# Physics Module 4: Electricity and Magnetism



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## Course overview

Year 11 Physics offers students the opportunity to observe and measure a wide range of physical phenomena in the world around them, including motion, mechanical interactions, mechanical waves, geometrical optics, heat transfer, electricity, and magnetism. Students learn to describe and make sense of these phenomena in terms of a limited number of physical laws. These include fundamental interactions (forces) between matter particles, such as gravity and electric and magnetic forces, as well as laws that govern how these interactions change the motion of particles and systems of particles, including Newton’s 3 laws of motion and conservation laws such as conservation of energy, linear momentum, and charge. Students strengthen and communicate their understanding using a range of representations, including descriptions, diagrams, graphs, and mathematical models.

## Teaching the Year 11 Modules

Students begin Stage 6 Physics with substantial experience of the world around them and, as a result, have developed explanations to make sense of their observations. Some of these beliefs may be inconsistent with accepted physics, such as the idea that objects naturally come to rest in the absence of a force, or that there is no gravity in space. However, due to the apparent explanatory power of these ideas in students’ everyday experience, they see objects consistently come to rest and know that astronauts float in the International Space Station. These misconceptions, also known as ‘alternate conceptions’ or ‘common naïve conceptions’, can be quite resistant to change, as convincingly demonstrated in [Three Incorrect Laws of Motion (2:28)](https://www.youtube.com/watch?v=Yf0BN0kq7OU). To shift these existing conceptions, students must find physics explanations for everyday physical phenomena more convincing than their own existing beliefs.

Physics education research has established that ‘traditional’ instruction styles are substantially less effective at improving students’ conceptual understanding of physics than ‘active learning’ approaches (Hake 1998). These ‘traditional’ styles include students watching and listening to an exposition of physics theory, completing ‘cookbook’ style practical investigations, as well as textbook problems that emphasise calculations and equation manipulation. ‘Active learning’ approaches are characterised by students’ active participation in constructing knowledge and substantial gains in student conceptual understanding have been found to be approximately double than those obtained from a ‘traditional’ approach (Hake 1998).

Learning activities that promote this kind of interactive engagement will generally:

* encourage students to actively express their thinking about physical phenomena in verbal or written form, or via other representations such as diagrams, graphs, or mathematical models
* involve receiving immediate or interactive feedback about their thinking from peers, a teacher, and/or their own observations
* utilise (as far as possible) real physical systems which require students to make observations and measurements
* involve students in making decisions about the most appropriate way to analyse (model and represent) observations
* encourage students to reflect on their thinking and how the physics they are learning about ‘fits together’ as an interrelated and coherent whole
* value and check for conceptual understanding in diagnostic, formative, and summative assessment.

**Some examples in practice**

Question 10 from the [2021 HSC Physics exam](https://educationstandards.nsw.edu.au/wps/portal/nesa/resource-finder/hsc-exam-papers/2021/physics-2021-hsc-exam-pack) can be used to probe students’ conceptual understanding. This question asks students about the direction of the force on a copper block as a strong magnet moves past it. This is an excellent question for active learning because it is experimentally testable. Students make predictions, explain their reasoning to others, and then check their beliefs by moving a magnet past a copper block. Videos can be used to resolve the question if the equipment is unavailable; for example, the last part of [5c Eddy currents and electromagnetic braking (1:11)](https://www.youtube.com/watch?v=RhqAVKm7rns).

Question 14 from the [2021 HSC Physics exam](https://educationstandards.nsw.edu.au/wps/portal/nesa/resource-finder/hsc-exam-papers/2021/physics-2021-hsc-exam-pack) asks about the gravitational interaction between the Earth and the Moon. While questions like this cannot be answered experimentally in the classroom, they can still be valuable in addressing common misconceptions (such as the force acting on the moon is smaller than the force acting on the Earth). When students engage in peer instruction in answering this question by ‘convincing’ each other, a deeper understanding of the concepts can be promoted.

**Resources on active learning approaches to teaching physics, including the characteristics of effective, research-based physics teaching:**

* [Ten results of physics education research that every physics instructor should know](https://www.physport.org/recommendations/Entry.cfm?ID=93336#:~:text=Download%20pdf%20of%20Top%2010%20talk)
* [What makes research-based teaching methods in physics work?](https://www.physport.org/recommendations/Entry.cfm?ID=93328)
* [Resource Letter ALIP–1: Active-Learning Instructions in Physics](https://www.semanticscholar.org/paper/ALIP-%E2%80%93-1-%3A-Active-Learning-Instruction-in-Physics-Meltzer-Thornton/ca2948752c56f60a71b544bd4032d8aea747d720)
* [Tools for Teaching Science](https://resources.perimeterinstitute.ca/products/tools-for-teaching-science?variant=32563928662094)
* [New-Time Questions](https://www.arborsci.com/pages/next-time-questions).

**Further reading**

* Knight R (2002) *Five Easy Lessons: Strategies for Successful Physics Teaching*, Pearson Education. ISBN: 9780805387025

This is a practical and readable guide to teaching physics effectively. It is suitable for both beginning and experienced physics teachers. Research-informed sample questions that focus on conceptual understanding and detailed suggestions for active learning activities are provided for each topic.

* Mestre J and Docktor J (2020) *The Science of Leaning Physics: Cognitive Strategies for Improving Instruction*, World Scientific Publishing Co Pte Ltd. ISBN: 9789811226540

This provides an overview of physics education research. In addition, it includes a review of the results of cognitive science and educational psychology on the effectiveness of practice testing and spaced repetition. The e-book version of this text is inexpensive and of excellent value.

* Arons AB (1996) *Teaching Introductory Physics*, John Wiley & Sons Inc. ISBN: 9780471137078

Thisincludes suggestions for research-based, conceptual questions that can be used with students. This text can be ‘borrowed’ from the [Open Library](https://openlibrary.org/books/OL979479M/Teaching_introductory_physics).

* Redish EF (2003) *Teaching Physics with the Physics Suite,* John Wiley & Sons Inc. ISBN: 9780471393788

This is an extremely engaging text from a very experienced physics educator that gives an overview of several research-based approaches to teaching physics. In addition, Redish provides a concise and convincing summary of how findings from cognitive science and physics education research can be utilised to teach physics effectively.

* Mazur E (1996) *Peer Instruction: A User’s Manual*, Pearson Education. ISBN: 9780135654415

The videos [Peer Instruction for Active Learning – Eric Mazur (13:56)](https://www.youtube.com/watch?v=Z9orbxoRofI) and [Confessions of a Converted Lecturer: Eric Mazur (1:20:08)](https://www.youtube.com/watch?v=WwslBPj8GgI) provide an engaging and convincing description of how student misconceptions are present everywhere, even amongst high-achieving students. Abridged and full versions of the videos are available on YouTube.

* Hieggelke et. al (2013) *TIPERs: Sensemaking Tasks for Introductory Physics,* Pearson Education. ISBN: 9780132854580, along with similar books (O’Kuma et al. 2003; Hieggelke et al. 2012)

These books consist of questions designed to engage students in sensemaking about the physics they are learning. For example, a question may offer several explanations that reflect common student misconceptions and ask students to choose which explanation they agree with. These questions are excellent material for ‘[Think-Pair-Share](https://app.education.nsw.gov.au/digital-learning-selector/LearningActivity/Card/645)’ activities in the classroom to engage students in thinking deeply about the physics they are learning.

* [Maryland Open Source Tutorials in Physics Sensemaking](https://www.physport.org/curricula/MD_OST/) (Scherr and Elby 2022) This package of research-based, open-source tutorials for mechanics topics includes student materials and detailed instructor guides. The instructor's guides provide the rationale behind the tutorial questions and tips for teachers from experienced instructors.

Educational psychology and cognitive science also offer valuable insights into assisting students in retaining and improving their understanding following initial instruction on a topic. Some of these findings include:

* Learning is most effective when interactions with a concept are spaced out over time (known as ‘distributed practice’). A ‘spiral teaching approach’ features in a freely available curriculum developed by [D’Alessandris](https://www.compadre.org/precollege/items/detail.cfm?ID=5666#:%7E:text=Spiral%20Physics%20is%20a%20research%20based%20introductory%20physics%20curriculum.,to%20concepts%20with%20increased%20complexity). The term ‘spiral teaching’ is also used as a general term in physics education to refer to the technique of returning to a concept in more depth or in a more sophisticated context.
* Practice is most effective when questions do not focus on a single topic but combine different topics. This requires students to make decisions about what physics principles and knowledge they need to use, rather than simply relying on their short-term memory to use the same approach they used in the previous question.
* Practice testing is much more effective than passive approaches such as re-reading and highlighting, as the process of recall under test conditions changes how information is stored in the brain.

**Resources on applying the results of educational psychology and cognitive science**

* [Strengthening the Student Toolbox: Study Strategies to boost learning](https://eric.ed.gov/?id=EJ1021069) (Dunlosky 2013) is an excellent resource for students, as it is written in easy-to-understand language. It summarises the results of the [Dunlosky et al. (2013) [PDF 1.54MB]](https://pcl.sitehost.iu.edu/rgoldsto/courses/dunloskyimprovinglearning.pdf) review article.
* Applying Cognitive Science to Education (Reif 2008) offers a thorough discussion of the implications of cognitive science for education, with a strong focus on physics.

## Module summary

Students are introduced to the concept of using lines to visualise the direction and strength of electric fields around various charged objects. Mathematical models are used in conjunction with field diagrams to qualitatively and quantitatively describe the interaction between charged particles. From electrostatics, students move into a basic introduction to electrical circuits and apply the concepts of energy, work, and power to gain a deeper understanding of the working of circuits. Models such as Ohm’s law and Kirchhoff’s laws are used to analyse a range of simple circuits mathematically.

Magnetic field lines are used to qualitatively model the direction and strength of magnetic fields produced by magnets, current-carrying wires, and solenoids. Students will also learn to apply mathematical models to solve simple magnetism and electricity problems. Using the inquiry questions as a conceptual framework, students will gradually build a strong foundational understanding of the connection between electricity and magnetism. This core idea is fundamental to Module 6.

By conducting investigations, students will receive valuable experiences in developing their Working Scientifically skills in the context of electricity and magnetism. In addition, providing opportunities for students to connect theory and experimental observations will help deepen their understanding.

## Big ideas

### Interactions

Electromagnetism describes the interactions between charged particles via electric and magnetic fields. It is possible to summarise these interactions as follows:

* Charges create electric fields, and electric fields exert forces on charges.
* Moving charges create magnetic fields, which exert forces on moving charges.
* Changing magnetic fields create electric fields, and changing electric fields create magnetic fields.

### Conservation and systems

**Conservation of energy**

This module addresses energy conservation in the context of electrical power generation and its conversion to other forms of energy such as heat and light. Kirchhoff’s **loop rule for circuits** is an expression of the conservation of energy. The displacement of charges in an electric field is associated with a change in electrical potential energy stored in the field.

**Conservation of charge**

The conservation of charge underpins the interaction between charged objects, and charged and uncharged objects in electrostatics. It is also the principle upon which Kirchhoff’sjunction rule for circuits is based.

### Observation and measurement

Students use ammeters and voltmeters (or multi-meters) to measure current and voltage in electrical circuits. For example, they may use the magnetic field sensor in their phones to measure the magnetic field strengths produced by currents (moving charges) in wires and solenoids.

Using various techniques, qualitative observations may be made of magnetic fields using iron filings, compasses, and electric fields.

Providing opportunities for students to investigate electrical and magnetic properties should help them grasp complex and abstract ideas. It should also help clarify misconceptions and gaps in prior learning.

### Models and representations

Mathematical models are used to describe the force between point charges (Coulomb’s law), as well as the magnetic field produced by a current in a wire and solenoid (Ampere’s law).

Magnetic and electric fields may be represented with field line diagrams. Such a diagram is often extended for electric fields to include equipotential lines perpendicular to field lines. These represent the paths a charge could take without the field doing work.

Circuit diagrams are used to represent electrical connections between circuit elements. Students should be prompted to see that these diagrams do not represent the spatial relationships between the components.

Ferromagnetism models the alignment of the magnetic domains in some materials (in the same direction) to explain their magnetic properties.

## Relationship to other modules

### Year 11 modules

In Module 2, students were introduced to the concepts of work, energy, and power, and applied them to analysing bodies in motion. In Module 4, these concepts and relationships are applied to gain a deep understanding of electrical systems and to form the foundational knowledge of electromagnetism. The skills and mathematical tools learnt in the previous modules are applied to building students’ knowledge of voltage, conservation of charge, the law of conservation of energy, and the principles that help explain electricity and magnetism.

Analogies can be used to help students better understand electrical potential energy. For example, gravitational potential energy is used as an analogy for electrical potential energy, requiring students to apply their knowledge from Modules 1 and 2. A useful video to use is [Hewitt-Drew-it! PHYSICS 90. Electric Potential (6:49)](https://www.youtube.com/watch?v=nnLf090OPNg).

### Year 12 modules

#### Module 6: Electromagnetism

This module lays the foundation for Module 6: Electromagnetism in Year 12. It addresses 2 ideas – that moving charges experience a force in a magnetic field and that a changing magnetic field produces an electric field. A discussion is given in the ‘[Big Ideas in Electromagnetism](https://hschub.nsw.edu.au/science-items/the-big-picture-of-electromagnetism-in-hsc-physics)’ resource on the HSC hub.

The first inquiry question in Module 6, ‘What happens to stationary and moving charged particles when they interact with an electric or magnetic field?*’* utilises several relationships first introduced in Module 4, such as Equation1: The force on a charged particle equals the product of the charge and the electric field strength. Note: that both force and electric field strengths are vector quantities so will need a direction associated with the value. Equation 2: The magnitude of voltage divided by the distance between the charged plates will equal the electric field strength between the charged parallel plates. Equation 3: The work done on a charged particle will equal the product of its charge and voltage strength., and . The required skills for success in the course go beyond simple substitution of values into equations. Developing an understanding of what each equation means and how they can be used to explain observations is needed. The development of these skills in Module 4 will help students to better grasp the concepts in Module 6.

In the third inquiry question of Module 6, ‘How are electric and magnetic fields related?’, students will need to use the concepts of electrical power developed in Module 4 to analyse energy conservation in transformers.

#### Module 7: The Nature of Light

The idea that accelerating electric charges produce changing magnetic and electric fields, and so electromagnetic radiation is central to the first inquiry question in Module 7.

In the third inquiry question in Module 7, *‘*What evidence supports the particle model of light and what are the implications of this evidence for the development of the quantum model of light?*’*, students will need to use the work-energy theoremThe relationship between work and energy can be described by the net work done equals the change in kinetic energy.() together with Work on a charged particle equals the product of the charge and the Voltage. to analyse experiments involving the photoelectric effect. They will also need to use their understanding of the magnetic field produced by solenoids to analyse problems involving electromagnetic induction.

#### Module 8: From the Universe to the Atom

The second inquiry question in Module 8, ‘How is it known that atoms are made up of protons, neutrons and electrons?’ focuses on the discovery of the electron by Thomson and the measurement of its charge by Millikan. Students solve problems that utilise their understanding of the motion of charges in electric and magnetic fields.

The fifth inquiry question, ‘How is it known that human understanding of matter is still incomplete?’ requires students to apply their knowledge of the forces acting on charges in electric and magnetic fields in the context of particle accelerators. They explain how charges are accelerated to near light speed by electric fields and guided along their path within the particle accelerator using magnetic fields.

## Core concepts

### Electrostatics

Students begin learning about electrostatics by investigating how objects can become charged and explain this using a particle model involving electron transfer from one object to another (with a different position on the [triboelectric series](http://soft-matter.seas.harvard.edu/index.php/Triboelectric_series)). Next, students use a particle model to explain the attraction between charged and uncharged objects due to polarisation.

In the second part of this inquiry question, students use Coulomb's law to investigate the forces between point charges using an action-at-a-distance model. They also use a field model, in which a charge or distribution of charges produces an electric field, and other charges experience a force due to the field. Students learn that electric fields can store and transfer energy and momentum. Electric fields are an effective and accepted model in physics for explaining and predicting the electrical interactions between charged particles.

The work done by an electric field due to the displacement of a test chargeLower case q is the symbol given to charged particles. in the field is used to define electrical potential energyThe change in potential energy equals work (work has a negative sign). , and thereby the electric potential as the potential energy per unit charge,Voltage equals the change in potential energy divided by the charge. .

### Electric circuits

The particle model explains the flow of current in electrical circuits. Students develop their understanding of current as the rate of flow of charge through a conductor and voltage (potential difference) as the energy per unit charge dissipated in (or produced by) a circuit element.

The resistance of an object is defined as the ratio of the voltage difference across the object to the current flowing through it,Resistance equals the Voltage divided by the current.Resistance equals the Voltage divided by the current.. If the resistance (as determined by the ratio V/I) of an object (that is, a circuit component) is independent of the voltage, it is said to be *Ohmic*. On the other hand, if the component has a resistance that depends upon the voltage applied, it is *non-Ohmic*. Good classroom examples of non-ohmic components are low voltage incandescent light bulbs.

Kirchhoff’s junction and loop rules express the conservation of charge and energy, respectively. They are extremely powerful tools that permit the analysis of arbitrarily complicated circuits. In this module, they are used to derive the equivalent resistance of resistors in series and resistors in parallel.

Students investigate the conversion of electrical energy to light (for example, in bulbs in a circuit) and heat (for example, in a heating element).

### Magnetism

Moving charges produce magnetic fields. Students investigate charges moving in straight wires, where the magnitude of the field is given byThe strength of a magnetic field around a wire equals the product of the magnetic permeability constant and current, divided by the circumference of the wire given by the product of 2, Pi and radius. , in a direction around the wire given by the right-hand grip rule. They also investigate solenoids, for which the magnetic field is the superposition of the magnetic fields due to the individual wires making up each turn.

Ferromagnetism occurs due to quantum interactions between electron magnetic dipole moments (since electrons have intrinsic angular momentum or ‘spin’). The short-range nature of these interactions results in localised areas known as ‘domains’ in ferromagnetic materials, within which the magnetic moments of electrons are aligned so that the regions are magnetised in a single direction. In its unmagnetised state, the domains in ferromagnetic materials are orientated in random directions. Ferromagnetic materials can be magnetised by applying a strong external magnetic field. This process is very clearly explained in [MAGNETS: How Do They Work? (6:25)](https://youtu.be/hFAOXdXZ5TM).

Module 4 develops the conceptual foundation for Module 6. Visually representing both magnetic and electric fields using field lines is essential to understanding electromagnetism concepts and the operation of motors and other devices. Having a sound understanding of both electricity and magnetism is fundamental to the understanding of electromagnetism concepts. This includes going beyond simple substitution and rearranging of the relevant equations, for example, understanding the links between the equations and their underlying principles.

## Opportunities for extending concepts

When looking for opportunities to extend student learning, one approach is to look for more complicated examples. Another approach could be to explore the ideas presented in the syllabus in greater depth.

For example, students may research and discuss the movement of electrons in circuits. Many students will already have a general, simplistic idea of how electrons move in a circuit. Students could begin by identifying common analogies used to describe electron movement, such as the water in a pipe analogy, and assess each analogy’s ability to accurately describe what is happening in a conductor in an electrical circuit.

This investigation could lead to the exploration of ideas such as drift velocity and electron movement or ‘flow’. In addition, other concepts such as energy, resistance, and work could be explored in the same way, that is, by comparing our everyday models to what a scientist would say.

In pursuing this course of learning, teachers should consider factors such as time availability and student capabilities. This goes beyond the syllabus's scope but could address underlying misconceptions regarding electrical circuits and energy.

Some students find electrical circuits exciting. Going beyond simple circuit diagrams can increase the relevance of learning and student engagement, and will also challenge your students to comprehend and analyse complex information. Real-world circuit diagrams, such as the circuit diagram for a classroom (please discuss this with your principal before sharing plans) or other plans available for free from the internet, will be suitable for this activity.

As an introduction to reading these complex plans, students can be asked to list questions they have about the plans. For example, you may ask the class:

* What do you think you understand and why?
* What areas do you need more information about?
* How do these plans differ from the ones you have seen in school?

Integrating technologies like the magnetron in mobile phones can facilitate extension activities beyond mapping field lines using iron filings. Having students take measurements and identify trends from data can help their understanding of magnetic field lines and develop their working scientifically skills at the same time.

## Misconceptions

### Electrostatics and magnetic fields

Students may confuse electrostatic interactions and magnetic interactions. Students often relate ‘north’ with ‘positive’ and ‘south’ with ‘negative.’ This misconception arises because both interactions occur through fields, share similar diagrammatic conventions, and use the concept of polarity. Issues occur when students predict that the north poles repel positive charges. Distinguishing electricity from magnetism will also be helpful in preparation for Module 6: Electromagnetism.

Practical activities such as the sticky tape electrostatics activity allow students to challenge their misconceptions by demonstrating that charged objects will attract uncharged objects. Also, both ends of a permanent magnet (an uncharged conductor) attract positive and negative charges. By the end of the module, students may recognise that magnetism arises because of the movement of electric charge and link permanent magnets to the alignment of their magnetic domains.

### Circuits

Electrical circuits can be confusing, and students may only develop a superficial understanding of the concepts. For example, a common misconception is that as the current travels around the circuit and the voltage drops across components, the current is ‘consumed.’ This also links to the idea that the order of the components is important in circuits, as earlier circuit elements ‘use up’ some of the power/current/energy/voltage. This means that later identical elements have less power/energy/current/voltage available (a bulb in such circuits would glow dimly).

Analogies can help students visualise concepts and relate abstract ideas to concrete ideas. The danger with some analogies is that they may instil misconceptions. When using analogies as a teaching activity, it is best practice to discuss the strengths, weaknesses, and assumptions they are based on. The article [Are we teaching electricity the wrong way around?](https://www.abc.net.au/science/articles/2014/02/05/3937083.htm) is an interesting read and can be used to reflect on teaching electricity in the junior years. It can also be used as a stimulus to investigate analogies, models, and explanations in science.

## Conceptual difficulties

Students can find developing a solid foundation understanding of electricity and magnetism difficult. Coupled with misconceptions and conceptual difficulties, students may find it challenging to construct concrete ideas on the topic. In addition, time restrictions and students' ability to think deeply can sometimes provide obstacles to learning.

The Year 11 course allows students to challenge their understanding and become critical thinkers.

Understanding how circuits transfer and transform energy can be a difficult concept for students to grasp. They have preconceived ideas on how circuits may work, and any misconceptions may be a barrier to learning scientific explanations. Furthermore, considering time availability, these ideas can be difficult to teach. Nevertheless, a good variety of learning activities can stimulate students to reflect deeply on their understanding.

Students can generally understand the 2 core ideas of electricity and magnetism separately in Module 4. However, in Module 6, students often struggle to link these concepts to form an in-depth understanding of electromagnetism. The Year 11 course can provide a narrative and a historical journey of key scientific developments, for example, how they led to Maxwell’s equations, and link to what students will learn in Year 12. This can provide more time to explore ideas across both stages of student learning.

## Suggested teaching strategies

### Prior understanding and foundational knowledge

Before teaching the prescribed descriptors in Module 4, it can often be helpful to begin the lesson sequence with a recap of the model of the atom. This can either be a small recap of the development of the atomic theory/particle model or asking students to draw a simple atom.

Suggested questions to provoke student thinking and discussion:

* Do you think the electrons can be gained or lost from the atom?
* Which electrons would be the easiest to remove and why?
* Would the same be true for the atoms in materials around you?

These questions can be used to assess students' prior understanding of Stage 5 Science and help lay a good foundation for teaching this topic.

Beginning Module 4 with a quick recap may assist students in better grasping the concepts in the first inquiry question. The video [The science of static electricity – Anuradha Bhagwat (3:38)](https://www.youtube.com/watch?v=yc2-363MIQs), could be used to support this activity to help consolidate student understanding.

This may also be a good opportunity to discuss the strengths and limitations of models used in physics to understand the world around us, especially the natural phenomena that can only be explained by describing interactions that occur on a small scale.

The teaching strategies presented in this resource are a sample of activities that may support your current teaching and learning unit to promote deeper thinking and build a range of skills for your students.

**Note:** Do not forget about Working Scientifically skills. Not all examples presented in this resource link to a knowledge and understanding outcome. However, they are great opportunities to focus on the skills needed to understand physics as a subject beyond recalling information. Although some links to Working Scientifically skills have been provided, these can be adjusted to focus on different skills, depending on the learning intentions.

### Electrostatics

**Inquiry question: How do charged objects interact with other charged objects and with neutral objects?**

Students conduct investigations to describe and analyse qualitatively and quantitatively:

* processes by which objects become electrically charged
* the forces produced by other objects as a result of their interactions with charged objects
* variables that affect electrostatic forces between those objects.

**Note:** The following activities should be linked to relevant Working Scientifically outcomes. It is recommended to only focus on one or 2 skills at a time. This will provide opportunities for targeted feedback to your students and reduce students’ anxiety when learning this topic.

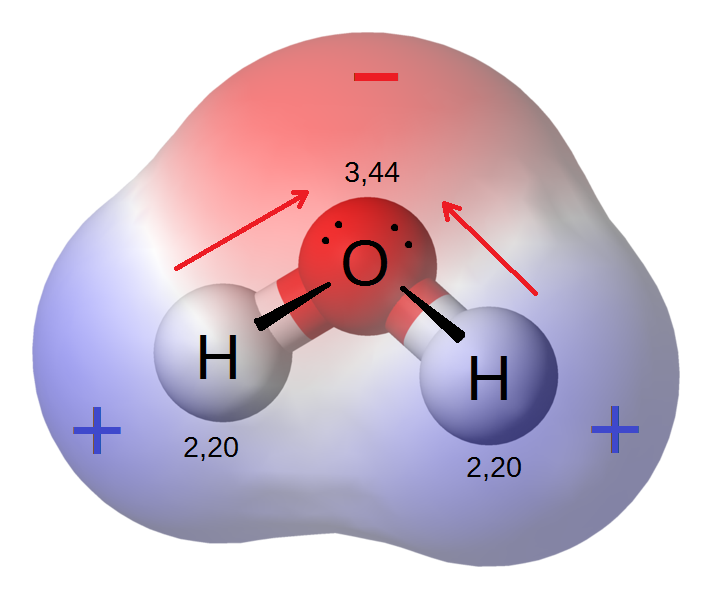
#### Water bending

This activity could either be a teacher demonstration or a student investigation. The purpose is for students to think about charging objects and explain their observations from some stimulus material.

Show students [Electric force between the water and the balloon – physics experiment (0:53)](https://www.youtube.com/watch?v=jkYz1WlpRSQ). A balloon is rubbed with a cotton cloth and then brought close to, but not touching, a gentle stream of water from a tap. Ask students to repeat what they saw on the clip in the laboratory. Allow students the opportunity also to rub different cloths on the balloon or rub the balloon on their head and record their observations. This should take no more than 10 to 15 minutes of a lesson depending on your class.

Ask students to propose an explanation for their observations or discuss this as a class. For example, show students a picture of a water molecule like the one below. How can they use this latest information to explain their observation? For example, some students may need to be directed to the regions of positive and negative charge or ask them what information they see in the diagram.

Figure 1 – water molecule



[“Dipoli acqua”](https://commons.wikimedia.org/wiki/File:Dipoli_acqua.png) by [Riccardo Rovinetti](https://commons.wikimedia.org/wiki/User:Riccardo_Rovinetti) is licensed under [CC BY-SA 3.0](https://creativecommons.org/licenses/by-sa/3.0/au/)

The clip [Static Electricity and Water (2:08)](https://www.youtube.com/watch?v=VhWQ-r1LYXY) can be used to conclude the lesson. **Students should also be allowed to refine their previous answers based on watching this clip or an explanation provided by the classroom teacher.**

#### Sticky tape electrostatics

**Note:** The [sticky tape prac (5:21)](https://www.youtube.com/watch?v=s54VD3Z-ke4) may help you or your students conduct the following activity).

We will use sticky tape to investigate the forces between insulators with the same and opposite charges, and between charged and uncharged insulators.

1. Obtain an approximately 12 cm long piece of sticky tape and fold one end over slightly to form a non-sticky ‘handle’. Stick this to the desk.
2. Repeat twice more, each time laying the new piece of tape over the previous one.
3. Label the upper tape with a ‘U’ (for ‘upper’) and the tape below this with an ‘L’ (for ‘lower’)
4. Pull the top 2 tapes together as one piece from the lowest tape.
5. Stick them to the edge of the desk and check whether the pair have any charge by placing your finger near them. If they do, try to discharge them by running your finger along the non-sticky side of the pair.
6. When the pair are no longer attracted to your finger, pull the top tape off the bottom one and place them side by side (but not too close!) on the edge of the desk.
7. Use a charged styrene rod or hair comb that has been rubbed on your hair (both of which are charged negatively according to the triboelectric series) to check which tape is negative and which is positive. Remember that if the pair started with no charge, then if one is charged when peeled apart, the other must have an equal and opposite charge.

**Write your results here**

The ‘upper’ tape is charged:

The ‘lower’ tape is charged:

Make a second, identical set of sticky tape pieces and then fill in the table below to show the results of the interaction between your sticky tapes and a range of materials. A [Predict-Observe-Explain](https://arbs.nzcer.org.nz/predict-observe-explain-poe) strategy can be employed at this stage to challenge students' thinking and application of their understanding. Students can be presented with the table below and asked to predict what they think they will observe and why. Then conduct the experiment to reflect on their predictions.

Table 1 – sticky tape electrostatics interactions summary

|  |  |  |
| --- | --- | --- |
| Material | Upper tape (attract/repel) | Lower tape (attract/repel) |
| Your finger | (Add interaction) | (Add interaction) |
| An uncharged insulator (for example, a plastic pen or wooden pencil) | (Add interaction) | (Add interaction) |
| An uncharged conductor (for example, a metal object) | (Add interaction) | (Add interaction) |
| The north side of a bar magnet | (Add interaction) | (Add interaction) |
| The south side of a bar magnet | (Add interaction) | (Add interaction) |
| Another upper tape | (Add interaction) | (Add interaction) |
| Another lower tape | (Add interaction) | (Add interaction) |

Draw a diagram representing what the charges inside the conductor looked like when they approached the tape (for example, draw a diagram showing polarisation in a conductor).

Draw another diagram representing what the charges inside the insulator looked like when they approached the tape (for example, draw a diagram showing polarisation in an insulator).

Explain why both the tapes are attracted to both the north and south sides of the magnet. Does it have anything to do with the fact that it is a magnet?

**Alternative methods and similar experiments can be found on the following sites**

* [Sticky Tape Experiments [PDF 84KB]](https://www.physicsclassroom.com/getattachment/reasoning/electrostatics/src23.pdf)
* [Physics Lab: Investigations of Electrostatics with Sticky Tape [PDF 488KB]](https://www.ntschools.org/cms/lib/NY19000908/Centricity/Domain/998/L19%20TAPE%20-%20Electrostatics%20with%20Tape.pdf)

#### From observation to measurement, what can we measure and how?

**Planning Investigations**

**Outcomes:** A student designs and evaluates investigations in order to obtain primary and secondary data and information (**PH11/12-2**).

**Content:** Students justify and evaluate the use of variables and experimental controls to ensure that a valid procedure is developed that allows for the reliable collection of data.

This activity allows students to build on their Working Scientifically skills, specifically those related to conducting investigations. Show students [Exploring Static Electricity (6:23)](https://www.youtube.com/watch?v=jLgSXryMxwM).

Ask students to design and conduct an experiment to gather quantitative data based on the video above. Students may need to be directed to select their variables and discuss how they can impact electrostatic force. To focus on the suggested descriptor, students should be asked to justify their procedure to be certain of the relationship they are trying to investigate.

This task could be used as a formative assessment. Students receive feedback and can evaluate and refine their methods during their investigation. The feedback should be actionable and allow students to improve their original work. More information on feedback can be found at [What works best in practice](https://education.nsw.gov.au/about-us/educational-data/cese/publications/practical-guides-for-educators/what-works-best-in-practice).

Students should be encouraged to keep a learning journal and record their experimental designs, reasons for changes, and challenges during this activity. [Why keep a journal – Think like a scientist (1/10) (7:18)](https://www.youtube.com/watch?v=-47lJ-fso7U) may help your students understand what to document in their journal. [Experimental Design Basics (6:01)](https://www.youtube.com/watch?v=-EAI9hiPDoU) may help students understand the basic foundational concepts in experimental design. Whilst not on the same topic, the same logic can be transferred to their investigation.

**Note:** If students have completed the water bending or sticky tape activities, or similar experiments, it may help them succeed in the following activity. Students could also be asked to present their method to the class, defend their methodology, and respond to questions from the audience.

### Electric circuits

#### The big misconception about electricity and the use of analogies/models

**Problem Solving**

**Outcomes**: A student solves scientific problems using primary and secondary data, critical thinking skills and scientific processes (**PH11/12-6**).

**Content**: Students use modelling (including mathematical examples) to explain phenomena, make predictions and solve problems using evidence from primary and secondary sources.

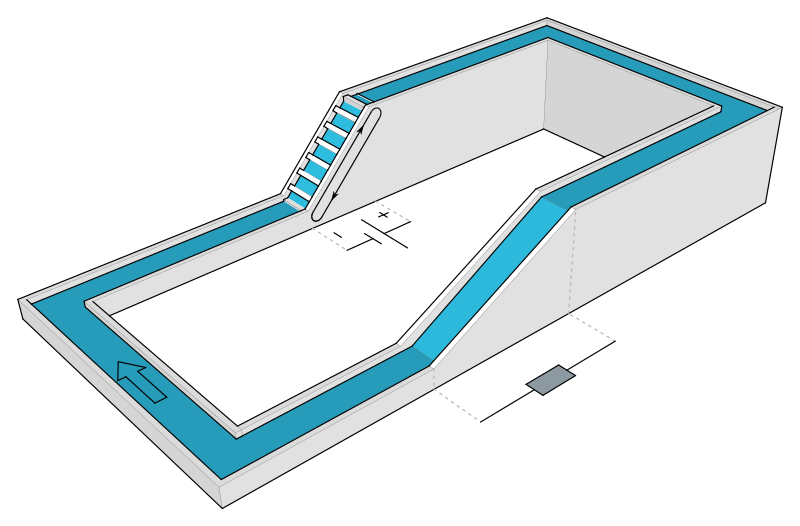
**Note:** The ideas explored in this inquiry question can be abstract and conceptually difficult. Using models, metaphors, and analogies is critical for developing students’ understanding of electric circuits. It is important to note that models, metaphors, and analogies have their own strengths and weaknesses. It is highly recommended that these aspects be explored and help reduce the chance of common misconceptions developing. For example, a common limitation of physical models is that they imply that any given electron travels around a circuit in a smooth continuous manner in a straight path for DC.

Depending on students’ learning needs, the following 2 videos may be a reference for yourself as a teacher or shown to the class. The clips are long and require teacher intervention to break up the clips and promote class discussion. The first clip is the original one presented by Veritasium [The Big Misconception About Electricity (14:47)](https://www.youtube.com/watch?v=bHIhgxav9LY) and the second clip is an analysis of the original clip from an engineering perspective [EEVblog 1439 – Analysing Veritasium's Electricity Misconceptions Video (45:33)](https://www.youtube.com/watch?v=VQsoG45Y_00).

**Note:** Whilst the water analogy is not recommended for Stage 6 Physics, it may be the one students are most likely to be familiar with. This activity aims to look deeper into analogies and their purpose in conveying information. For each simplification, ask, ’What is the cost? Why use them’? It is best to conduct this activity when students have a good prior understanding to evaluate different analogies or models. Good knowledge of relevant concepts is required to examine the models' and analogies' strengths and limitations. The article from ABC Science, ‘[Are we teaching electricity the wrong way around? Analysis and Opinion](https://www.abc.net.au/science/articles/2014/02/05/3937083.htm)’ can be used in conjunction with this activity and is highly recommended for teachers to read.

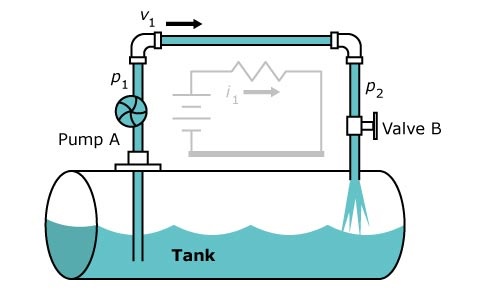
A popular analogy used in science classrooms is the DC circuit-water analogy. Students can be given diagrams like those shown in Figure 2 and Figure 3, or [Water circuit analogy to an electric circuit](http://hyperphysics.phy-astr.gsu.edu/hbase/electric/watcir.html).

Figure 2 – ****water-circuit****



“[Water-circuit-R1](https://commons.wikimedia.org/wiki/File:Water-circuit-R1.svg)” by Mike Run is licensed under [CC BY-SA 4.0](https://creativecommons.org/licenses/by-sa/4.0/deed.en)

Figure 3 – ****water circuit with a pump****



[“Water circulates endlessly around this closed loop much like an electrical current”](https://physics.stackexchange.com/questions/98428/why-do-batteries-work) by [StackExchange](https://stackexchange.com/) (n.d) is licenced under [CC BY-SA](https://stackoverflow.com/help/licensing).

Ask students to describe the strengths and weaknesses of this analogy. It can be framed as:

* What concept could this analogy be used to explain?
* What aspects of the concept does this analogy cover well?
* What elements of the analogy could be improved upon?
* What are the limitations of using this analogy?

The video [3-2 Water analogy (3:05)](https://www.youtube.com/watch?v=7O4vhW3mdh0) may also be used to help students understand this analogy. Another approach could be to give students definitions for ‘voltage’, ‘current’, and ‘resistance’, and have them develop a simple analogy. As a part of this activity, they would also need to justify their choices and provide clear reasoning behind their thinking.

Analogies like these are essentially scientific models used to explain concepts and make predictions. This activity could be extended to discuss other scientific models, including mathematical models and diagrams such as electric field diagrams. As students encounter different scientific models, they could evaluate their explanatory and predictive powers, including any assumptions used to construct those models.

[Going with the flow: Using analogies to explain electric circuits](https://www.academia.edu/33380466/Going_with_the_flow_Using_analogies_to_explain_electric_circuits_Going_with_the_flow_Using_analogies_to_explain_electric_circuits) presents some interesting ideas about analogies.

#### Investigating simple and complex circuits

**Inquiry question: How do the processes of the transfer and the transformation of energy occur in electric circuits?**

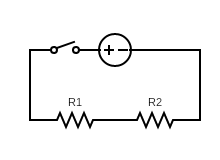
Students qualitatively and quantitatively investigate series and parallel circuits to relate the flow of current through the individual components, the potential differences across those components, and the rate of energy conversion by the components to the laws of conservation of charge and energy by deriving the following relationships:

* The algebraic sum of all currents entering and exiting a node must equal zero. (Kirchhoff’s current law – conservation of charge)
* ![The algebraic sum of all voltage differences around any closed loop is zero. An alternate statement of this law is:
  The sum of the voltage rises around a closed loop must equal the sum of the voltage drops around the loop.](data:image/png;base64,iVBORw0KGgoAAAANSUhEUgAAABIAAAASCAMAAABhEH5lAAAAAXNSR0IArs4c6QAAAARnQU1BAACxjwv8YQUAAABLUExURQAAAP///////////////////////////////////////////////////////////////////////////////////////////////4OZCwcAAAAZdFJOUwABAgMFBgcICQoREhUWGRoeHyIjJCUmJyhmD5ZnAAAACXBIWXMAADLAAAAywAEoZFrbAAAAZElEQVQoU6XO2wqAIBBF0TE1zbKL9///0upg0kMQ1H5R1qAM/YrrASlegfhawpnPC6uk8mbGI+OLqKSdwZTZKAEgnMymB+pxeaPbw/p9I5XchGK6lujmjFVDtNeqxIREosmHiHZzbQUUFVrhOgAAAABJRU5ErkJggg==) (Kirchhoff’s voltage law – conservation of energy)
* The sum of resistors in a series circuit equals the equivalate single resistor value.
* Summing the inverse of the values in a parallel circuit equals the inverse of an equivalate single resistor value.

**Note:** It is recommended that the theory behind Kirchhoff’s laws be taught after this activity. This investigation aims for students to collect first-hand data about circuits and identify patterns/trends to develop simple relationships. This activity could also incorporate the Working Scientifically skill, ‘Analysing Data and Information’ (derive trends, patterns and relationships in data and information). Students must identify the symbols representing electrical components before reading and interpreting circuit diagrams.

Show students a simple circuit with 2 resistors in series, as shown in the diagram below.

Figure 4 – a DC circuit consisting of 2 resistors in series



Hypothetical values can be provided for students at this stage. Note that these values should be realistic and reflect the equipment available because students will set up the circuit and take measurements in the second part of the activity.

Ask students to predict what they would expect the relative values to be if an ammeter were placed before R1, between R1 and R2, and after R2 (in an anti-clockwise direction). This does not need to be a numerical answer. It can be a simple statement: ‘The values on each ammeter will be the same, the values will decrease from the first to the third ammeter’, and so on. Students would also need to support their predictions with the reasoning they used.

Now ask students, ‘If a voltmeter was placed across the power source, resistors 1 and 2, what do you think the relative values would be now and why?’

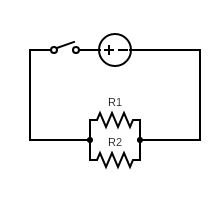
After students have made their predictions, ask them to set up the circuit and test their predictions. The following questions can be used to direct their investigation:

* Does their experimental data support their earlier predictions?
* What would happen if they changed the values of the supply voltage and resistor values?
* Compare your data to other groups. Is a trend evident?

**Note:** At this stage, the collected data could be shared and the relationships discussed as a class (teacher-directed).

After the class discussion, present students with the diagram shown below. Ask them to investigate current and voltage across a circuit with 2 resistors in parallel. This can be guided like the previous activity or can be an opportunity for students to transfer the lessons learnt from the series circuit to a parallel circuit.

Figure 5 – a DC circuit consisting of 2 resistors in parallel



After both investigations, show [Kirchhoff's First Law – A Level Physics (2:50)](https://www.youtube.com/watch?v=pJ7xrmUb_UQ) and [Kirchhoff's 2nd Law – A Level Physics (5:30)](https://www.youtube.com/watch?v=xZvPaqZnkHU) to help students consolidate their learning.

**Note:** This content area can be challenging for students. This activity, supported with worked examples on applying these relationships, provides students with a chance to apply their understanding to various situations and should help them build their confidence in analysing electrical circuits.

### Magnetism

The suggested activities in this section require using a student’s mobile phone as a measuring tool. A mobile phone can be transformed into a powerful multi-purpose measuring tool using built-in sensors with freely available applications. As a class, watch [What Sensors Are in a Smartphone? (2:12)](https://www.youtube.com/watch?v=CxC1KCoGbIM).

Before utilising mobile phones as ‘data loggers’, consult your school’s policy on mobile phones and discuss with your head teacher or senior executive how the phone will be used as a learning tool in the classroom.

**Note:** Activities 4 and 5 use phyphox, which is freely available to download at [phyphox – Physical Phone Experiments](https://phyphox.org/). The [phyphox YouTube channel](https://www.youtube.com/c/PhyphoxOrg) also includes some examples of experiments that could be useful across the entire Stage 6 Physics course.

#### Smartphones magnetometer

**Safety**: Students should not expose their devices to strong and/or excessive magnetic fields directly. This may damage their devices.

**Communicating**

**Outcomes**: A student communicates scientific understanding using suitable language and terminology for a specific audience or purpose (**PH11/12-7**).

**Content**: Students select and use suitable forms of digital, visual, written and/or oral forms of communication.

**Note:** Each student, or at least one group member, will need access to the application on their mobile device. For first-time users, it is important to gain some familiarity before using the application in investigations. The purpose of this activity is for you and your students to understand how the sensor works and how it may be used in investigations.

Before using any of the activities below, it is suggested that the following videos [NASA | Magnetometry 101 (1:53)](https://www.youtube.com/watch?v=ljfa1R9JXWk) and/or [How magnetometer works? | Working of magnetometer in a smartphone | MEMS inside magnetometer (3:50)](https://www.youtube.com/watch?v=_ZiLwoClRGQ), be shown to your students to help them understand magnetometry and use the app on their mobile phones.

##### Locating the magnetometer on your smartphone

Table 2 – phyphox magnetometer instructions

|  |  |
| --- | --- |
| Steps | Notes |
| Screenshot of the sensor options from the mobile application provided by phyphox. | Direct your students to the magnetometer under the raw sensors on the home screen.  Select this option. |
| Screenshot of the magnetometer from the mobile application provided by phyphox. | Students should see a screen like the one shown on the left.  Press the play button to start collecting data.  Questions to ask students while they explore:  Why are 3 different graphs used to display the data?  Why is the line graph not a steady straight line?  Why is it important to locate the magnetometer on your phone? |
| Screenshot of a graph in the magnetometer phyphox app. | Using a pointed object like a pointed pair of scissors, an iron nail, or a small screwdriver, scan the tip over the surface of the phone while observing the magnetic field along the z-axis (by clicking on the ‘z’ graph). It will enlarge the graph.  If the tip is magnetic, you will observe an abrupt change when the tip is close to the sensor. You can then slowly repeat the movement to find the exact centre of the sensor by maximising the magnitude of the magnetic field measured by the sensor. |

Students can be asked to create a half-page infographic as an instruction set for others to locate the magnetometer on their phones. Then, if students have the same type of phone, they could compare the location they found. This would be a good learning exercise to discuss which method was used and which result is more accurate and why.

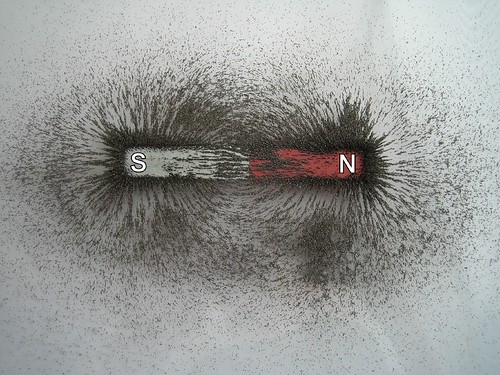
Students can also explore other functions at this stage. For example, can they export the collected data from their phone to a computer?

##### Mapping the fields around bar magnets (quantitively)

Students will need access to a standard bar magnet, iron filings, and a compass for this activity. It can be a good idea to wrap the bar magnet with a small amount of cling wrap or place the magnets in a resealable plastic bag. This will help prevent the iron filings from sticking to the magnet.

Initially, students use iron filings to map the field lines around a single bar magnet. They should achieve results, as shown in the diagram below. A bar magnet could be placed under an overhead transparency and the filings scattered above.

Figure 6 – ****iron filings around a bar magnet indicating the magnetic field lines****

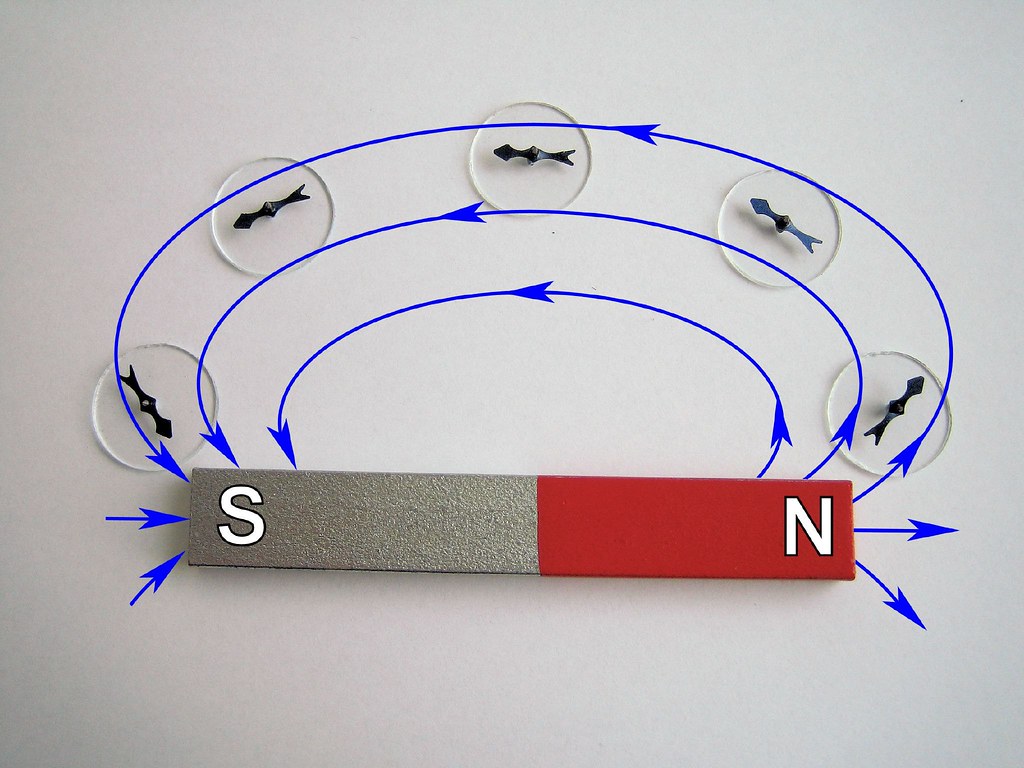


[“iron filings tracing the magnetic field of a bar magnet”](https://www.flickr.com/photos/daynoir/2181293650/) by [dayna mason](https://www.flickr.com/photos/daynoir/2181293650/) is licensed under [CC BY-NC-SA 2.0](https://creativecommons.org/licenses/by-nc-sa/2.0/)

**Whole-class discussion**: The results could be discussed regarding what information this investigation provides and what further questions it raises.

In the next stage, students use a compass to investigate the magnetic field around the bar magnet. What new insights does this investigation provide?

Figure 7 – ****compass needles used around a bar magnet to show the direction of the field****



[“magnetic field lines with compass needles”](https://www.flickr.com/photos/daynoir/2181294218/) by [dayna mason](https://www.flickr.com/photos/daynoir/2181293650/) is licensed under [CC BY-NC-SA 2.0](https://creativecommons.org/licenses/by-nc-sa/2.0/)

Finally, students use phyphox on their mobile phones to collect quantitative data around the field lines.

Using results from all 3 investigations, students can be asked to create a visual representation of the magnetic field around a bar magnet in 2D and/or 3D. They should also incorporate the numerical data collected. Physical models, software, or drawings can be used. Students should be encouraged to think about how best they can represent their findings and how the collected data or information is conveyed.

[The Earth's Magnetic Field: An Overview](http://www.geomagnetism.bgs.ac.uk/education/earthmag.html) has a range of representations that can be used as a stimulus for students.

#### Representing and quantifying magnetic field strength around wires and solenoids

**Inquiry question: How do magnetised and magnetic objects interact?**

Students investigate and describe quantitatively the magnetic fields produced by wires and solenoids, including:

* The strength of a magnetic field around a wire equals the product of the magnetic permeability constant and current, divided by the circumference of the wire given by the product of 2, Pi and radius.
* The strength of a magnetic field from a solenoid equals the product of magnetic permeability, the number of turns and the current, divided by its length.

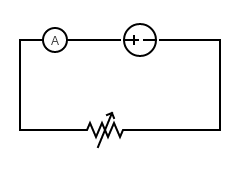
**Note:** First, students follow the procedure provided to collect initial data from the investigation. This will need to be adjusted to include the equipment and materials available to your students. Give students time to analyse the raw data and then improve the investigation. Each change should be supported with a reason and students should have sufficient time to conduct, refine, and analyse their investigation.

##### Magnetic field as a function of current in a straight conductor

1. Arrange an experimental setup similar to the diagram below. This experiment requires a variable power supply, variable resistor, and an ammeter meter.

**Note**: The variable resistor is included in the circuit to prevent a short circuit or the wires from overheating.

Figure 8 – a DC circuit consisting of a variable resistor and ammeter



1. Place a mobile phone a set distance from a wire. The [phyphox](https://phyphox.org/) application should be available on the phone and students use the magnetometer to record data.
2. Evaluate potential functions for the dependence of magnetic field versus current and plot the data using a function that results in a linear fit.
3. Using the relationship for the magnetic field for a straight conductor\*, calculate the magnetic permeability,mu μ0, from the slope of your fit in [the next activity](#_b._Plan_and).

\*Relationship for the magnetic field for a straight conductor:The strength of a magnetic field around a wire equals the product of the magnetic permeability constant and current, divided by the circumference of the wire given by the product of 2, Pi and radius.

##### Plan and conduct investigation to verify mathematical models.

1. The Stage 6 Physics syllabus presents 2 mathematical models for magnetic fields produced by wires (1) and solenoids (2). They are shown below:

* The strength of a magnetic field around a wire equals the product of the magnetic permeability constant and current, divided by the circumference of the wire given by the product of 2, Pi and radius. … (1)
* The strength of a magnetic field from a solenoid equals the product of magnetic permeability, the number of turns and the current, divided by its length. … (2)

1. Select a relationship from the variables for either equation to investigate. Then, suggest how the relationship may be verified and assess the strength of the conclusion drawn from your investigation.
2. Conduct your investigation and create a presentation outlining the method you took and your results.
3. Present your findings to the class and identify the methodology's and results' strengths and limitations. Answer any questions related to your presentation from the audience.

**Note:** This activity is an opportunity for students to design, conduct, and present their investigations to the class. The presentation aspect of the activity allows students to reflect on the choices made in their investigation and justify their claims. Again, this would be best completed if students worked in groups.

**Other useful resources**: These resources provide additional ideas and teaching strategies not presented in this module guide:

* [Guide To Smartphone Sensors – NASA [PDF 9.95 MB]](https://spacemath.gsfc.nasa.gov/Sensor/SensorsBook.pdf)

This is a PDF document by Dr Sten Odenwald (NASA Space Science Education Consortium). It contains a large number of investigations using smartphone sensors. The investigations are not limited to Module 4 but can be utilised across the entire physics course. However, it is recommended that you trial any of these investigations first before using them with your class.

* [Experiments | Physics II: Electricity and Magnetism | Physics | MIT OpenCourseWare](https://ocw.mit.edu/courses/physics/8-02-physics-ii-electricity-and-magnetism-spring-2007/experiments/)

A shortlist of investigations targeted at the post-high school level. While not directly referencing content in the Stage 6 Physics course, it can give rise to ideas for investigations that can be carried out in your classroom. The post-lab and investigation questions are a good starting point for creating your own questions based on the practical work.

* [Circuit Diagram Web Editor](https://www.circuit-diagram.org/editor/)

A simple online program to help draw circuit diagrams.

* [phyphox – Physical Phone Experiments](https://phyphox.org/)

The physical phone experiments website has helpful clips showing experiments that could be conducted with your class. The experiment class material, however, is in German.

* [PhET: Free online physics, chemistry, biology, earth science and math simulations](https://phet.colorado.edu/)

Free online interactives can support a wide range of investigations across the physics course. By signing up to the site, you will also be able to access various worksheets for each simulation. You should check the quality and suitability of these resources before using them with your class.

## References

**Links to third-party material and websites**

Please note that the provided (reading/viewing material/list/links/texts) are a suggestion only and implies no endorsement, by the New South Wales Department of Education, of any author, publisher, or book title. School principals and teachers are best placed to assess the suitability of resources that would complement the curriculum and reflect the needs and interests of their students.

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