains more analogies and explanations, and the page contains links to a related revision page and test, which are useful revision aids.

Activity 6

Thermistor Experiment

YouTube
https://www.youtube.com/watch?v=TkI9flzIi0I

A video demonstration of an experiment to calibrate a thermistor.

Despite the spelling error in the title text (learners may enjoy spotting it), this is an interesting experiment, whose reliability can be tested by checking predicted temperature (from calculated resistance due to measured current) against measured temperature.

Curriculum content

Subtopic 4 – P3.4 What determines the rate of energy transfer in a circuit?

P3.4.1	Describe the energy transfers that take place when a system is changed by work done when a current flows through a component
P3.4.2	Explain, with reference to examples, how the power transfer in any circuit device is related to the energy transferred from the power supply to the device and its surroundings over a given time power (W) = energy (J) ÷ time (s) M1c, M3b, M3c, M3d
P3.4.3	Recall and use the relationship between the potential difference across the component and the total charge to calculate the energy transferred in an electric circuit when a current flows through a component energy transferred (work done) (J) = charge (C) x potential difference (V) M1c, M3b, M3c, M3d
P3.4.4	Recall and apply the relationships between power transferred in any circuit device, the potential difference across it, the current through it, and its resistance power (W) = potential difference (V) x current (A) power (W) = (current (A))2 x resistance (Ω) M1c, M3b, M3c, M3d
P3.4.5	Recall and apply the relationships between power transferred in any circuit device, the potential difference across it, the current through it, and its resistance power (W) = potential difference (V) x current (A) power (W) = (current (A))2 x resistance (Ω) M1c, M3b, M3c, M3d
P3.4.6	explain how transmitting power at higher voltages is more efficient way to transfer energy

General approaches:

This is the point in the chapter where most analogies break down, mostly because of their limited accuracy when describing the processes that give energy to charged particles. It is also hard to create experiments and activities that demonstrate the phenomena concerned without simply using the relevant equipment and testing the results, and, since the relationship between magnetic and electric fields has not yet been properly established, it is difficult to go further with the explanation of transformers than a statement of the relationship between primary and secondary coils and voltages. Thus, a lot of the teaching in this topic can concentrate on increasing learners' abilities to use and manipulate the relevant equations and combine smaller parts into an understanding of a more complex system.

Common misconceptions or difficulties learners may have:

At this stage, confusion about the identities and definitions of the proliferating terms and quantities can confuse learners. Keeping track of the meanings of the variables in equations in terms of 'basic' quantities such as charge and energy can be hard. Even though the calculations are becoming harder, it is still possible to link them to an understanding that scientists create and define these terms in order to make it easier to calculate quantities that would require even more complex equations if we insisted on leaving everything in terms of charge, energy, time and so on, especially considering that many of the quantities are more practically useful and measurable than their derivations.

The different types of energy per charge that can be measured in Volts are also a potential source of confusion; again, potential energy between charges and voltage drop across circuits are different, but obviously related, things. Some patience may be required to solidify these concepts for uncertain learners.

The fact that potential difference and resistance determine current may make the idea of power confusing to some learners; if the voltage and the current depend on each other and the resistance, what does the power do? It can be useful to talk about power being drawn or used rather than given or added; the idea can again be reinforced that power is a measure of the rate at which energy is being given to charge by the voltage, and the relationship between this statement or equivalents and the relevant equations can be pointed out. Learners can be encouraged to realise that, given a steady voltage, power drawn does indeed depend on the resistance of the circuit. Manipulations of the relevant equations can show that both resistance and power can be reduced to relationships between time and energy, although in the case of resistance this relationship is not as straightforward as with power.

Conceptual links to other areas of the specification – useful ways to approach this topic to set learners up for topics later in the course:

Since this is the last subtopic before the full introduction of the magnetic element of electromagnetism in subtopic 5, it represents the culmination of what can be understood at this level in terms of electric potential without reference to magnetism, induction and so on; indeed, induction has already been introduced via transformers. Thus, it is a useful point at which to make sure that the basic concepts of the electrical component of this chapter are grasped by learners before moving to the next stage.

Approaches to teaching the content:

It is rather hard to find ways of dealing with this area of the topic without simply addressing the phenomena concerned. There are, no useful analogies for transformers, since they depend on very specific relationships between the electrical and magnetic aspects of electromagnetism that have no analogy in other forces available to us in experiments or demonstrations. Thus, this is necessarily a slightly 'dry' part of the chapter, featuring much recapping and practising of techniques. This can be counterbalanced somewhat with the satisfaction successful learners should get as their ability to manipulate equations and juggle concepts increases.

Using more power than most amplifiers.

Activity 1

Bitesize - GCSE Physics - How do current and energy differ?

BBC
http://www.bbc.co.uk/education/clips/zmr6sbk

Learner resource 1
www.ocr.org.uk/Images/281303-electric-circuits-learner-resource.doc

A short video explaining the difference between energy and current.

As well as being another decent stab at an analogy, this video allows us to ask learners an interesting question that tests their understanding of concepts introduced in previous chapters, as outlined in the associated learner resource..

Activity 2

Molecular Expressions: Electricity and Magnetism

Molecular Expressions
http://micro.magnet.fsu.edu/electromag/java/transformer/index.html

A simple interactive Java application that shows output voltage in a transformer with a varying input voltage and number of windings on each coil.

This should give learners an idea that it is the relationship between the number of windings on each coil and not the absolute number that determines the relationship between the input and output voltages. However, learners may speculate about why we bother using more than the minimum possible number of coils, which leads on to the next subtopic quite neatly.

Activity 3

Transmission Lines

MagLab
https://nationalmaglab.org/education/magnet-academy/watch-play/interactive/transmission-lines

A very simple interactive graphic with a power source, transformers and lightbulbs to represent energy transfer in which users can alter the voltage between transformers and see the energy lost when carrying higher current, along with a brief explanation of the results.

The idea that higher currents lose more energy can be related back to the fact that higher currents cause more energy to be transferred to components in circuits, for instance by making bulbs glow brighter and resistors get hotter.

Activity 4

Power Line on Metal Swing

YouTube

https://www.youtube.com/watch?v=28Xq3JulV1o

A short video of an electrical fire caused by a power line falling on a metal swing.

Learners can be encouraged to ask questions about the interactions involved and to relate the events in the video to what they already know about the behaviour of currents and fields.

Activity 5

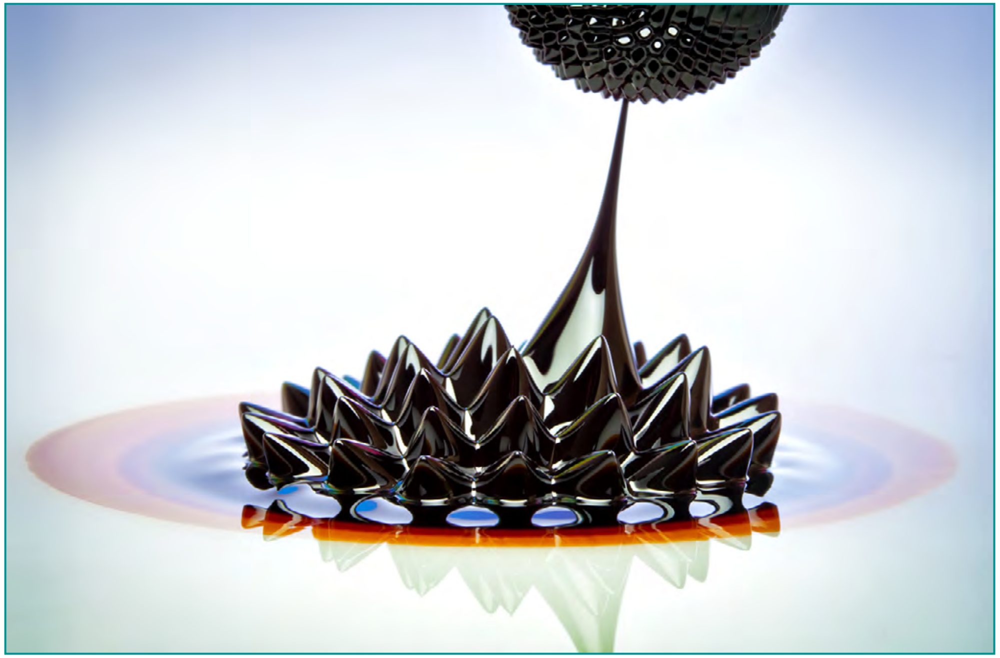
Transformers are Awesome!

Doc Physics
https://www.youtube.com/watch?v=jDuxFEgtSAQ

A medium-length (18 minutes) video about transformers, which goes into some advanced details but strongly reiterates some basic mathematical relationships and answers one or two questions more able learners may have.

This is slightly idiosyncratic, and largely pen-and-paper-based, but deals with some important concepts, including conservation of energy in a transformer, and includes some worked examples that learners can try for themselves.

P3.5.1	Describe the attraction and repulsion between unlike and like poles for permanent magnets
P3.5.2	Describe the characteristics of the magnetic field of a magnet, showing how strength and direction change from one point to another
P3.5.3	Explain how the behaviour of a magnetic compass is related to evidence that the core of the Earth must be magnetic
P3.5.4	Describe the difference between permanent and induced magnets
P3.5.5	Describe how to show that a current can create a magnetic effect
P3.5.6	Describe the pattern and directions of the magnetic field around a conducting wire
P3.5.7	Recall that the strength of the field depends on the current and the distance from the conductor
P3.5.8	Explain how the magnetic effect of a solenoid can be increased
P3.5.9	Explain how a solenoid can be used to generate sound in loudspeakers and headphones



Fun with ferrofluids.

General approaches:

Having introduced a lot of terms and equations, we are back to concepts. Learners should be familiar with the basics of magnetism, so it is usually possible to dive in and start discussing the specifics of the behaviour of magnetic fields and their interaction with electric charges. In this subtopic it is the relationship between the electric and magnetic fields and the occasionally counterintuitive implications thereof that learners need to grasp. Visual aids can be very important in this area; luckily, magnetism is easier to demonstrate visually than electrostatic field; all the obvious uses of iron filings and compasses in this regard are to be encouraged.

Common misconceptions or difficulties learners may have:

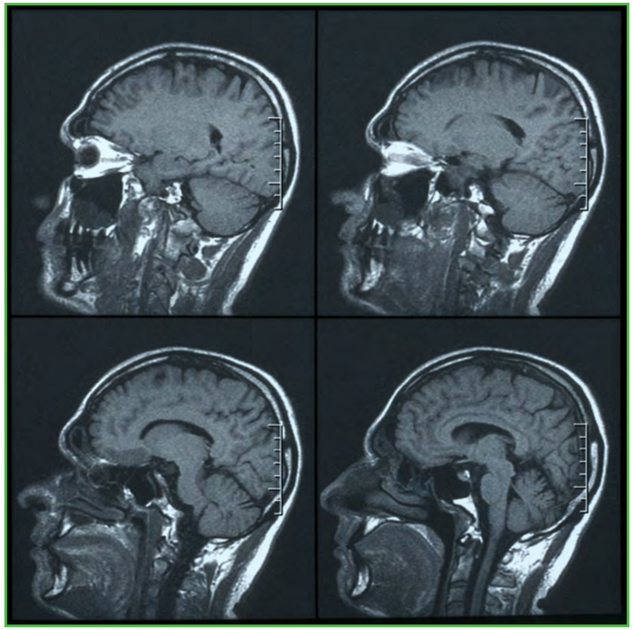
At first sight, the perpendicular nature of electric and magnetic fields may not seem to tally with the circular fields we see around wires; pointing out that the wire is actually an object in three dimensions and imagining a thicker cylinder with a current where the circular field is the result of field lines being perpendicular to the surface of the cylinder at any point may help. With any luck, later explanations of how coils generate stronger fields that 'line up' along the cylinder the conducting wires are coiled around should be understandable with enough reference to visual aids; the way the wheels under a conveyor belt rotate but move the belt in one direction is a useful image.

If we define magnetic fields as resulting from the motion of electric charges, many learners will be confused; ferromagnets seem to have no moving parts. Of course, the moving parts, as in circuits, are electrons, and, although the theory behind this is advanced, the fact that electrons spin inside atoms should not be difficult for learners to grasp, and the knowledge that it is the motion of the same particles in both ferromagnets and currents in circuits that creates magnetic fields may be satisfying.

Conceptual links to other areas of the specification – useful ways to approach this topic to set learners up for topics later in the course:

The relationship between magnetism and electricity is central to the next two subtopics, and achieving a clear understanding of magnetic fields as resulting from moving electric charges and the reciprocal induction of electric charges by moving magnetic fields is the main goal of this part of the chapter. Equations featuring new terms, such as magnetic field strength, should not be too hard to introduce. More able learners may be interested to know that the perpendicular relationship of electric and magnetic fields is connected to the polarisation of light, a subject touched on briefly in chapter 1, and some more advanced ideas about how waves can propagate in the electromagnetic field may be referred to if learners are sufficiently interested.

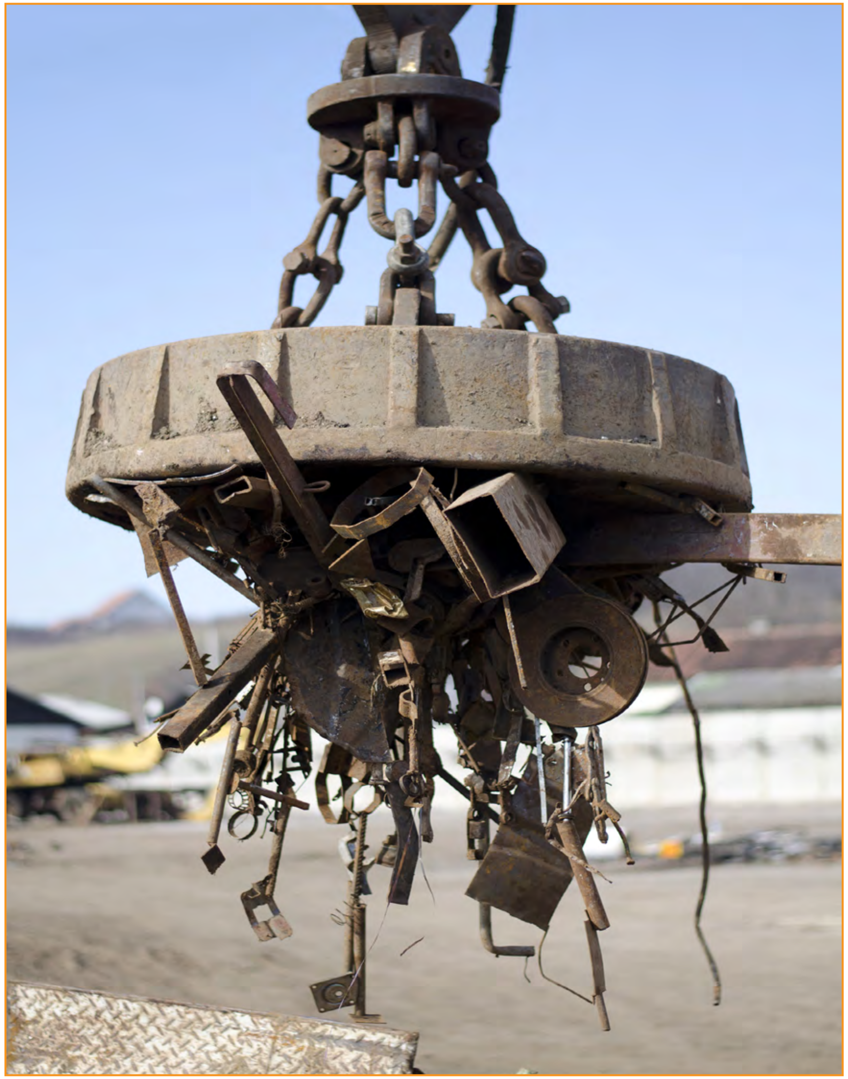
The difference between the behaviours of metals and non metals when it comes to electromagnetism can be linked to topics in Chemistry chapters 2 and 3 for more able learners.



Magnetic Resonance Imaging.

Approaches to teaching the content:

This area is much easier to deal with in visual and physical ways than ideas introduced in the previous two subtopics. Magnetism is relatively harmless, easy to visualise using magnetic materials and familiar to most people. Many of the experiments traditionally used to explain concepts in magnetism can seem like 'light relief' to many learners after the maths-heavy topics of energy transfer, resistance calculations and so on; this part of the chapter can favour more practical and visual learners who may have struggled in those areas. Likewise, those who have trouble visualising spatial relationships may need some reminders of relationships such as the right hand rule, and perhaps verbalisations (the field direction is anticlockwise if the [conventional] current direction is pointing towards you). Given that there are so many simple and obvious experiments, the resources attached are mostly visualisation aids, explanations of interesting phenomena and so on.



An electromagnet picks up scrap metal at a junkyard.

Activity 1

Electromagnetism - Magnetic Force: The Four Fundamental Forces of Physics #4b

SciShow
https://www.youtube.com/watch?v=cy6kba3A8vY

Part two of a pair of videos linking electrostatics and magnetism, and observing some interesting links to other parts of the curriculum.

A pleasingly clear and simple introduction, this links neatly from the previous video in the series, which is included in the resources for subtopic 3.1.

Activity 2

Magnets and Electromagnets - Magnetism, Magnetic Field, Electromagnets

PHET – University of Colorado Boulder
http://phet.colorado.edu/en/simulation/magnets-and-electromagnets

An interactive Java application in which a magnet and an electromagnet can be moved relative to a compass, with a large number of variable parameters and several visualisation options.

This is a very neat visualisation, and can help learners understand the nature of magnetic fields. Reference to, and comparison with, earlier electric field activities can be encouraged. Learners may notice that the Earth's magnet appears to be pointing the wrong way, with the south pole facing north. They should be encouraged to work out the reason why for themselves, if they haven't already been told.

Activity 3

Faraday's Law 1.0.2

PHET – University of Colorado Boulder
https://phet.colorado.edu/sims/html/faradays-law/latest/faradays-law_en.html

An interactive Java application allowing users to move a magnet relative to coils in order to produce a voltage.

Simpler than the previous interactive, this allows users to move a bar magnet relative to two differently-sized coils and see the resultant voltage.

Activity 4

How do magnets work? - James May's Q&A

Head Squeeze
https://www.youtube.com/watch?v=hcORdjvxvDg

A short video in which James May explains magnetism.

Another introductory video, this time in a more traditionally televisual style, with plenty of amusing visualisations and examples.

Activity 5

Magnetic Field lines, 3D

YouTube
https://www.youtube.com/watch?v=8IlkHQtaOlg

A video of a simple experiment with a suspension of iron filings to show magnetic field lines in three dimensions.

It is easier to show magnetic fields in two dimensions than in three; this simple video shows the standard field pattern extended around the magnet.

Activity 6

The Lenz Effect: Aluminium, Moving Magnets, Electricity, and Magnetism

YouTube
https://www.youtube.com/watch?v=yk4ACjzDFRY

A short video demonstrating interactions between a moving magnet and a non ferromagnetic electrical conductor.

This video deals only with the basic fact of the interaction between fields, and does not go into detail about the specifics of the shapes of the fields. This contains a fun demonstration of a magnet falling slowly through an aluminium tube, and all of the experiments in the video should be easily replicable in the classroom.

Activity 7

Why Earth's Magnetic Shield Matters

Science Channel
https://www.youtube.com/watch?v=hcORdjvxvDg

A short video about Earth's magnetosphere.

This video links ideas from various other areas with this subtopic, and may help learners visualise Earth's magnetic field as the result of rotation in its core, connecting with the idea of a linear magnetic field generated by a rotating charge referred to before when discussing electrons creating ferromagnetism.

Activity 8

Melt metal with magnets

YouTube
https://www.youtube.com/watch?v=8i2OVqWo9s0

A short video of a piece of metal being melted by an electromagnet with no contact.

This should spark some interesting conversations about the processes involved. Learners can be reminded about the effect on conductors of very high currents.

Activity 9

How do speakers work?

ABC
https://www.youtube.com/watch?v=lTkzxflX4EY

A short video showing the basic mechanism of a speaker and a simple speaker made from a cardboard sheet.

The fact that speakers and microphones still use reasonably simple mechanisms based on the relationship between electricity and magnetism despite the increasing computerisation of the devices we use to play the music might be interesting to some learners.

Activity 10

FWS - Doing SCIENCE! with ferrofluid

Myles Power
https://www.youtube.com/watch?v=1EuyZ5Lml4k

A short video about ferrofluids, including a brief description of how to make one.

Ferrofluids can be used to demonstrate magnetic field patterns in three dimensions in ways that are difficult with, say, iron filings.

Activity 11

Richard Feynman on magnets

YouTube
https://www.youtube.com/watch?v=MO0r930Sn_8

A ten-minute video of Richard Feynman being asked to explain magnetic attraction and repulsion.

The first few minutes of this video are really a philosophical digression, but the points made are of course brilliant and apposite, and it is never a bad time to hear from Richard Feynman. This video connects to ideas in IaS1 and elsewhere in this chapter about the usefulness of analogies and models.

P3.6.1	**Describe the interaction forces between a magnet and a current-carrying conductor to include ideas about magnetic fields**
P3.6.2	**Show that Fleming's left-hand rule represents the relative orientations of the force, the conductor and the magnetic field**
P3.6.3	**Select and apply the equation that links the force (F) on a conductor to the strength of the field (B), the size of the current (I) and the length of conductor(l) to calculate the forces involved** **force (N) = magnetic field strength (T)×current (A) × length of conductor (m)**
P3.6.4	**Explain how the force on a conductor in a magnetic field is used to cause rotation in the rectangular coil of a simple electric motor** ***detailed knowledge of the construction of motors not required***

The rollers rotate; the conveyor belt moves in one direction; an analogy for several circular fields resolving to a single linear one.

General approaches:

Most of the important concepts needed in order to understand this subtopic have already been introduced; this is the point at which the implications of the phenomena we have previously observed can be put together and the potential uses explored. The geometry of the right-and left-hand rules and their applications is very important here, and errors are easily corrected; mistakes are likely to result in behaviour that is clearly the opposite of that predicted. Luckily, Fleming's left-hand rule seems peculiarly memorable. The relationships between moving, rotating, linear and circular fields are the most important basic concepts here; learners should find the equations no harder to manipulate than those in previous subtopics, although relationships between terms may be less intuitively clear.

Common misconceptions or difficulties learners may have:

Learners may experience some confusion when dealing with the spatial relationships between fields, and the equations governing force and field strength can seem unconnected to previous quantities, relationships and terms. Analogies between force on a conductor and force on a mass due to gravity can be made to some extent. Reminding learners that the length of the conductor and the current combined are proportional to the number of charged particles flowing through it can help.

Conceptual links to other areas of the specification – useful ways to approach this topic to set learners up for topics later in the course:

This subtopic is very clearly one of two parts of the finale of this assessment of the essential characteristics and uses of electromagnetic charges, currents and fields. The idea that motors and generators are two almost opposite ways of exploiting the same phenomenon, just as microphones and speakers are, should become clear to learners; some may reach this conclusion before being told. The introduction of force and its units will connect directly to chapter 4, and some discussion of forces and motion may need to take place if the relationship between force and energy is queried by any learners.

Approaches to teaching the content:

This subtopic is an opportunity to demonstrate some obvious practical applications of the principles introduced over the course of the chapter. The simplicity of the most basic motors may surprise some learners, and the knowledge that rotating motion is relatively easy to generate next to linear motion may interest some.

Predicting the direction of motion/current using the hand rules is an easy way of testing intuition; this can be turned into a very simple game.

An electric car charging.

Activity 1

It really spins around! - Simple models of electric motor

EU-HOU
http://www.euhou.net/index.php/exercises-mainmenu-13/classroom-experiments-and-activities-mainmenu-186/195-it-really-spins-around-simple-models-of-electric-motor

A set of simple motors that can be made with easily available materials.

There are a few different models, of varying complexity; these activities can be chosen with reference to the time available.

Activity 2

DIY MOTOR School Project DC Electric Motor with Commutator

YouTube
https://www.youtube.com/watch?v=vg2dOxxwcA0

A more advanced DC motor with commutator and brushes.

The building of this motor is not explained, though the materials used are. More able learners may wish to try working out how to build it.

Activity 3

Magnetic Field Around a Wire, I

MagLab
https://nationalmaglab.org/education/magnet-academy/watch-play/interactive/magnetic-field-around-a-wire-i

A simple interactive page in which the magnetic field around a current-carrying wire is shown.

This contains not only another representation of the three-dimensional relationship between moving charge and magnetic fields, but also a handy reminder of the difference between the direction of conventional current and electron flow.

Activity 4

Right and Left Hand Rules

MagLab
https://nationalmaglab.org/education/magnet-academy/watch-play/interactive/right-and-left-hand-rules
A very basic page with graphics showing both the right hand rule and Fleming's left hand rule.

A follow-on from the previous interactive.

Activity 5

Electric Motor

Animated Science
http://animatedscience.co.uk/blog/electric-motor

An interactive application in which the user can set voltage, number of magnets and number of coils on a simple virtual motor to observe the effect on its motion.

The ability to take a top-down view is helpful in this application.

Curriculum content

Subtopic 7– P3.7 What is the process inside an electric generator?

P3.7.1	**Recall that a change in the magnetic field around a conductor can give rise to an induced potential difference across its ends, which could drive a current**
P3.7.2	explain the action of a moving coil microphone in converting the pressure variations in sound waves into variations in current in electrical circuits
P3.7.3	**Recall that the direction of the induced potential difference drives a current which generates a second magnetic field that would oppose the original change in field**
P3.7.4	**Use ideas about electromagnetic induction to explain a potential difference / time graph showing the output from an alternator being used to generate a.c.**
P3.7.5	**Explain how an alternator can be adapted to produce a dynamo to generate d.c., including explaining a potential difference time graph**
P3.7.6	**Explain how the effect of an alternating current in one circuit in inducing a current in another is used in transformers**
P3.7.7	**Describe how the ratio of the potential differences across the two circuits of a transformer depends on the ratio of the numbers of turns in each**
P3.7.8	**Apply the equations linking the potential differences and numbers of turns in the two coils of a transformer, to the currents and the power transfer involved and relate these to the advantages of power transmission at high voltages:** **potential difference across primary coil x current in primary coil = potential difference across secondary coil x current in secondary coil** **potential difference across primary coil ÷ potential difference across secondary coil = number of turns in primary coil ÷ number of turns in secondary coil**

General approaches:

Again, we are dealing with the implications of ideas introduced in earlier subtopics; most of the information required to draw the necessary conclusions has already been seen. If learners have grasped them adequately, they should be easily guided through the final stages. Reference to resources from previous chapters is encouraged. If learners have struggled with particular elements of the chapter, this subtopic is an opportunity to recap.

Common misconceptions or difficulties learners may have:

At this stage, learners may have trouble following the many different terms and concepts they will be required to manipulate. The idea of conservation of power through a transformer might not seem obvious; of course it can, and probably should, be pointed out that in fact no mechanical process is 100% efficient, but that the point is that it is a highly efficient process, and more importantly that you cannot get more power out of a transformer than you put into it. This relates to the conservation of energy, a concept that should be referred to whenever possible at this stage. Analogies between gravitation and electromagnetic attraction and repulsion will have broken down by now, so it is important that learners begin to think of electromagnetic phenomena on their own terms instead of as water flowing through pipes or balls rolling down slopes.

Conceptual links to other areas of the specification – useful ways to approach this topic to set learners up for topics later in the course:

Questions of how electric power can be generated relate to chapter 2 – Sustainable Energy, and the understanding of the relationship between energy, fields, force and motion is directly relevant to chapter 4 – Explaining Motion.

Approaches to teaching the content:

At this point, only demonstrations of the actual phenomena described and reiterations of the important concepts are of any real use. This is also a time to practice manipulating equations and using different terms to describe processes. Learners should by now be familiar with all the tools they need to calculate and predict the behaviour of the basic processes by which devices convert electrical energy to and from mechanical energy, while understanding that, for instance in batteries, other types of energy can just be converted just as effectively; it is mostly a question of familiarity and confidence with the relationships and symmetries concerned.

One of the simplest examples of a generator.

Activity 1

How Transformers Work

YouTube
https://www.youtube.com/watch?v=ZjwzpoCiF8A

A short video explaining how transformers work.

This is nicely methodical, and recaps much that has been before, while covering the theory of transformers in more depth and joining some other dots..

Activity 2

Generator - Generator, Magnetism, Magnetic Field

PHET – University of Colorado Boulder
http://phet.colorado.edu/en/simulation/generator

An interactive Java application featuring a virtual magnet, electromagnet, transformer and generator.

An extension of the 'Magnets and Electromagnets' activity from subtopic 5, this contains several interactives, each following from the last, all with plenty of parameters and visualisation options. This is a very useful tool for recapping and demonstrating the application of principles encountered in previous subtopics to the subject of this one.

Activity 3

Generator - AC

Molecular Expressions
http://micro.magnet.fsu.edu/electromag/java/generator/ac.html

A simple Java application showing an AC generator.

A very basic interactive, to be compared and contrasted with the following one.

Activity 4

Generator - DC

Molecular Expressions
http://micro.magnet.fsu.edu/electromag/java/generator/dc.html

A simple Java application showing a DC generator.

Learners may enjoy spotting the difference between this generator and the previous one.

Activity 5

Guitar Pickup

MagLab
https://nationalmaglab.org/education/magnet-academy/watch-play/interactive/guitar-pickup

A simple demonstration of the principles by which electric guitar pickups work.

Learners may be interested to discuss question of why pickups cannot be used on acoustic guitars with nylon strings, and also to explore the differences between a pickup and a microphone.

Activity 6

Generation of Alternating Current

PBS Learningmedia
http://www.pbslearningmedia.org/resource/ate10.sci.phys.energy.generation/generation-of-alternating-current/

A presentation explaining AC generation.

This is a touch dry, but there is a nice demonstration of a sinusoidal voltage graph at the end.

Activity 7

How do microphones work?

FAQbites
https://www.youtube.com/watch?v=d_crXXbuEKE

A short video explaining how different kinds of microphones work.

This includes a reminder that loudspeakers are microphones in reverse.

Converting mechanical energy into electrical energy and back again, also known as rock and roll.

The small print

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