FLEET Schools

Electricity, conductors and insulators

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Contents

Introduction

From the dawn of time we have witnessed electricity as a primal force of nature in the form of lightning. The ancient Greeks would rub amber with a cloth and get small electric shocks – the same static electricity we experience when we rub our feet along the carpet and then touch something conductive, for example a metal bench or your friend. But it took us until early in the 19th century before we started to learn how to generate, control and harness this energy in a way that would change the world as we know it. It was not until the late 19th Century and early 20th Century before we began to understand how it worked. It started with simple circuits to produce light and heat, revelations that led to today's digital revolution where the world's economies have become reliant on electricity and would collapse without it.

This resource is for students from upper primary to lower secondary. It enables students to explore the nature of electricity; how we managed to harness this power; how it changed human society and paved the way to the digital age we live in today. Students can engage in critical thinking activities to analyze and reflect on how we produce and consume electricity, and the value of research being conducted to develop the next generation of electronic and digital technologies. The resource has a range of hands-on scientific activities to help students understand electricity, conductors, insulators, resistance and consider the value, acceptability and direction of the research, technologies that will help shape their future.

How long before the digital revolution enables a new generation of technologies?
It may be sooner than you think and the way we generate and consume electricity is one of the main drivers of the research that will help evolve digital technologies and enable driverless cars, advanced artificial intelligence, robotics and advances in human health. It could enable computers the ability to monitor and track your every movement, conversation and your proximity to others. That computer could analyse and interpret the meaning of your conversation and actions and make decisions based on that data. What are acceptable uses of such technologies? Who should control such technology? Such questions should be part of the dialogue about the direction and application of scientific research and, alongside the hands-on experiments, are part of the critical thinking activities in this unit.

Learning outcomes

By the end of the unit, students will have….

- A solid understanding of electricity, conductors, insulators, resistance and the basic structure of the atom
- Knowledge about the features and functions of circuits
- Awareness of the history and philosophy that led to our understanding of electricity, circuits, energy and modern digital technologies
- A basic understanding of how electricity and resistance works at the quantum level
- The ability to think critically about the social implications of how we use electricity and modern digital technologies
- The ability to apply experience from each stage of the unit to predict or develop hypotheses in novel contexts

- Be able to use evidence to generate a discussion about what is happening.
- Effectively reflect on their experimental design and understand the limitations, make improvements to add greater rigour to experimental design and therefore outcomes
- Think critically about the use of electricity and its implications for society

Victorian Curriculum Links Years 5-6

Scientific understandings, discoveries and inventions are used to inform personal and community decisions and to solve problems that directly affect people's lives	• Considering how electricity and electrical appliances have changed the way some people live • Considering how guidelines help to ensure the safe use of electrical devices
Energy from a variety of sources can be used to generate electricity; electric circuits enable this energy to be transferred to another place and then to be transformed into another form of energy	• Recognising the need for a complete circuit to allow the flow of electricity • Exploring circuit features, for example, wires and switches, and electrical devices, for example, light globes, LEDs and motors • Investigating different electrical conductors and insulators • Investigating how moving air and water can turn turbines to generate electricity • Investigating how solar panels can generate electricity
With guidance, pose questions to clarify practical problems or inform a scientific investigation, and predict what the findings of an investigation might be based on previous experiences or general rules	• Exploring a range of questions that can be asked about a problem or phenomena and, with guidance, identifying those questions that could be investigated by students • Refining questions to enable scientific investigation • Applying experience from previous investigations to predict the outcomes of investigations in new contexts
With guidance, plan appropriate investigation types to answer questions or solve problems and use equipment, technologies and materials safely, identifying potential risks	• Following a given procedure to design an experimental or field investigation • Experiencing a range of ways of investigating questions, including experimental testing, creating models, internet research, field observations, simulations and trial and error methods • Discussing the advantages and disadvantages of certain types of investigation for answering certain types of questions • Discussing possible hazards involved in conducting investigations, and how these risks can be reduced
Construct and use a range of representations, including tables and graphs, to record, represent and describe observations, patterns or relationships in data	• Using familiar units such as grams, seconds and metres and developing the use of standard multipliers such as kilometres and millimetres • Using digital technologies to record data as digital images or in spreadsheets and to present data in tables and simple graphs • Using digital technologies to construct representations, including dynamic representations
Compare data with predictions and use as evidence in developing explanations	• Discussing the difference between data and evidence • Referring to evidence when explaining the outcomes of an investigation • Sharing ideas as to whether observations match predictions, and discussing possible reasons for predictions being incorrect
Suggest improvements to the methods used to investigate a question or solve a problem	• Working collaboratively to identify where testing was not fair and suggesting how fairness could be improved • Identifying improvements to investigation methods, and discussing how these improvements would affect the quality of the data obtained
Communicate ideas and processes using evidence to develop explanations of events and phenomena	• Discussing how models represent scientific ideas and constructing physical models to demonstrate an aspect of scientific understanding

and to identify simple cause-and-effect relationships	• Using a variety of communication modes, for example, reports, explanations, arguments, debates and procedural accounts, to communicate science ideas • Using labelled diagrams, including cross-sectional representations, to communicate ideas and processes

Victorian Curriculum Links Years 7-8

Scientific knowledge and understanding of the world changes as new evidence becomes available; science knowledge can develop through collaboration and connecting ideas across the disciplines and practice of science	
Science and technology contribute to finding solutions to a range of contemporary issues; these solutions may impact on other areas of society and involve ethical considerations	• Investigating the development of vehicles over time, including the application of science and technology to the designs of solar-powered or electric vehicles
Energy appears in different forms including movement (kinetic energy), heat, light, chemical energy and potential energy; devices can change energy from one form to another	• Using flow diagrams to illustrate changes between different forms of energy
Identify questions, problems and claims that can be investigated scientifically and make predictions based on scientific knowledge	• Considering whether an investigation using available resources is possible when identifying questions or problems to investigate • Using information and knowledge from their own investigations and secondary sources to predict the expected results from an investigation • Recognising that the solution of some questions and problems may require consideration of social, cultural, economic or moral factors in addition to results from scientific investigation
Collaboratively and individually plan and conduct a range of investigation types, including fieldwork and experiments, ensuring safety and ethical guidelines are followed	• Identifying whether the use of their own observations and experiments or the use of other research materials is appropriate for their investigation • Using simulations and identifying their strengths and limitations • Developing strategies and techniques for effective research using secondary sources, including use of the internet
In fair tests, measure and control variables, and select equipment to collect data with accuracy appropriate to the task	• Taking into consideration all aspects of fair testing, available equipment, safe investigation and ethical considerations identifying and explaining the differences between controlled, dependent and independent variables when planning investigations • Using specialised equipment to increase the accuracy of measurement within an investigation
Construct and use a range of representations including graphs, keys and models to record and summarise data from students' own investigations and secondary sources, and to represent and analyse patterns and relationships	• Understanding different types of diagrammatic, graphical and physical representations and considering their strengths and limitations • Comparing and contrasting data from a number of sources in order to create a summary of collected data • Using diagrammatic representations to convey abstract ideas and to simplify complex situations
Use scientific knowledge and findings from investigations to identify relationships, evaluate claims and draw conclusions	• Identifying data that provides evidence to support or refute the hypothesis being tested • Drawing conclusions based on a range of evidence including from primary and secondary sources
Reflect on the method used to investigate a question or solve a problem, including evaluating the quality of the data collected, and identify improvements to the method	• Identifying and considering indicators of the quality of the data when analysing results • Discussing investigation methods with others to share ideas about the quality of the inquiry processes used • Suggesting improvements to investigation methods that would improve the accuracy of the data recorded

Communicate ideas, findings and solutions to problems including identifying impacts and limitations of conclusions and using appropriate scientific language and representations	• Using digital technologies to access information, to communicate and collaborate with others on and off site and to present science ideas • Selecting and using appropriate language and representations to communicate science ideas within a specified text type and for a specified audience

Victorian Curriculum Links Years 9 - 10

Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries	
Electric circuits can be designed for diverse purposes using different components; the operation of circuits can be explained by the concepts of voltage and current	• Investigating parallel and series circuits and measuring voltage drops across and currents through various components • Investigating the properties of components such as LEDs, and temperature and light sensors • Comparing circuit design to household wiring • Exploring the use of sensors in robotics and control devices
The interaction of magnets can be explained by a field model; magnets are used in the generation of electricity and the operation of motors	• Investigating the movement of a magnet and a wire to produce electricity • Investigating the effect of a magnet on a current from a battery to produce movement
Energy flow in Earth's atmosphere can be explained by the processes of heat transfer	• Recognising that the Law of Conservation of Energy explains that total energy is maintained in energy transfers and transformations • Recognising that in energy transfers and transformations, a number of steps can occur and the system is not 100% efficient so that usable energy is reduced
Formulate questions or hypotheses that can be investigated scientifically, including identification of independent, dependent and controlled variables	• Formulating questions that can be investigated within the scope of the classroom or field with available resources • Developing ideas from students' own or others' investigations and experiences to investigate further • Revising and refining research questions to target specific information and data collection or finding a solution to the specific problem identified
Independently plan, select and use appropriate investigation types, including fieldwork and laboratory experimentation, to collect reliable data, assess risk and address ethical issues associated with these investigation types	• Explaining the choice of variables to be controlled, changed and measured in an investigation • Deciding how much data are needed to obtain reliable measurements • Using modelling and simulations, including using digital technologies, to investigate situations and events • Using the internet to facilitate collaboration in joint projects and discussions
Select and use appropriate equipment and technologies to systematically collect and record accurate and reliable data, and use repeat trials to improve accuracy, precision and reliability	• Applying specific skills in the use of scientific instruments • Selecting and using probes and data loggers to record information • Identifying how human error can influence the reliability of data
Construct and use a range of representations, including graphs, keys, models and formulas, to record and summarise data from students' own investigations and secondary sources, to represent qualitative and quantitative patterns or relationships, and distinguish between discrete and continuous data	• Using spreadsheets to present data in tables and graphical forms and to carry out mathematical analyses of data • Designing and constructing appropriate graphs to represent data and to look for trends and patterns

Analyse patterns and trends in data, including describing relationships between variables, identifying inconsistencies in data and sources of uncertainty, and drawing conclusions that are consistent with evidence	● Exploring relationships between variables using spreadsheets, databases, tables, charts, graphs and statistics ● Describing data properties (for example mean, median, range, outliers, large gaps visible on a graph) and their significance for a particular investigation sample, acknowledging uncertainties
Use knowledge of scientific concepts to evaluate investigation conclusions, including assessing the approaches used to solve problems, critically analysing the validity of information obtained from primary and secondary sources, suggesting possible alternative explanations and describing specific ways to improve the quality of data	● Discussing what is meant by 'validity' and how we can evaluate the validity of information in secondary sources ● Judging the validity of science-related media reports and how these reports might be interpreted by the public ● Using primary or secondary scientific evidence to support or refute a conclusion or claim ● Suggesting more than one possible explanation of the data presented
Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations	● Using secondary sources as well as students' own findings to help explain a scientific concept ● Using a range of representations, including mathematical and symbolic forms, to communicate science ideas ● Presenting results and ideas using formal experimental reports, oral presentations, multimodal presentations, poster presentations and contributing to group discussions

FLEET research and the need for the next generation of electronics

Digital technologies (anything with a computer chip) consume about 10% of global electricity and this proportion is increasing each year as year as demand for computation increases and we desire smarter, more powerful computing systems to be integrated into our daily lives. For instance, taking a single photo on your phone requires about 1 trillion computations, which you then post on Facebook and send to friends – more computations, more energy.

Today, a lot of that computer processing happens in huge factory-sized data centres. Some of the bigger data centres are more than 20 times bigger than the MCG (Australian sport stadium) and each use about the same amount of electricity as a large city suburb. Think Google, Facebook and Amazon, Microsoft. While scientists and engineers have developed ways to make these data centres extremely energy efficient compared to how your laptop or desktop computer stores and processes data, our increasing digital demands mean we continue to build more data centres and so our digital energy consumption continues to increase.

Facts to get you thinking

Bitcoin consumes more electricity than Sweden, or somewhere between 40 and 445 terawatt hours (TWh) per year, with a central estimate of about 139 TWh, according to The University of Cambridge Centre for Alternative Finance (CCAF) [https://www.jbs.cam.ac.uk/faculty-research/centres/alternative-finance/]

See other interesting CCAF comparisons here (https://cbeci.org/cbeci/comparisons).

Australia's fastest supercomputer housed in the National Computational Infrastructure (NCI) at Australian National University consumes about the same amount of energy as the average suburb of an Australian city. https://nci.org.au/

Internet traffic has tripled in the past five years. Calculations made in 2017 estimate that about 90% of the data in the world at that time was created in the previous two years. (International Energy Agency. *Digitalization and Energy* 2017). How would the same calculation done today compare?

No More for Moore

Moore's Law (though it is not really a law) predicts that the number of transistors on a computer chip would double every 18-24 months, and it was right…until now.

For many years, the energy demands of an exponentially growing number of computations was kept in check by ever-more efficient, and ever-more compact silicon-based microchips. The microchips contain the transistors responsible for processing all your data. They are really the brains of the computer. But we can't make the transistors much smaller without breaking some laws of physics. This is another motivation behind FLEET's research into the next generation of materials that will enable energy-efficient electronics and computation. Having said that, IBM claims it has produced the 2 nanometre chip – we are currently at the 5nm chip - but it is still a prototype and its efficacy is yet to be proven.

What is a nanometre?
A nanometre is one billionth of a metre – or about 100,000 times thinner than a human hair. A single strand of DNA is about 2.5 nanometres in diameter. Today's technology enables humans to manipulate single atoms and build stuff at the atomic level. Different atoms are different sizes, but an atom is about 0.5 nanometres or 1 million times thinner than a human hair. Researchers can pick up, manipulate and use atoms like Lego bricks to build novel materials and tiny new technologies.

What is FLEET doing?

There are three broad technological approaches to a more sustainable digital future. FLEET has focused on the third approach.

1. The development of renewable energy technologies.
2. The construction of algorithms and their use in artificial intelligence to help us use technologies more efficiently, for example detecting when an appliance is not in use and switching it off.
3. Energy-efficient electronic technologies. This is where FLEET comes in. While climate change and environmental sustainability are integral to the problem FLEET is trying to solve, unless we develop a new generation of technologies that consumes less energy than today's digital technologies, the future of computing could be choked by the lack of available energy in the next one to two decades.

Of course, we can also change human behaviour. A question for students to consider is what sort of world do we want to strive for, to live in? What are acceptable goals for technology development and how should they be used?

FLEET's aim is to develop the next generation of low-energy electronics that will enable energy-efficient computing. A focus of FLEET's research is the development of novel, atomically thin materials - materials that can be just one atom thick. These and other novel materials such as superfluids have the potential to conduct electricity without resistance, which means nearly all the energy is used for computing and none is wasted as heat. See the section, Conductors, insulators and resistance. FLEET's research will help reduce how much energy our technologies use and underpin the transition to technologies that use novel (non-digital) ways to compute.

A Quantum Solution

FLEET works in the quantum world, which is where some of our deepest understanding yet of universe is. A focus of FLEET's research is the development of novel and atomically thin 2D materials. FLEET researchers want to understand how these materials behave at the quantum level so they can manipulate and control their useful properties. They then need to be able to develop ways to fabricate these materials at a commercial scale.

The following are just some of the ways FLEET researchers are building the knowledge to help develop low-energy electronics:

FLEET researchers are experimenting with different methods to force novel materials to temporarily become either topological insulators or shift to a superfluid state. They are also conducting research on exciton-polaritons, a weird quantum hybrid of light and matter.

Topological materials are new materials that are being investigated for their use in the next generation of transistors, even quantum computers. Topological insulators behave as electrical insulators in their interior, but can carry a current along their edges without resistance and therefore energy loss as heat. Resistance is where electrons interact with other particles in their journey through a circuit, in this case around a semi-conductor. Read more about topological insulators and topology here.

A superfluid is a quantum state. Whereas a superconductor can conduct electrical current flow without resistance, a superfluid has no charge, but can flow without resistance, meaning there is no friction that can impede its movement. But this superfluid state occurs only at massively cold temperatures (close to zero Kelvin or -273 degrees Celsius). FLEET is conducting research into developing superfluids that operate at room temperature with the aim to integrate them into transistors.

Exciton-Polaritons: Light and matter (anything made of atoms or the particles that make up an atom) are not supposed to mix. But scientists have now found a way to combine light and matter (electrons in this case) to make a new object called the exciton-polariton, whose weird quantum properties may enable us to develop electronic technologies that use a lot less energy, help build the quantum computer, detect black holes and stars colliding and build new types of low-energy lasers. Read more about these weird quantum particles here.

See also the following FLEET video https://youtu.be/LV4uFHqdio4

What is electricity?

We observed and harnessed electricity way before we understood how it worked. Electricity is a range of phenomena associated with the flow of charge.

See Activity 1, *What is electricity* that will get students to think critically about how electricity has changed the world, where it comes from and how we generate and use electricity.

To understand what electricity is and how it works, it helps to understand the structure of the atom, knowledge that the scientists of the 17th through to the 19th centuries lacked when developing their ideas about the nature of electricity.

Get students to draw an atom in Activity 2 that will help teachers establish students' baseline understanding of the structure of the atom. The critical thinking and draw and atom activity is below.

After drawing an atom, take students on an in-depth examination of the atom and the scientific journey to understand its structure, a journey that got it wrong a lot of times before reaching the understanding we have today. And we are still working out the finer details.

Activity 1: What is electricity

Learning Intentions
Student will think critically about how electricity has changed the world, where it comes from, how we generate and use electricity and the risk, benefits and acceptability of these uses.

Materials
None

Teacher Notes	Teaching Notes: Running the activity
We observed and harnessed electricity way before we understood how it worked. Electricity is a range of phenomena associated with the flow of charge. *Value of electricity* Electricity might mean children can pump and purify their water, they can switch on a light at night and read a book, do their school work, have better access to healthcare because for example, many medicines, and especially vaccines need refrigeration. Electricity enables us to get those medicines to these children and others. *Our production of electricity* Think about how we produce electricity from fossil fuels (gas and coal), nuclear, solar, wind, hydro. What are the benefits and risks with each of these sources? What risks are acceptable and why? For example, US and UK university research has found that about 8 million people die each year from fossil fuel pollution. There are many other reasons we should reduce our energy consumption and change the way we use electricity.	**Small student groups** Students brainstorm how they think electricity has changed the world. Get students to consider the following questions: ● What would the world, your life be like without electricity? ○ How cold/hot it would be, how dark it would be? ○ How would you feel? ● How many things do you do in a day that require electricity? ○ How would you do those same tasks without electricity? ● How might electricity help children such as yourselves, but from areas in developing nations that today still don't have electricity in their homes or village? ● Where does our electricity come from? How do we generate it? ○ What are some of the problems with how we generate and use our electricity?

Activity 2. Draw an atom

Learning Intentions
Students will think critically about their understanding of an atom.

Materials

- Pencils, crayons
- Paper
- Online drawing tool (optional)

Teacher notes	Teaching notes: Running the activity
To understand electricity, it helps to understand the structure of the atom, knowledge that the scientists of the 17th through to the 19th centuries lacked when developing their ideas about the nature of electricity. Compare student drawings to the historical models such as J. J. Thompson's Plum Pudding model outlined in the resource below. As part of a more in-depth explanation of the atom following their drawing of the atom, explain some of the limitations associated with each model. This is the preparatory activity for the activity, Build an atom. Repeat this activity at the end of the unit or the activities you conduct to see if students' understanding of the atom and its structure has changed.	**Small student groups** With only minimal introduction to the concept of an atom, ask student to draw what they think an atom looks like. This first drawing will provide a baseline understanding of students' perception of an atom.

The atom and the electron

Atoms have a core (nucleus) that is made up of protons and neutrons. The protons carry a charge, the neutrons are neutral – no charge. Surrounding the nucleus is a cloud of charged particles known as electrons. Electrons have charge that is opposite to the charge on the proton.

It was Benjamin Franklin in 1748 that suggested there were two types of charge that were opposites*. The opposite charges attracted each other and like charges repelled each other. We now call these charges, positive and negative, but we could easily call them Bob and Jenny or Ping and Pong. At the time, Franklin had no means to measure or quantify his ideas, but it turned out he was correct – sort of. What Franklin got wrong was his suggestion that current flowed from the positive to the negative. And Franklin and his contemporaries at the time used the concept of flow in the literal sense because electricity was considered a form of invisible ethereal fluid. It was not until 1897 when J. J. Thompson experimentally determined the existence of the electron using devices called cathode ray tubes that we realized Franklin's mistake. See the section, 'Finding the electron' below. Soon after finding the electron we learned that it was the loss and gain of electrons from the atom and the movement of the electron being drawn toward a positive charge that generates the flow of charge (electricity) in a circuit. But the convention of understanding that charge travels from the positive to the negative has stuck and we now have two conventions: the conventional model (charge flows from positive to negative) and the electron model (charge flows from negative to positive). It can be confusing, but the important point is that the math is the same and the outcome is the same whichever model is applied. This unit will apply the electron model in its explanations and activities.

*While probably the more famous and the one credited with the idea of charged particles, there were other natural philosophers before Benjamin Franklin that used language to describe phenomenon similar to Franklin's ideas on charges and electrification. A slightly more academic review article that gives one historical perspective and overview on the history of electricity is Marton and Marton, Evolution of the Concept of the Elementary Charge. Editor(s): L. Marton, C. Marton, Advances in Electronics and Electron Physics, Academic Press, Volume 50, 1980, Pages 449-472.

Understanding the atom

Proton says to the electron: "I don't feel well."
Electron: "Are you sure?"
Proton: "I'm positive."

Our understanding of the atom today went through a few iterations over a few decades. J.J. Thomson was the first to experimentally determine the existence of the electron, but his model of the atom was still based on limited data and understanding, and consequently wrong. In his model, he had the charged particles (electron and protons) all mixed in together in something akin to a charged soup, or as it was dubbed, a "plum pudding". See Figure 1. Later we learned that an atom was mostly empty space, which is the knowledge that led us to our current understanding of the atom that has a nucleus where the protons and neutrons sit. Buzzing randomly around the nucleus in discrete energy levels are the electrons, with lots of space between the electrons and the nucleus.

Imagine a tennis ball in the centre of a football ground. Inside the hollow tennis ball are all the protons and neutrons. Out in the grandstand where the crowd sit is the cloud of electrons randomly buzzing around the outside of the ground. This is a rough approximation of the distance between the nucleus and electrons and why atoms and therefore everything is mostly empty space. For the older or more advanced students you can talk about each grandstand tier representing a distinct energy level or shell that the electrons are confined to as they move randomly though the tier that corresponds to their given energy level.

The number of protons an atom has will determine what element it is. For example, Hydrogen has one proton, Helium has two, Lithium has three...and so on. The atom is most stable when it has the same number of protons and electrons that give it a neutral charge. Some atoms will lose or donate an electron and become positive. Others can gain an electron and become negative. Charged atoms are called ions. Oppositely charged ions can form bonds with each other. For example, Na+ (sodium) and Cl- (Chloride) when bonded make salt (NaCl).

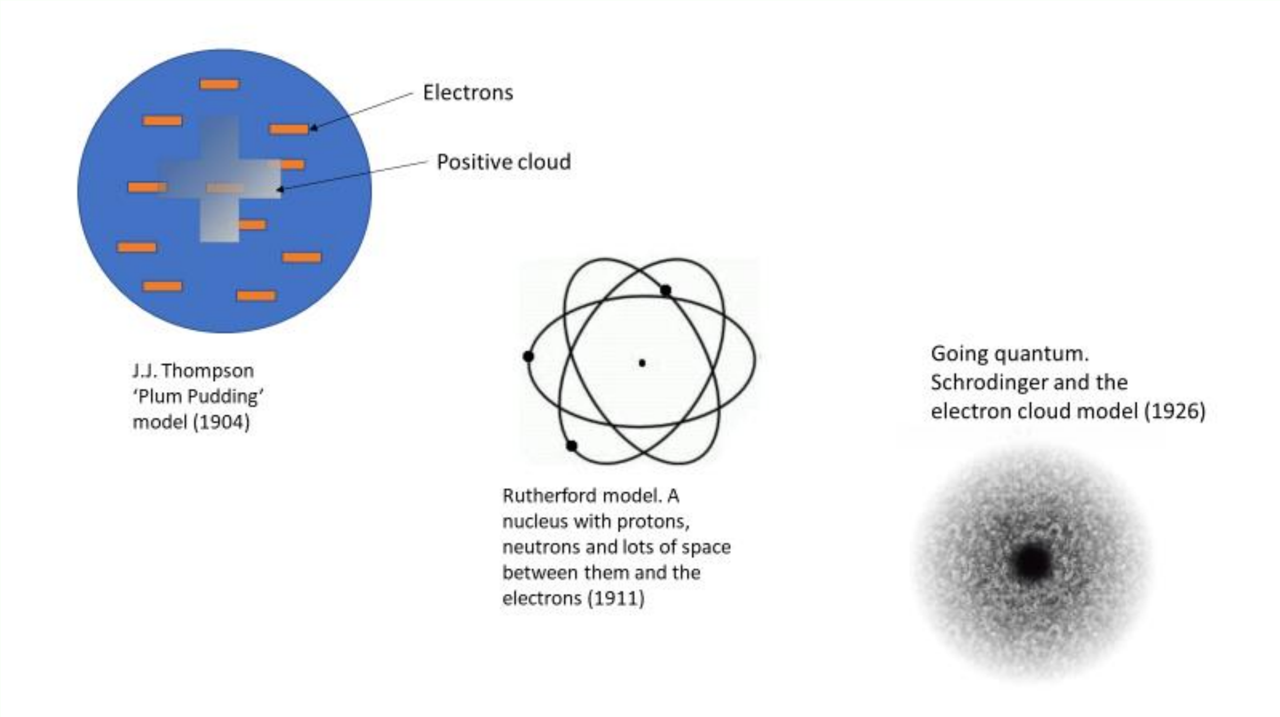


Figure 1. Atomic models starting from J.J. Thompson's plum Pudding in 1904 through to Schrodinger's electron cloud in 1926.

There are loads of images on the web of the different atomics models as they were developed over time. Here is one

Try the activity, *Build an atom*, for more detail about the nature of charge and an opportunity to make an edible atom model. The concept of charge will also be elaborated on as we move through the activities. Students will learn more about some of the scientists involved in making the initial discoveries that led to our current understanding of electricity.

The quantum model of the atom

The electron cloud model of the atom attempts to represent the quantum nature of the atom – always a tough ask because we have to get our heads around the concept of superposition.

For our purposes we will focus on the electron. Many definitions of superposition state it as a system being in multiple states at the same time. But something can't really be in multiple states, such as position, at once. It is all about probability. We have really good and well understood math that enables us to calculate the probability of the position and momentum of an electron (or quantum state). We can measure and calculate the probability that an electron will have a certain state (eg, position or momentum). This is very different to it being in or having multiple states at the same time.

The electron also has a wave function. That it, it behaves as a wave rather than a particle. As a wave it still has the quantum version of a position, momentum and energy level.

Quick activity – a role play

Get students to examine a Rutherford model of the atom – which is the one they will likely be most familiar with (and the one they will typically draw if you ask them to draw an atom).

Ask students where on the Rutherford model the electrons are. Students will inevitably point to a dot/particle in the image that represents an electron.

Role play. Select an element from the periodic table (keep it simple and select H, He or Li).
Get students to play the neutrons and protons in a nucleus. In helium, for instance, this will require 2 student protons and 2 student neutrons. They will need to stand close together to simulate a nucleus. Technically if you simulated a neutral atom, you will need two electrons. But for this exercise, you will just simulate one. You will need about 7-10 students to represent this one electron. Get the students to form a circle around the nucleus and join hands. Get the students representing the electron to do the Mexican wave. Remember the student electrons doing the wave represent just one electron. As a (Mexican) wave they surround the nucleus. Ask the remaining students to now point to the electron.

This should get the students thinking because they cannot definitively say the electron is in a particular point in space like they can in the Rutherford model.

Check out Minute Physics modelling of the quantum atom – a thing of beauty.

Activity 3: Build an atom

Learning Intentions

Students will develop an understanding of the structure of the atom and its relationship to electricity. Students will begin to familiarize themselves with the periodic table, how to use it and learn that there are many types of atom that make up the world around us.

Atoms have a core (nucleus) that is made up of protons and neutrons. Surrounding the nucleus is a cloud of particles known as electrons. The atom has two types of charged particles, the proton (+) and the electron (-). There is energy in these particles. It is the electron that is mobile and can leave its atom and it is the electron's movement through a circuit that creates electrical energy (electricity). Except in certain circumstances, protons are fixed in the nucleus. They are immobile.

Atoms are mostly empty space and nearly all of this exists between the nucleus and the electrons.

The number of protons an atom has will determine what element it is. For example, Hydrogen has 1 proton, Helium has 2, Lithium has 3…and so on. The atom is most stable when it has the same number of protons and electrons that give it a neutral charge. Now it is time to build an atom model – one you can eat.

Before the activity

You will be building the model of an atom from different lollies and some skewers/toothpicks.
Atoms have a core (nucleus) that is made up of protons and neutrons. Surrounding the nucleus is a cloud of particles known as electrons. The atom has two types of charged particles, the proton (+) and the electron (-). There is energy in these particles. It is the electron that is mobile and can leave its atom and it is the electron's movement through a circuit creates electrical energy (electricity). Except in certain circumstances, protons are fixed in the nucleus. They are immobile.

Atoms are mostly empty space and nearly all of this exists between the nucleus and the electrons. Think about this when you design your lolly atom.

The number of protons an atom has will determine what element it is. For example, Hydrogen has 1 proton, Helium has 2, Lithium has 3…and so on. The atom is most stable when it has the same number of protons and electrons that give it a neutral charge. Now it is time to build an atom model – one you can eat.

Materials

- Three different types of lolly, (or fruit if you want to be healthy). You will need three types to represent the neutrons, protons and electrons. Consider marshmallows, jubes or jelly beans. Anything you can stick a tooth pick or skewer into.
- Toothpicks
- Bamboo skewers
- Periodic table

Teacher Notes	**Teaching Notes**
Teachers will have to point out where on the periodic table students find the atomic number. You may need to emphasize that this represents the number of protons an element has. We have found that for upper primary students the process of looking at the periodic table, selecting their element and building it facilitates an understanding among many students that there is more than one sort of atom and they come in different sizes. **The Atom and The Electron** It was Benjamin Franklin in 1748 that suggested there were two types of charge that were opposites. The	**Method** Students select an atom from the periodic table to build. Choose one with a lower atomic number otherwise you won't have enough lollies or fruit. Look for the atomic number to know the number of protons and neutrons. Use the materials to build the model of your selected element. Assume you are building a neutral version – one that has equal numbers of protons, neutrons and electrons. Select which lolly or fruit will be the proton, neutron and electron. Use the toothpicks to join the protons and neutrons together to make the nucleus.

opposite charges attracted each other and like charges repelled each other. We now call these charges, positive and negative. It was not until 1897, however, that J. J. Thompson experimentally determined the existence of the electron and found it was the negatively charged particle. Our understanding of the atom today went through a few iterations over a few decades. J.J. Thomson used his knowledge of the electron to develop a model of the atom. It was still based on limited data and understanding, and consequently wrong. His model had the charged particles (electron and protons) all mixed in together in something akin to a charged soup, or as it was dubbed, a “plum pudding”. Later we learned that an atom was mostly empty space, which is the knowledge that led us to our current understanding of the atom that has a nucleus where the protons and neutrons sit. Buzzing randomly around the nucleus in discrete energy levels are the electrons, with lots of space between the electrons and the nucleus. Imagine a tennis ball in the centre of a football ground. Inside the hollow tennis ball are all the protons and neutrons. Out in the grandstand where the crowd sit is the cloud of electrons randomly buzzing around the outside of the ground. This is a rough approximation of the distance between the nucleus and electrons and why atoms and therefore everything is mostly empty space. For the older or more advanced students you can talk about each grandstand tier representing a distinct energy level or shell that the electrons are confined to as they move randomly though the tier that corresponds to their given energy level. Students can compare how their lolly models compare to different models through history. See Figure 1 in the main resource. Or there are loads of images on the web of the different atomics models as they were developed over time. Here is one. Other resources Try the PHeT simulation to build an atom. This website has a periodic table aimed at the primary level This site is more for the older kids – year 6-8, but it does contain insightful videos for each element.	Use the bamboo skewers to join your nucleus to your electrons. Note the large amount of space between the electrons and the nucleus. This reflects the fact an atom is mostly empty space. Take a photo of your model. Name the element and label the protons, neutrons and electrons ***Extension*** Get students to consider what a charged version would be. How would they change their atom to make it negative or positive charged atom (ions)? That is, add or remove an electron. Get students to write the element with the correct charge eg, Na^{+} or Cl^{-}

Before you explore in more detail the nature of electricity, get students to consider what they think electricity is. See Activity 4, Draw a circuit that establishes a baseline understanding of circuits and electricity. It can be compared to their understanding at the end of the selected activities. After completing Activity 4, we go back further in time to examine how we first perceived the concept of electricity.

Activity 4. What is electricity? Draw a circuit

Learning Intentions
Students will explore and articulate their perception of the concept of electricity and what a circuit is. This activity establishes a baseline understanding of circuits and electricity. It can be compared to their understanding at the end of the selected activities.

Materials
- Paper
- Pencils, crayons
- Online drawing tools (optional)
- Worksheet for Draw a circuit

Teacher Notes	Teaching Notes: running the activity
At this point we simply want to assess student perceptions of what electricity and a circuit is. We do not correct it here. They get to test/challenge their assumptions, reflect on and refine their ideas as we proceed through the activities. While we want the student to provide their initial perception without prompts, for teacher background the following basics may be useful. In the construction of the atom, students learned the atom has charged particles and one of those particles – the electron – is responsible for making electricity. To generate electricity, we need to make those electrons flow in one direction. How do we do that? We need a force or source of energy of some sort. The battery is one common source. It converts chemical energy into electrical energy. Remember we are not magicians. We cannot magic up electrical energy from nowhere. We need to convert one form of energy into a form that is useful for what we want to do. The form of energy that is useful to us in a circuit is electrical energy and in Activity 10 we will use it to make a light globe glow. It is your battery that provides the energy to push and pull the electrons along – to make them flow through a circuit. The negative half of the battery contains electrons that when connected to a circuit will provide a repulsive force to push the electrons through the circuit. The positive side of the battery provides an attractive force to pull the electrons through a circuit. The flow of charge in a properly made circuit results in electricity. A correct circuit is a closed circuit. That is, where there is a continual circuit from the negative terminal through the load source (light globe) and to the positive terminal.	**What is electricity?** Students brainstorm in small groups about what they think electricity is. Students can use whiteboards or butcher's papers to draw or describe what they know about electricity and what they think it is. Alternatively, if they have access to software drawing tool, they can attempt to draw them on their devices. **Draw a circuit** In small groups, students brainstorm how they would make a functioning circuit using the following three components: a battery, wires and a light globe. Students use their drawing tools to draw their perception of a functional circuit using the three components. Get students to describe why they think their circuit will work.

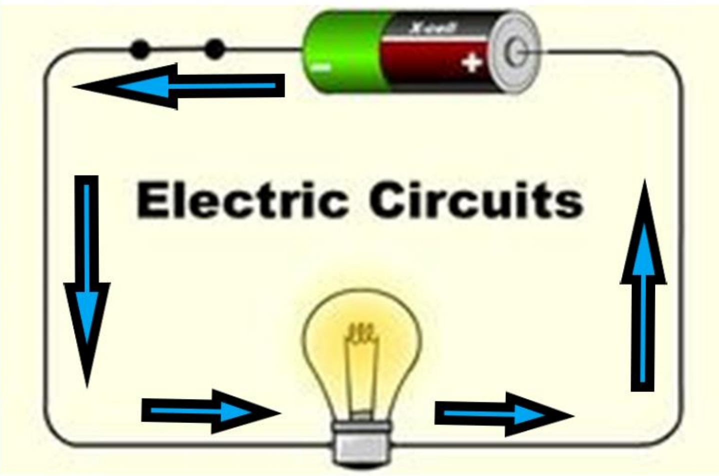


Figure 1. A closed circuit. The arrows show the direction of flow of the electrons through the circuit.

In Activity 10, students can build on their initial perceptions of electricity and circuits and build their own circuit in the activity, *Graphite circuit.* Following completion of Activity 10, get students to draw a circuit again, this time labelling the direction of electron flow. Higher year levels could include different circuits such as parallel or series.

Time for some history: It is time to dig a bit deeper into how our understanding of electricity developed and to play around with it ourselves by building some circuits. Students will test their perceptions and think critically about what the implications are for society. We start with static electricity and then delve into conductors, insulators and resistance.

How we built an understanding of static electricity

Apart from our observation of lightning, the ancient Greeks were probably the first to at least record their experience with static electricity that they themselves generated by rubbing amber with a cloth. As noted below, we did not at the time understand that lightning was electricity and that it and the sparks coming from the amber were one and the same thing. That understanding came much later.

Francis Hauksbee, a scientific instrument maker in the early 18th Century was one of the first to build a machine to demonstrate the concept of static electricity. He built a machine that rotated a hollow glass sphere that had the air sucked out by an air pump (also designed by Hauksbee). When you placed your hands on the rotating glass sphere, the machine generated static electricity that could be seen as an aura within the sphere. It was demonstrated to an audience of the Royal Society and it was one of the first demonstrations to suggest that electricity could be something other than amusement, though the initial use of Haukebee's machine was by entertainers who used electricity to perform what we would consider magic shows. Back then people who experimented with electricity or used it to make entertainment called themselves electricians.

Stephen Gray has been called 'the father of electricity'. In the 1720s and 30s, he used one of Hauksbee's rotating spheres to demonstrate that he could create a charge and transfer that charge to another object and that electricity could be conducted through some materials, but not others. For a deeper insight check this Royal Society blog.

It was not long after this that Benjamin Franklin proposed an experiment that the French actually carried out, which demonstrated that lightning was actually electricity, the same stuff that Gray, Hauksbee and the ancient Greeks had made. They erected a long metal rod in a frame, one end pointing the sky, the other end insulated from the ground in the frame. Then they waited for a storm. One came and lightning struck the metal rod, storing some of that electrical energy in the rod. Just after the lightning struck the rod, one brave French person ran out and put their hand close to the rod and electricity jumped across the rod to their hand, giving the poor unfortunate and shock and minor burn, but ultimately showing that lightning was indeed electricity. It was these experiments and observations that validated Ben Franklin's assumption and eventual development of the lightning rod that we now have on all buildings to protect them from lightning.

We still did not know how electricity worked. We were still only observing the phenomenon.

What we know now is that static electricity, or any electricity, is the movement of charge (usually the electron) through a material. With static electricity, electrons build up on an object or area until there is sufficient potential or attractive force for a charge (electrons) to jump to an area with an overall positive charge. This is visualized in the form of a spark. In the case of static electricity that movement of electrons is through air and air is a good insulator, which is why in the case of lightning you need loads of electrons to build up in the clouds before they can make the explosive jump (a really big spark) all the way to the ground that is acting as the positively charged object (or object that is less negative than the electron charged atmosphere of the sky).

It would be another century before we started to understand how electricity worked and that it was intimately connected to magnetism. We will get to this in more detail in the section below on electricity and magnetism.

See Activities 5 and 6, *Static, sticky and flappy plastic*, and *Water Bender* below to witness static electricity in action and help students conceptualize charge and the movement of charge.

Activity 5. Static, sticky, flappy plastic

Learning Intentions
Students get to think, observe and learn about the difference between insulators and conductors and how charged particles (electrons and protons) function to generate static electricity.

Materials
Flexible plastic sheet such as an overhead projector sheet
Bulldog clip or similar
Pencil (or pen, piece of wood)
Metal nail
Your finger

Before the activity
You will be observing static electricity in action. You need to think about how charged particles repel or attract each other and how insulators or conducting materials will affect their action.

Hypothesis
Observe each step of the activity and try to predict what will happen to the two strips of plastic and why.

Teacher Notes	Teaching Notes: Running the activity
Get students to predict outcomes in each step of the following demonstration. Can students explain their observation when you run your fingers down the plastic strips? Why do the two pieces of plastic repel each other? Using what students know about how charges attract and repel, what ideas do they have to explain their observation? Get students to predict what will happen when you place the pen/pencil, metal nail and your finger between the repelling strips of plastic. **What is happening?** When you run your finger down the plastic strip, electrons are being ripped off your fingers and onto the plastic. This makes the plastic strips more negative or with an overall negative charge. Because both bits of plastic are negative, they will repel each other and be sticking out like bird wings as they try to get as far apart from each other as possible. If you put an insulator such as plastic pen between the two repelling strips of plastic, nothing should happen. The two plastic strips will continue to repel each other because the plastic is a good insulator. As an insulator the electrons are stuck tightly to their atoms and can't easily move. The insulator remains neutral ensuring the repelling force between the plastic strips remains. If your stick a conductor such as a nail or your finger between the two plastic strips, the strips should close over the conducting object. That is, they will be attracted to the nail/finger. Why? Because the electrons in conductors are more mobile they will be repelled by electrons on the plastic strip, and they will	**Method** Cut two strips (about 1cm by 10cm) of flexible plastic. Place one strip on top of the other and secure one of the narrow ends with a bulldog clip (or peg). Hold the bulldog clip with the two sheets of plastic. With your thumb and pointer/index finger, run them down each side of the strips of plastic – from top to bottom. Observe what happens to the bits of plastic. Run your finger down the strips again (to charge it up again) Now try placing different items between the two bits of repelled plastic - the pen/pencil, metal nail, your finger. What is happening and why?

move along the nail or finger to get away from the electrons in the plastic strip. That leaves your nail or finger as an overall positive conductor in the middle of the plastic strip. Negative and positive attract. The negative plastic strip will be attracted to the now positive conductor (nail, finger).	

Activity 6. Water Bender

Learning Intentions

Students get to think, observe and learn about the difference between insulators and conductors and how charged particles (electrons and protons) function to generate static electricity.

Materials

- A dry latex balloon (if you don't have a balloon you can use a dry plastic comb, a section of PVC pipe, or plastic pen)
- A water tap (or a bottle with a small hole cut in the bottom which allows the water to drizzle out at a slow and steady speed)
- A head of hair (or towel).

Teacher Notes

Have you noticed your hair sticking out on a dry day? Have you ever given someone a shock after rubbing your feet against a carpet? This experiment will help you understand static electricity and you will use this power to bend water.

FLEET has a short video of the experiment that can be seen here

What is happening

This is all about a tale of opposing forces, how opposites attract and symmetry.

Water molecules are polar molecules. This means that the two hydrogen atoms and one oxygen atom that make up a water molecule form a shape that gives one end of the molecule a slightly positive charge and the other a slightly negative charge. A technical explanation is that they have an asymmetric charge distribution. But water molecules are still neutral overall; it is just their shape means that one end is more positive, the other end more negative.

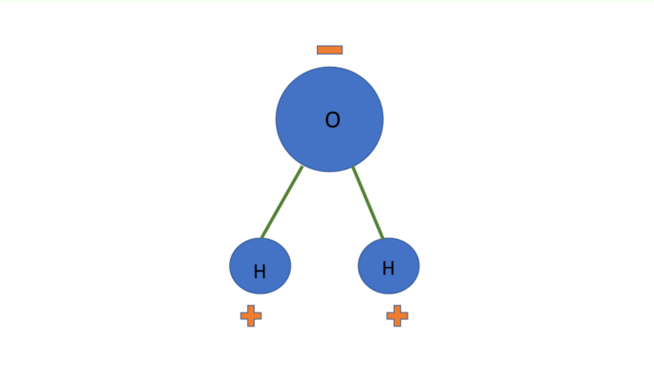


Figure 1. Water molecule showing its polar and asymmetrical shape that means one side is positive (where the hydrogen (H) atoms are) and the other side is negative (where the oxygen (O) atom is).

Teaching Notes: Running the activity

Aim

To investigate how charge (electrons) can transfer between objects and how that can affect either objects' behaviour or cause an effect.

Before the experiment:

You will do two things in this experiment. First you will rub an inflated balloon against your hair. If you don't have any hair use a towel or the nearest person to you with hair – borrow their head, but ask nicely. Second you will hold that balloon that you rubbed against a head of hair next to a stream of water coming from the tap.

Your hypothesis

What do you think will happen when you rub the balloon on your head? Write this down.

What will happen when you hold the balloon next to the stream of water? Write this down

Did you notice any other weird/unexpected effects when you rubbed the balloon against your hair? Describe any effects that you observed. This is not really part of your hypothesis for this experiment, but it is often the unexpected or odd things that scientists notice that can sometimes lead to amazing new discoveries and knowledge.

Safety: Don't let the balloons go outside. They will end up in the ocean and harm marine animals. Dispose of the balloons appropriately.

Method

1. Rub the balloon through your hair back and forth around 20 times (20-30 seconds).
2. Turn on the water tap so only a thin stream of water is running.
3. Hold the balloon to the side of the water stream – about 1-2 cm from the stream and about 8-10 cm below the tap. Make sure the balloon does not touch the water. Make sure it is the side of the balloon that you rubbed on your head that you put near the water. Observe what happens.

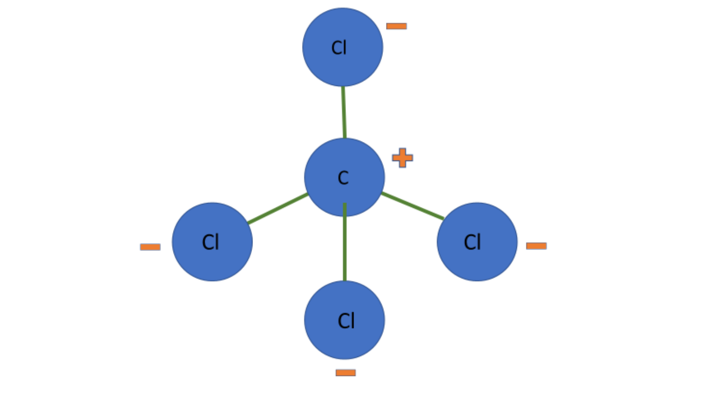


Figure 2. An image of a non-polar, symmetrical molecule where the charge (positive and negative) are evenly distributed around the molecule. The molecule is called Carbon Tetrachloride and the National Library of Medicine has a good animation that shows its symmetry https://pubchem.ncbi.nlm.nih.gov/compound/Carbon-tetrachloride

Polarity of molecules describes how the electrical charge is distributed around the molecule. In non-polar molecules, charge is evenly distributed. In a polar molecule such as water, that charge is unevenly distributed so it has regions that are more negative and regions that are more positive. A non-polar molecule is neutral at any position or region on the molecule.
More information here: https://sciencenotes.org/polar-and-nonpolar-molecules/

The latex in a balloon is neutral – it has an equal number of positive and negative charges. But when you rub the balloon on your hair, electrons transfer from your hair to the balloon giving the balloon an overall negative charge. Electrons in some materials, such as your hair, are loosely bound to their atoms. By rubbing the balloon onto your hair, the electrons on your hair leave their atoms and transfer to the balloon.

When you put the negatively charged balloon next to the stream of water, the water molecules in the stream will tend to flip so that their negative side is facing away from the balloon. Remember like charges repel – the negative charges (electrons) from the water and balloon will try to get as far apart from each other as they can. This means the positive sides of all the water molecules is now facing the negatively charged balloon. And what do opposite charges like to do? They are attracted to each other. The water molecules are attracted to the balloon, which is why you see the water bend toward the balloon. Gravity is also at work here. The gravitational force is pulling the water down, which is why the water stream does not fly straight out onto the balloon.

4. Move the balloon slowly up and down the stream of water. Observe what happens.
5. Move the balloon around the stream of water. Observe what happens.
6. Have a play and test some other ideas out. Try the comb (use it to comb your hair), plastic or glass rod rubbed on a towel and hold these items near the water stream. What happens if you get the balloon wet, or you have wet hair when you rub the balloon on it? Write down what you do here, step-by-step.

Tips: If it does not work, turn down the tap a bit to reduce the pressure of the water stream or run the balloon through your hair a few more times.

Results

Describe what you observed after each of the tests in steps 3 to 6 above.
(Did you notice anything about your hair when you rubbed the balloon against it? Can you describe it here?

Discussion

What do you think was happening here? What does your data tell you that might help you answer this and the following questions? Use your knowledge of how charges behave to help you. That is, that opposite charges attract and like charges repel.

Why did the water behave the way it did?
Why did you get different effects/outcomes when your hair or balloon were wet?
Why does the water not fly straight to the balloon and stick to it? (Think about gravity.)
How did your findings match your hypothesis? Can you describe why your hypothesis was correct or incorrect?

Extend your thinking

What if the balloon or your hair is wet? What difference does it make to how your hair and stream of water reacts and why?

Did your hair stick out and try to attach to the balloon as you pulled the balloon away from your head? This happens because after rubbing the balloon on your hair, the electrons from the atoms in your hair jumped across to the balloon to make the balloon negative. What can't move is the atoms that make up your hair. What is left after the electrons transfer from your hair to the balloon is atoms with more protons than electrons, which means your hair has a positive charge. Now what is your positive hair going to want to do when it is near a negatively charged balloon? Remember opposite charges attract. Remember also that each of your hairs is now positive. What do like charges want to do? Each hair on your head is trying hard to get as far away from all the other hairs

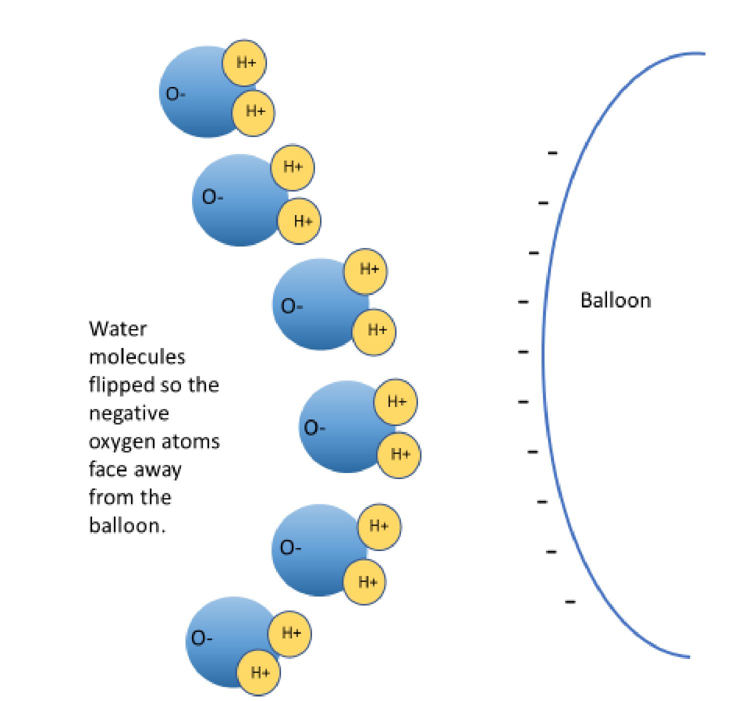


Figure 3. Water molecules in the presence of a negative charge (balloon) will orientate themselves so their negative side is facing away. The creates an overall positive charge closer to the balloon which is attracted to the negative charges (electrons) on the balloon.

What if the balloon or your hair is wet? What difference does it make to how your hair and stream of water reacts and why? Moisture prevents electrons moving around easily. If you fill your house with indoor plants this will reduce your ability to produce static electricity in the house because plants release water from their leaves and increase the humidity.

More stuff to figure out

1. Look at a periodic table and count the number of protons and neutrons one oxygen atom and two hydrogen atoms have. There will be equal numbers of each which gives water (H2O) an overall neutral charge.
2. Insulators such as plastic work best to hold onto the electrons transferred from your hair or cloth. The electrons in metals are mobile and when you transfer electrons from your hair or cloth to a metal rod, the free electrons in the metals will tend to run away from the transferred electrons from your hair (like charges repel). This makes it hard to build up an excess of electrons on a surface of metals. With insulators such as plastic the electron in the atoms are more tightly bound to their atoms, that is it is difficult for them to run away from the transferred electrons, so you can more easily get a build-up of electrons on a plastic balloon, comb or rod.
3. If your liquid was non-polar it would not flip the same way as the polar water molecule could because the charge is equally distributed around the molecule. There is no part of the molecule

(positive and positive will repel) while also being attracted to the negative balloon. It is why your hair is also all puffy and sticky out.

More stuff to figure out

Why is water – H20 – neutral? Use the periodic table to find the number of protons and electrons on the hydrogen and oxygen atoms and explain how the water molecule is neutral.
What would happen if you used a metal comb or rod to try and transfer the electrons to?
What if you had a non-polar liquid coming out of your tap? Could you make that bend with your negatively charged balloon?

that is more positive or negative. There would a much weaker (or zero) attractive force between the balloon (or plastic comb, rod, etc) and a non-polar liquid. Acknowledgement: Thanks to FLEET Volunteer, Reza Asgari, for help with this activity.	

Conductors, insulators and resistance

We have noted that how tightly bound electrons are to their atom influences how good they are at conducting electricity. This mobility is based on how easily electrons that are in the outermost valence shell – the electrons furthest from the nucleus – can leave their atom and move through the material.

An insulator is a material whose atoms have their electrons tightly bound to the nucleus and are unable to easily free themselves to flow through the material to generate electricity.

A conductor is a material that has electrons in the outer shell that are loosely bound to their atoms, which enables the electrons to flow easily through a material when an electrical force (voltage) is applied. Metals are good conductors for this reason. But even good conductors have some level of what is known as resistance that will impede the flow of electrons through the material.

Resistance

Resistance is a property of the material that impedes the flow of electrons. Therefore, the greater the resistance of a material, the more energy is required to get electrons to flow through that material and fewer electrons will be moving. There will be a reduced flow of charge. See Figure 2. Where there is resistance – and there is always some – energy in the electron is lost as heat rather than being used to perform the task we want such as powering the TV or computer. The heat is generated as electrons flow through a material and interact with and transfer their kinetic energy to atoms in the atomic lattice. The energy gained by the atoms in the lattice makes them jiggle about a lot more and this kinetic energy is transformed into heat. Materials with high resistance can make good insulators because of the difficulty to generate any flow of charge. Materials with low resistance make good conductors because it requires only low voltages, or energy, to get the electrons moving and generate electricity.

Quantum look at resistance

As noted, even the best conductors in today's circuits have some resistance. You can feel this resistance as heat.

Phonons and resistance

Electron waves interact with the atomic lattice waves (phonons) and transfer some of their energy and momentum into the lattice waves. Phonons are similar to a sound wave that an atom will give off as it vibrates, which all atomic lattices and atoms do unless they are cooled to absolute zero, which is theoretically impossible. This extra energy gained by the atomic lattice makes the lattice jiggle a bit more and this greater kinetic energy = loss of energy as heat. The electrons have lost energy in the process, which slows their flow through a circuit and therefore generates less electrical energy.

In room temperature metals/conductors, nearly all the resistance is from phonons. See Figure 3 below.

*It is important to note to students that electrical energy is not the flow of electrons (current). The kinetic energy of electrons moving through a circuit is what enables the generation of the electrical energy used to do the work. To understand more about the concept of energy and work see the section, Energy and work in the FLEET Schools resource on Energy

Ask students what they feel when they use their mobile or laptop for a while? What are the devices giving off? Hopefully they eventually say, heat. This heat is resistance and lost energy. It is energy unavailable to do work.

In Activity 7. *Conduct and resist; the dance*, there are two main objectives: to help students visualize how resistance works at the quantum level, and to challenge potential student understanding of resistance, which is typically based on the classic model of the atom and the intuitive concept of the electron as a particle.

What would the implications be if we could conduct electricity without resistance?
In Activity 8. *Life without resistance,* students have to think critically about what it would mean if we could conduct electricity without resistance.

Resistance is behind what we call "compensatory emissions." These emissions are the result of the extra electricity – often generated from fossil fuels – required to compensate for energy lost throughout out grid because of resistance. It has been calculated that worldwide, compensatory emissions amount to nearly a billion metric tons of carbon dioxide equivalents a year, in the same range as the annual emissions from heavy trucks or the entire chemical industry.

Energy loss through transmission alone ranges from 2-50% depending on the country.

[https://theconversation.com/we-calculated-emissions-due-to-electricity-loss-on-the-power-grid-globally-its-a-lot-128296]

In Australia, energy lost through transmission is about 10%. That figure would be greater the further you are from where the energy is generated. [https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/market-operations/loss-factors-and-regional-boundaries]

Students can get active and conceptualize how resistance works in Activity 8 by performing the Conduct-Insulate-Resist dance.

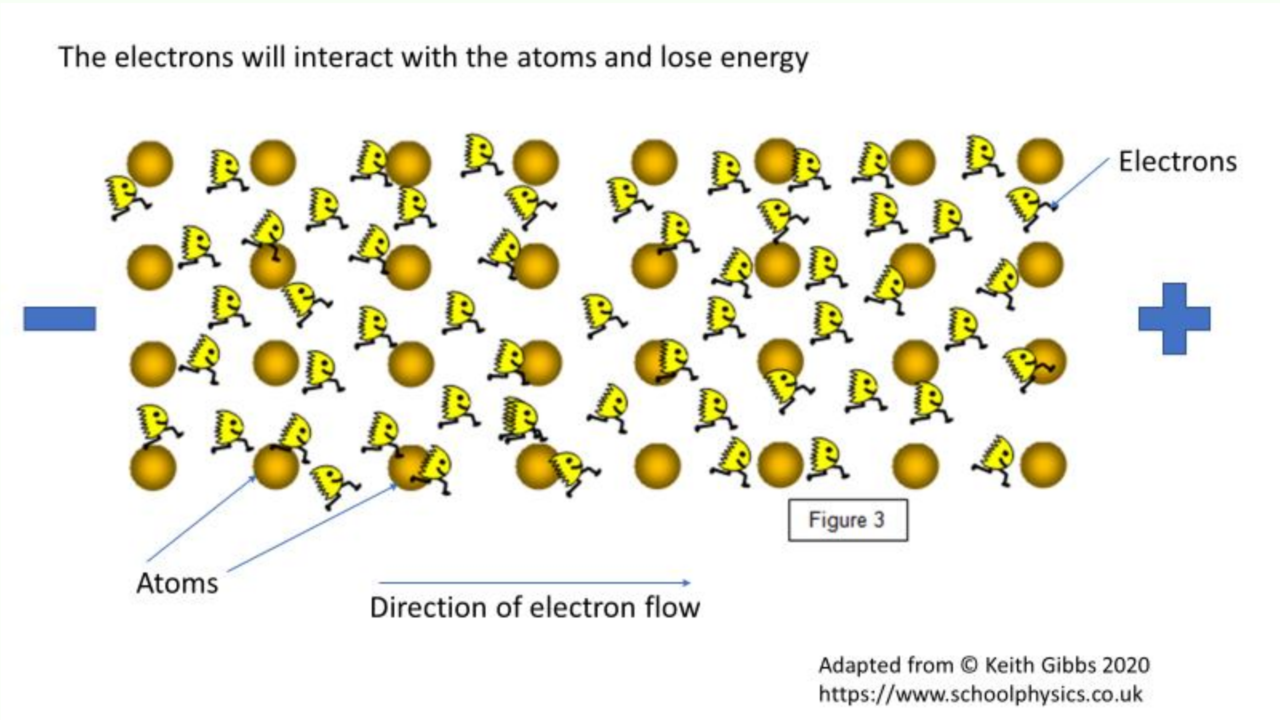


Figure 2. The greater the interaction of electrons with other atoms and the tighter the electrons are bound to their atom, the greater the resistance.

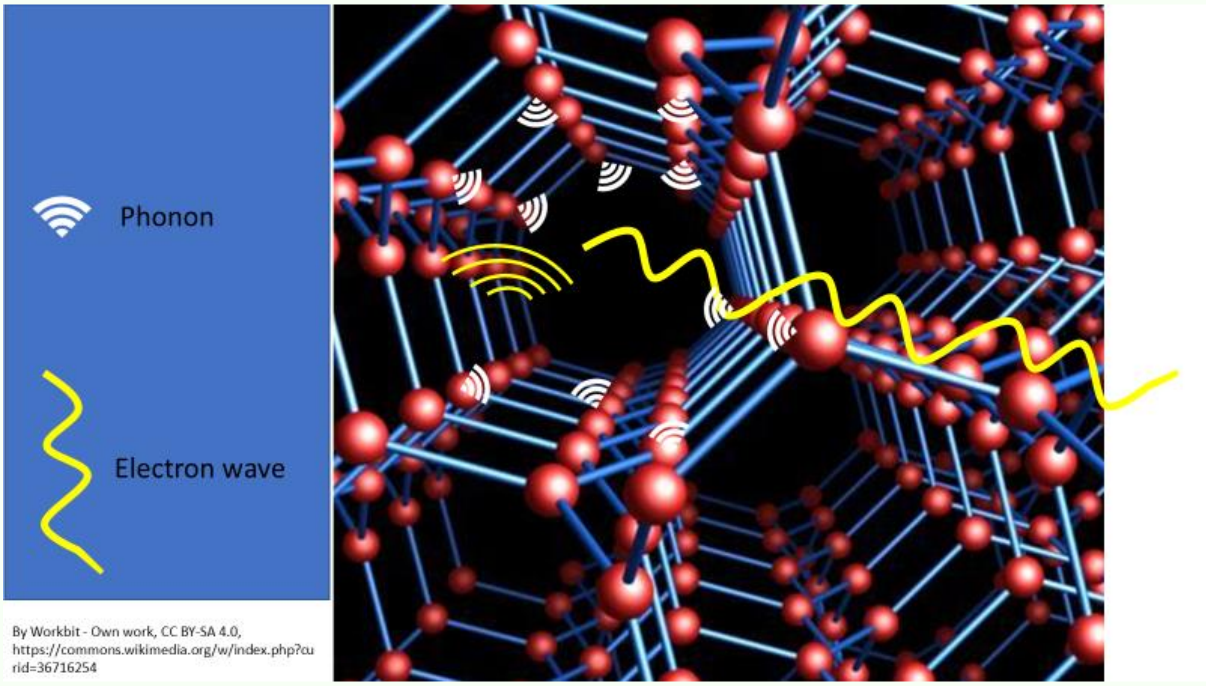


Figure 3. Electrons have a wave-like behaviour. They don't actually physically hit the atoms as they flow through a circuit. The electron wave interacts with the phonon (which is a form of sound wave) that is given off by a vibrating atom. Energy is passed from the electron to the atom via these waves

Activity 7. Conduct and resist: The quantum dance

Learning intentions
Students will have a deeper understanding about the nature of resistance at the quantum level and its implications for how we produce and use energy.

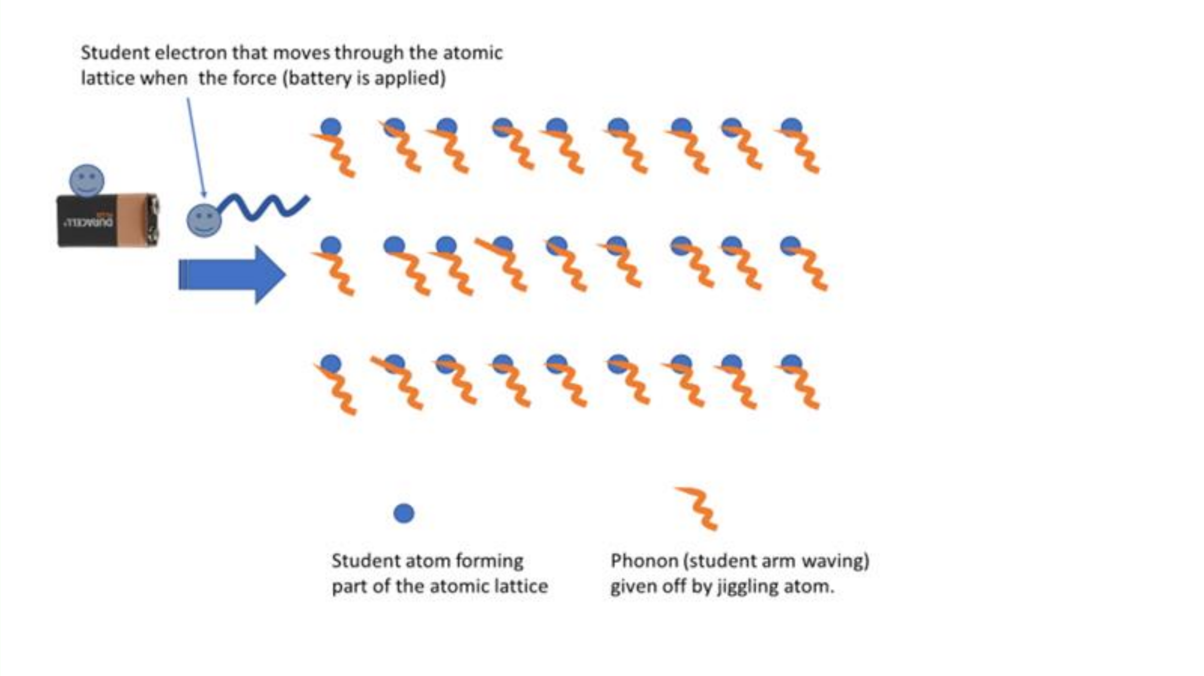
Materials

- Lots of students
- Three funky hats that you can stick pipe cleaners in
- Lots of long pipe cleaners
- Funky music, should you choose

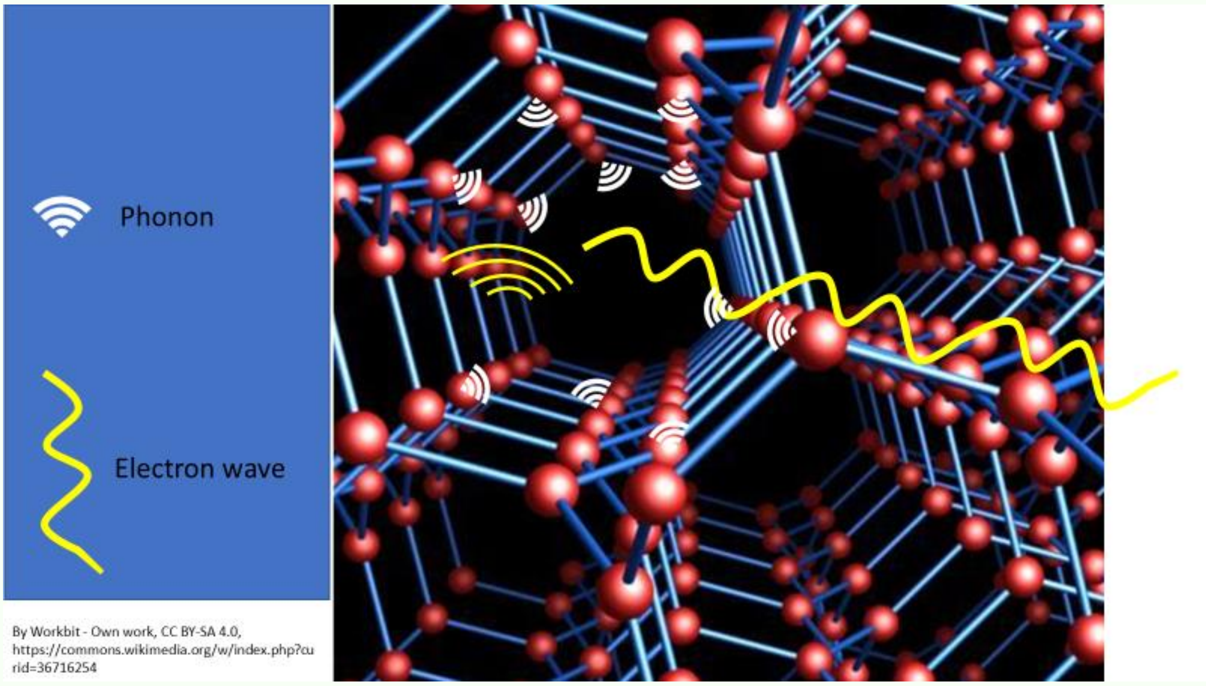
Teacher notes	**Teaching notes: running the activity**
There are two main objectives with this exercise: to help students visualize how resistance works at the quantum level, and to challenge potential student understanding of resistance, which is typically based on the classic model of the atom and the intuitive concept of the electron as a particle. Conductors V insulators Conductors allow electrons to flow more easily than insulators. The more electrons per unit of time that move through a space, the greater the current and therefore the amount of electrical energy that can be generated*. For the electrons to move in the first instance, they need a force or form of energy such as the chemical energy from a battery. But even the best conductors in today's circuits have some resistance. This resistance you can feel as heat. In this activity, student atoms that gain more energy and jiggle and dance more	**Method** This dance, come in three Acts. The first two Acts demonstrate resistance in materials. In Act 3, students simulate the flow of electrons in a material where there is zero resistance. Students will play either the role of the atoms in the atomic lattice of the conductor or an electron. The pipe cleaners will be inserted into the hats and represent the energy of the electron. The more pipe cleaners in the hat the more energy you have given the electron. The student electron will wear the relevant hat for each Act. In the hat for Act 1. Insert about 5 pipe cleaners. For Act 2, insert about 15-20 pipe cleaners in the hat. For Act 3. Insert just one pipe cleaner in the hat, which will represent the minimum amount of energy required to do the work required, eg make an LED light up.

vigorously will hopefully notice they are giving off more heat. This is essentially what is happening in a circuit where kinetic energy is being transformed into heat. In a good insulator the electrons are too tightly bound to their atoms and do not flow. Without electron flow there is no current and therefore no generation of electrical energy. **Phonons and resistance** Electron waves interact with the atomic lattice waves (phonons) and transfer some of their energy and momentum into the lattice waves. Phonons are similar to a sound wave given off when the atomic lattice jiggles, which all atomic lattices and atoms do unless they are cooled to absolute zero, which is theoretically impossible. This extra energy gained by the atomic lattice makes the lattice jiggle a bit more and this greater kinetic energy = loss of energy as heat. The electrons have lost energy in the process. In room temperature metals/conductors, nearly all the resistance is from phonons. See Figure 2 below. *It is important to note to students that electrical energy is not the flow of electrons (current). The kinetic energy of electrons moving through a circuit is what enables the generation of the electrical energy used to do the work. To understand more about the concept of energy and work see the section, Energy and work in the FLEET Schools resource on Energy **Limitations** In our scenario, the electrons (students) stop moving when they run out of pipe cleaners (energy). In reality they would still be being pushed and pulled through the circuit but at such a slow rate (because of resistance) there is insufficient electrical energy to do the work. The further along the circuit from the battery the more resistance there will be. This can be observed with the LEDs in Activity 10 Graphite circuits. Answers to student questions to explore In Act 1 and 2. Students should observe that the electron loses energy and the atoms gain that energy. The student atoms that gain electron energy should observe that they start giving off more heat (if they are dancing harder). Ask students what they feel when they use their mobile or laptop for a while? What are the devices giving off? Hopefully they eventually say, heat. This heat is lost energy. It is energy unavailable to do work.	Get students to arrange themselves in 3 lines of 5-8 students per line (although the longer the line the better, if you have the students to spare). Each student in the grid represents an atom in the atomic lattice. Students playing the atoms should place themselves at least one arm's length from each of the other atoms. See Figure 1 below. IMPORTANT: student atoms are fixed in place. They cannot move their feet. First, this more correctly simulates the actual behaviour of an atom in such a lattice. Second, it prevents student atoms being tempted to chase the student electron and steal all the energy (pipe cleaners). Each atom will use one of their arms to represent a phonon. This phonon wave is waving (in time to the music, if you have a beat going). Select one or two students to be electrons. Remember electrons are waves (or have a wave function). Student electrons will be performing a one-person Mexican wave and move randomly through the atomic matrix, but through the length of the circuit. That is, we have connected a battery to the circuit with a certain force and this applies the necessary force that enables the electron to flow through the circuit. Student electrons (doing the Mexican wave) will interact with atoms (doing the one-arm phonon wave). Student atoms use their wavy phonon arms to steal one (just one) pipe cleaner, if the electron passes within reach In Act 1. Place a funky hat with the approx. 5 pipe cleaners on the student electron. Pretend to connect the battery which is the signal for the electron to "flow" through the circuit. As the student electron loses pipe cleaners (energy) they slow down and get less wavy. The student atoms that steal a pipe cleaner gain energy and should start wriggling and getting extra wavy (in the funkiest way they know how). Observe how far the student electron got through the lattice. **Questions for students** Ask students what happened. What was happening to the electrons? What are the implications for the amount of current and the amount of work that can be done? What was happening to the atoms that gained energy from the electrons. (Ask them what they were feeling as they started dancing with more vigour?)

In Act 2. To ensure we had sufficient current and therefore electrical energy to do the necessary work, we had to use a higher voltage battery. Discuss this scenario with students. How sustainable is it to use a larger battery? The same scenario applies to our centralized energy sources that supply the grid. If a device requires 10 joules of energy to do the required work, we will need to burn an amount of coal that contains a lot more energy (say 15 joules) to ensure there is enough energy for the device to work. That is because 5 joules is lost as heat (resistance) as the current flows through the grid and circuits to our device. In Act 3, where our conductor is a topological insulator there is no resistance and therefore no heat and no energy loss. The battery in this scenario would be a tiny fraction of the voltage used in Act 1 and 2 because without resistance, it only takes a small amount of force to generate the required current. Or, we would only need to burn the amount of coal containing 10 joules. Note: topological insulators are still part of on-going research and development. They are not ready for commercial application – yet. You can read more about the problem of the unsustainable energy consumption of digital technologies here and FLEET's research on topological insulators here.	Assuming the electrons lacked enough energy to flow through the circuit at a rate necessary to do the work, what do we need to change to ensure there is enough energy to do the work required, eg make the light work. In Act 2. Place on the student electron's head the hat with up to 20 pipe cleaners. Repeat what you did for Act 1. In Act 2. The extra energy in the electrons comes from a bigger battery (one with more volts). Select a student to act as the extra force supplied by the bigger battery. That student will gently push the student electron through the atomic lattice. The student battery should push the student electron hard enough so the electron is propelled faster than they went in Act 1. How far did the electron travel through the circuit this time compared to Act 1? How much extra energy did the atomic lattice gain? (A lot more) What are the implications of this? (More heat generated – possibly the conductor catches fire.) Questions for students Ask students whether the outcomes of Act 2 are desirable. What might be a better way to ensure there is sufficient current (energy) to do the necessary work. Act 3. Place on the head of the student electron, the hat with just one pipe cleaner. In Act three we change our conductor to a novel 2D material called a topological insulator. In such materials, electrons will flow around the edge of the material without resistance – no energy loss. See links below for more information about topological insulators. Simulate the closing of the circuit (ie connect the battery). This time the electron should pass down the outside of the atomic lattice and there is no interaction between the atoms and electron. The electron continues to move through the length of the circuit without losing its energy. That is, there is no resistance. Questions for discussion What are the implications of this for the function of circuits and energy consumption? In our scenario, where the force used to enable electrons to flow comes from a battery, what would it means for the type of battery we now need – assuming we require the same amount of energy as in Act 1 and 2.?



Activity 7. Figure 1 Role playing scenario to represent how resistance works at the quantum level. Students played the role of electrons (with specific amounts of energy) and atoms/phonons.



Activity 7. Figure 2. Electrons have a wave-like behaviour. They don't actually physically hit the atoms as they flow through a circuit. The electron wave interacts with the phonon (which is a form of sound wave) that is given off by a vibrating atom. Energy is passed from the electron to the atom via these waves.

Activity 8. Life without resistance

<table>
<tr><td colspan="2">Learning Intentions
Students get to think critically about the concept of resistance and the value of research that aims to develop materials that can conduct electricity without resistance.</td></tr>
<tr><td colspan="2">Materials
Pencils, crayons, etc
Paper</td></tr>
<tr><td>Teacher Notes</td><td>Teaching Notes: Running the activity</td></tr>
<tr><td>Resistance is a property of the material that impedes the flow of electrons. Therefore, the greater the resistance of a material, the more energy is required to get electrons to flow through that material and fewer electrons will be moving. There will be a reduced flow of charge. Where there is resistance – and there is always some – energy in the electron is lost as heat rather than being used to perform the task we want such as powering the TV or computer.

Digital technologies [anything with a computer chip] consume about 10% of global electricity and this proportion is increasing each year as we demand smarter, more powerful computing systems to be integrated into our daily lives.

Today, a lot of that computer processing happens in huge factory-sized data centres. Some of the bigger data centres are more than 20 times bigger than the MCG (Australian football stadium) and each use about the same amount of electricity as a whole city of Melbourne suburb. Think Google, Facebook and Amazon, Microsoft. Scientists and engineers have developed ways to make these data centres extremely energy efficient compared to how your laptop or desktop computer stores and processes data. Despite these efficiencies, our increasing digital demands mean we continue to build more data centres and so our digital energy consumption continues to increase.

Resistance is behind what we call “compensatory emissions.” These emissions are the result of the extra electricity – often generated from fossil fuels – required to compensate for energy lost throughout out grid because of resistance. It has been calculated that worldwide, compensatory emissions amount to nearly a billion metric tons of carbon dioxide equivalents a year, in the same range as the annual emissions from heavy trucks or the entire chemical industry.</td><td>Method
Students form small groups to brainstorm the following questions:

What would it mean if we could conduct electricity without resistance?

How would this affect how you use energy?

What would this mean for society?

Consider the following ways to communicate your brainstorming:
Construct a mind map, to connect all your ideas with the central theme, ‘Electricity without resistance’.
Draw images to represent your ideas. Explain these in a story to the rest of your class.</td></tr>
</table>

Given these facts, there is considerable scope to improve the efficiency of our digital technologies and the way we generate and transmit electricity around the world if we can develop materials that conduct electricity without resistance. This is why FLEET is working on developing atomically thin materials – materials just one atom thick – that can conduct electricity without resistance. These materials will be used in digital technologies to make them use a lot less energy. Note: Ensure students understand that having zero resistance does not equate to suddenly having extra lethal levels of electricity coursing through our circuits.	

Bringing in the next tech generation – zero resistance
There are some materials that when cooled down to really cold temperatures (about -170 degrees Celsius) will conduct electricity with zero resistance. These materials are called superconductors. The fact they only exhibit this behaviour at such low temperatures makes them impractical for most purposes, but the goal of researchers in this field is to develop materials that can superconduct at room temperature.

The 2D materials and superfluids that FLEET is working on will conduct with near-zero resistance at room temperature and are alternatives to the superconductor. But we are only just beginning to learn about the potential of these materials and there is still a lot of research to go before we can realize that potential and use such materials to develop energy-efficient electronics. See FLEET research and the need for the next generation of electronics.

As noted, the next step in our understanding of electricity came when we realised that electric and magnetic fields were intimately linked and it is this intimate link that ultimately led to Einstein's theory of relativity and quantum field theory, which is what FLEET applies to develop energy-efficient electronics.

Electricity and magnetism - electromagnetism

Electromagnetism is all about how charges affect each other and how the interaction of electrical and magnetic fields induce the flow of charge. It is still the movement of charge, but in this context, it is the movement of a charge through a circuit. As electrons move through a circuit they induce a magnetic field. Conversely, a moving magnetic field will induce the movement of electrons through a circuit. It is the principle behind how we generate most of our electrical energy today through the burning of coal or gas, nuclear power generators, wind turbines, or hydro-power. All rely on spinning coils of copper wire inside a magnetic field to induce that flow of charge. The important point here is that there needs to be a circuit for a current to occur. We outline what a circuit is further below in the section, Make a circuit, create a current.

Hans Christian Oersted, a Danish physicist and chemist, was considered the first to demonstrate the connection between electricity and magnetism. His 1820 experiment used an electric current to deflect a magnetic compass needle. Before this revelation, electricity and magnetism were considered distinct phenomena.

It was known that electricity could produce heat and light. But what Oersted showed was that a flow of charge produces a magnetic field and that we could use electricity to make things turn.

Starting about a decade after Oersted's discovery, Michael Faraday built on Oersted's research by working out that while the flow of charge induces a magnetic field, a changing magnetic field will also induce a flow of charge, which he turned into mechanical motion and the world's first motor. The motor was crude and rather impractical, but nonetheless it paved the way for the modern electric motor and, soon after, the knowledge to turn that mechanical motion into electricity, which is the way we still generate most of our electricity today. Students can replicate Faraday's simple electric motor in Activity 9, *Electric motors: spinning wires*.

Key Point: a charge affects the electrical field; a moving charge affects the magnetic field

Finding the electron

About 70 years after Oersted's discovery, a scientist named J. J. Thomson used the effect of electrical and magnetic fields to determine the existence of the electron – and that atoms were not the smallest units of matter. See Figure 4 below.

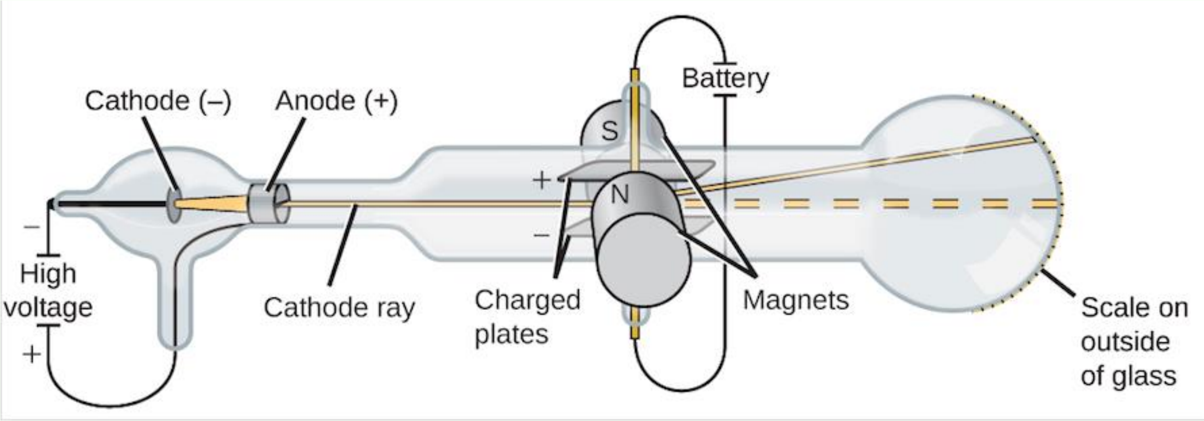


Figure 4. A diagram of J.J. Thomson's cathode ray tube. Thomson used a high voltage (lots of electric force) applied across two electrodes: one was the cathode (with a negative charge), the other an anode (with a positive charge). The ray or beam of electrons originates at the cathode where it travels in a straight line to the end of the vacuum tube and interacts with a chemical substance that glows where the particle beam hits. Thomson set up a charged set of metal plates in the middle of the tube and opposing magnets on each side. Thomson found the particle beam was deflected away from the negatively-charged electric plate, and towards the positively-charged electric plate. *Image* from Openstax, *CC BY 4.0*

Further research determined the size of the particles we now call electrons and scientists realised it was tiny – about 1000 times lighter than the smallest atom, which explained why they could pass right through materials and travel through circuit wires. Thompson used this understanding to develop a new model of the atom, which as noted above, was wrong, but the discovery of the electron paved the way for others to develop the nuclear or quantum model that we now consider to be correct. Our most recent understanding is based on the electron cloud model. See Figure 1 above

References: Britannica - https://www.britannica.com/science/atom/Rutherfords-nuclear-model
Khan Academy: https://www.khanacademy.org/science/ap-chemistry/electronic-structure-of-atoms-ap/history-of-atomic-structure-ap/a/discovery-of-the-electron-and-nucleus

Make a circuit, create a current

Electrons – the charged particles – can only move when there is a continuous (closed) circuit for the electrons to flow through. Any break in that circuit and the current will not flow. An effective circuit needs a power or energy source, in our case that is a battery. The battery is a source of electrons (from the negative terminal) and the force that pushes the electron through a circuit once you have a closed or complete circuit. In a closed circuit, the positive terminal of the battery will also pull electrons through a circuit because of the attractive force between the positive and negative charges. Without the source of energy, in this from the battery, electrons just move around randomly. When the energy source is present and a closed circuit exists, the electrons are pushed (and pulled) in one direction. See Figure 5 below. But remember it is only the electrons that move through the circuit. It is this movement or flow of electrons that enables the generation of electrical energy to power our lights, computers, or any item that runs on electricity. The protons – or positive charged particles – are fixed and cannot move. The energy stored in the battery is chemical energy. When the battery is connected to a circuit, the chemical energy is transformed into electrical energy that we use to provide light and run our household appliances.

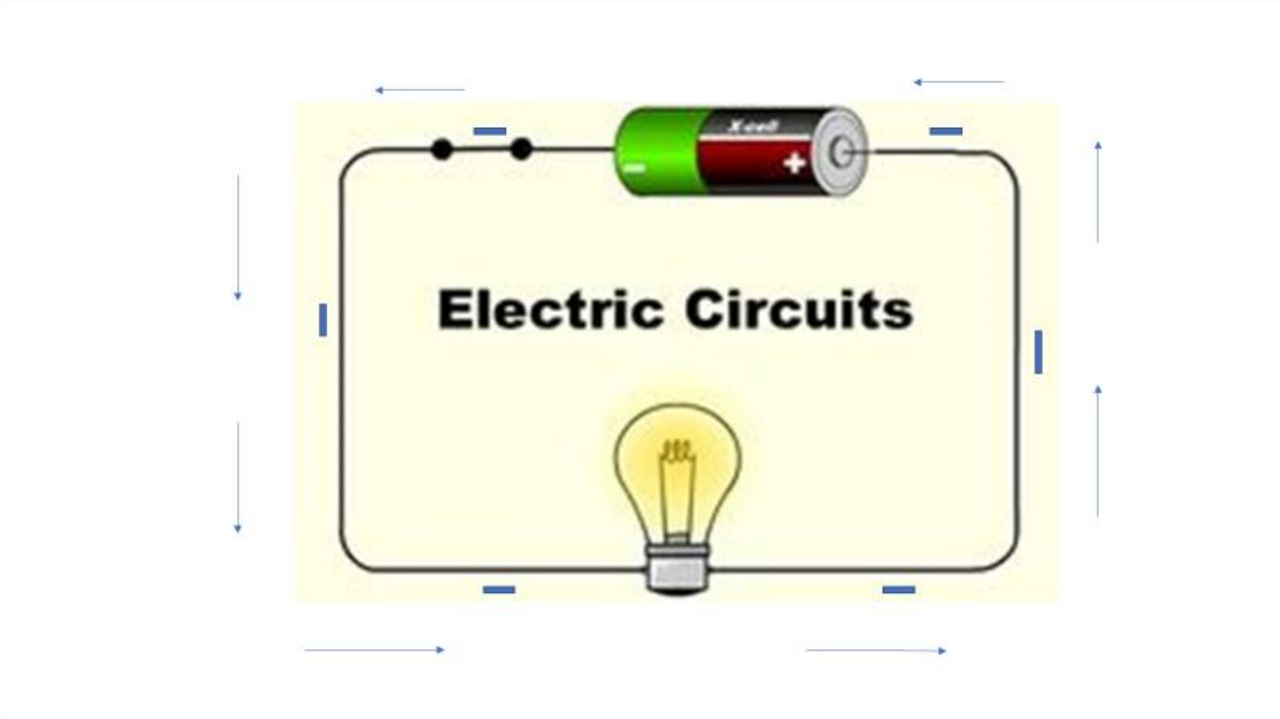


Figure 5. Image of a closed electrical circuit.

Further examination of students' perception of circuits can be found here https://www.education.vic.gov.au/school/teachers/teachingresources/discipline/science/continuum/Pages/electriccircuit.aspx

Activity 9 Electric Motors: Spinning wire

Learning intentions

Students will replicate Faraday's simple electric motor to build on their understanding of the relationship between magnetism and electricity.

Aim

To examine and understand the relationship between electricity and magnetism and use that knowledge to build an electric motor.

Before the experiment

You are going to use magnets, a battery and copper wire to replicate one of the first electric motors. The physicist, Michael Faraday, was probably the first to demonstrate that the forces generated by electric currents and magnetism could be turned into mechanical forces that he used to demonstrate the first electric motor. His research and crude electric motor paved the way for the modern electric motor and, soon after, the knowledge to turn mechanical motion into electricity, which is the way we still generate most of our electricity today.

Hypothesis

You have formed a circuit because you have connected a wire between the positive and negative terminals of a battery. There will be a charge flowing through the wire, that will generate a magnetic field.

The magnet you will place on the end of your battery will generate its own magnetic field that the wire with its flow of charge will pass through. Make some predictions based on the following questions:

There are forces in operation here. Where will the forces have to be applied to make the wire spin?

What effect will the magnetic field from the electrical wire have on the magnetic field from the magnet?

What would happen if you turn the battery up the other way and place the wire on top of the opposite terminal?

What would happen if you added two (or more) magnets?

What would happen if you moved the bottom section of wire touching (or nearly touching) the bottom terminal away from the terminal?

Materials

AA battery

Copper wire (Hardware or craft supply stores)

A round neodymium magnet (online, or electrical supply stores such as Jaycar)

Teacher notes	**Teaching notes: Running the activity**
The year level and knowledge of the student will determine the level of critical thought required for a hypothesis. Upper primary students should be able to understand that a magnetic force is affecting the wire in some way to make it spin. Older students should be able to think about the interaction of the magnetic fields to generate the force necessary to make	**Method** Attach your neodymium magnet to one end of the battery. Place the battery upright on a table with the magnet at the bottom (between the table and battery). Fashion your copper wire as shown in Figure 1. Place the wire on top of the battery

the wire spin. Students get the opportunity to build a circuit in Activity 10. **What is happening** Electrons travelling through our circuit will generate a magnetic field that will interact with the magnetic field generated by the magnet. Note that magnetic fields from a magnet emanate outward from the North pole to the South pole on the outside of the magnet. See Figure 2. The interaction of the two magnetic fields generate what is known as the Lorentz force, which is simply the force you get when you bring the same magnetic poles of a magnet together. They will oppose each other, but in this case the Lorentz force is perpendicular (at a 90-degree angle) to both the direction of the electron movement and the magnetic field. To visualise this, think about standing in the corner of a room and put your arms along each wall. One arm is pointing in the direction the current travels (negative to positive*). Your other arm points in the direction of the force from the magnet's field. Your head and feet point in the direction of the Lorentz force. It is the Lorentz force that is acting on your wire to make it spin. In Figure 2 note that in the left-hand image that represents the set up in this experiment, the direction of the magnetic field on one wire is the opposite on the other wire. This means the Lorentz force will push the wire on one side and pull it on the other side, which is why your wire keeps spinning. *In the conventional model the current is considered to travel from the positive to the negative terminal. You will often see reference to the right-hand rule, which is similar to the analogy above where you stand in the corner of a room to work out the direction of current, magnetic field and the Lorentz Force. In the electron model where the current flows from negative to positive you would use your left hand to achieve the same effect.	Watch it spin (you may have to give it a small nudge to get it going). Check the video to watch its operation Test your hypotheses by controlled experiment. Construct a table such as the one below to record your observations. In your table, observe and record what the wire did in each of the following scenarios (plus any other cool ideas you want to test): Closed circuit and magnetic field (as described in steps 1-4 in the Method above) Battery turned up the other way Two or more magnets Wire moved away from bottom battery terminal **Safety note:** When you have finished, remove the wire from the battery as the wire can rapidly heat up and cause a fire. Remove the magnets from the battery as leaving them attached can drain the battery. **Extended thinking** The Earth has a magnetic field. Why does it not make all our wires start spinning? What is missing to make this happen? Consider what the world would be like if we did not have the electric motor – in other words if there was no such thing as the Lorentz Force? How many things do you have at home or use that require an electric motor? Note the position of the North-South poles of the battery in your experiment. The poles are vertical, North above South. Think about the direction of the magnetic field that comes from this orientation of the magnet. What would happen to the wire if you used a magnet with the poles aligned horizontally, left-right, as in the right-hand image in Figure 2. Note the magnetic field lines and the direction they travel in through

	the wire. Compare this to the left-hand image.

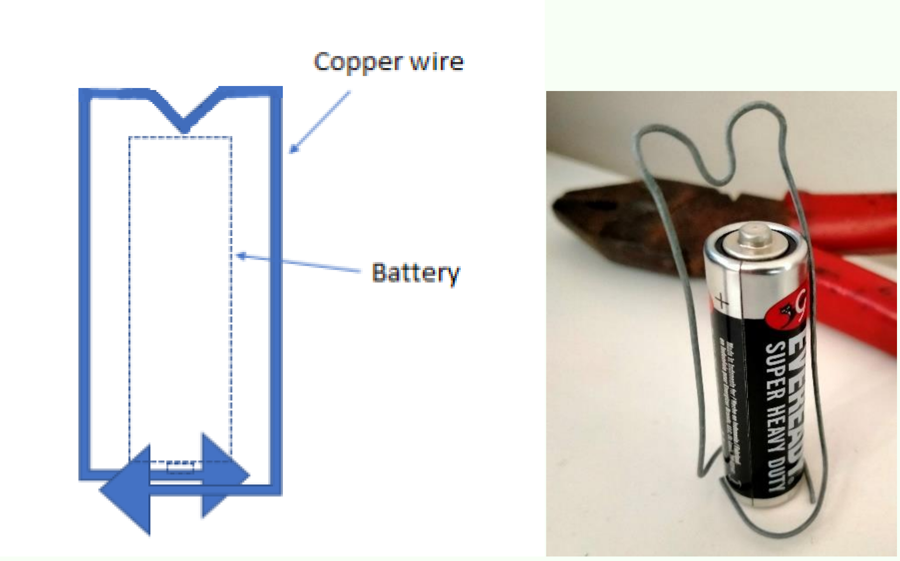


Figure 1. Shape of copper wire to fit over the battery and magnet.

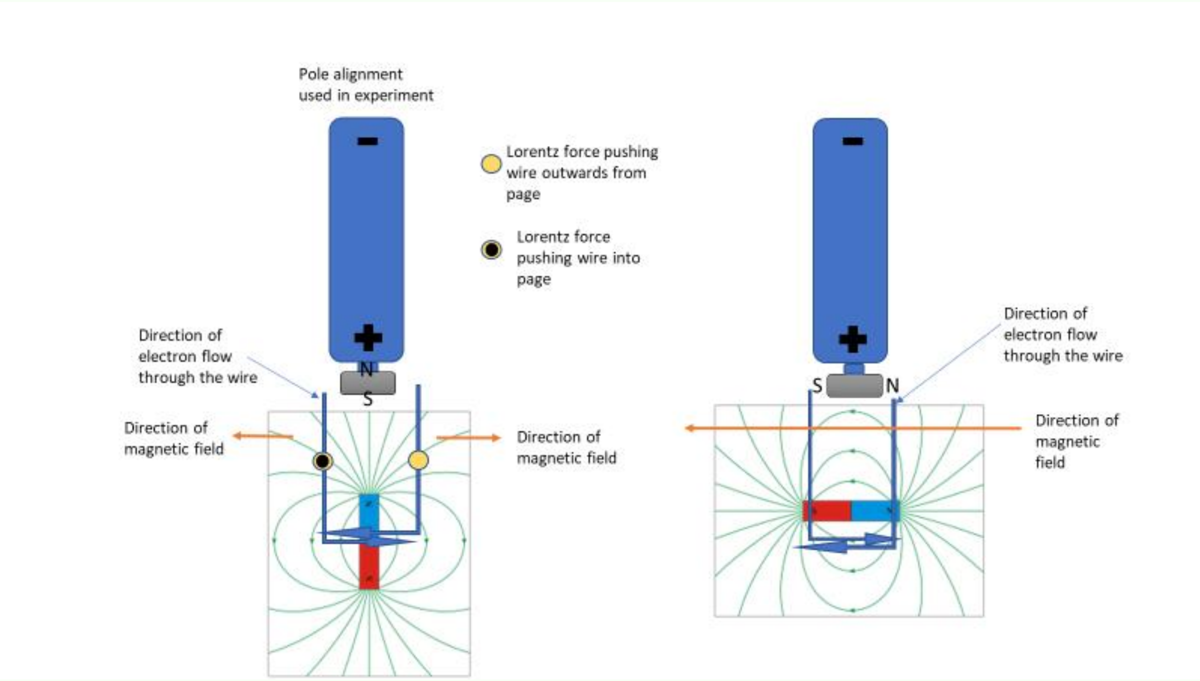


Figure 2. Operation of spinning wire showing direction of electron flow through the wire, the magnetic field and effect of Lorentz Force.

Example table to record observation of the wire in different scenarios. You may want to adapt this to suit your own hypotheses and observations.

Scenario	Wire not moving	Wire spinning	Wire spins faster	Wire spins slower	Wire spins the opposite way (reverses direction)	Other observations
Closed circuit and magnetic field						
Battery turned up the other way						

Two or more magnets						
Wire moved away from bottom battery terminal						

Graphite circuits

Graphite is a form of carbon. In fact, so are diamond and charcoal. These different forms are called allotropes. They are all carbon, but the way the carbon atoms are arranged is different. For example, diamond has its carbon atoms arranged so that each atom is strongly bound to 4 other carbon atoms. This means there are no spare electrons and it can't conduct electricity. Graphite has carbon atoms arranged in layers and each atom is only bound to three other atoms, which leaves a spare electron floating around that becomes 'delocalised' from its atom. This just means the electron is no longer associated with the atom and it is these delocalised electrons that make graphite (and graphene – see below) conductive. The layers in graphite are weakly bound together by what are called van der Waal forces – the same forces that allow Geckos' feet to stick to the ceiling. Your pencil lead is graphite and it works because the weakly bound layers come apart easily and onto your paper. You can test the conductivity of graphite in the Activity, *Graphite Circuit*.

A single layer of graphite is called graphene. Its delocalised electrons and structure make it highly conductive. Graphene is incredibly strong. By weight, it is about 200 times stronger than steel. FLEET works with graphene as one of its 2D materials.

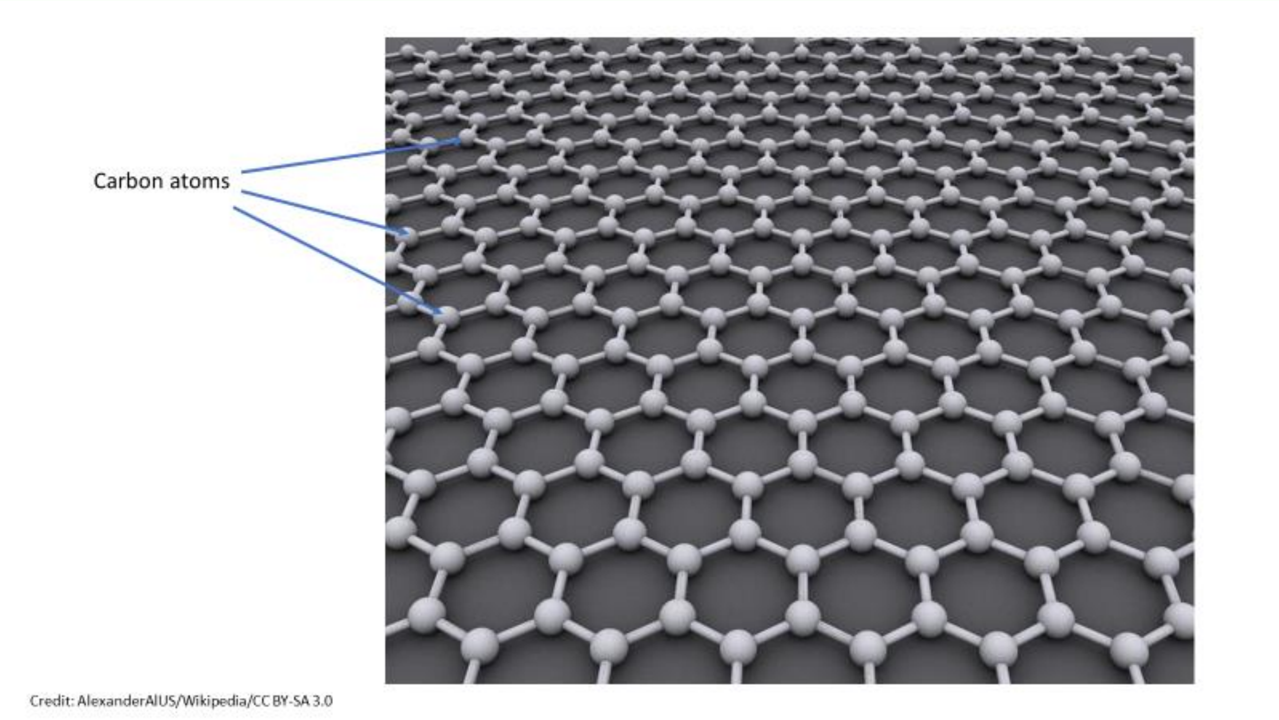


Figure 5. Graphene. Each carbon atom is joined to three other carbon atoms by strong bonds that makes graphene about 200 times stronger than steel.
By AlexanderAlUS - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=11294534

Activity 10. Build a Graphite circuit

Learning intentions

Students will develop a deeper understanding of conductors and insulators and resistance and how to construct an effective circuit.

Before the experiment

You will use graphite, a form of carbon that we can find in a pencil, to help make a circuit. You will examine the conductivity (how well something conducts electricity) and resistivity (how well a material prevents the flow of electricity) of graphite.

If you pool what you have learned so far in this resource, you will understand why you should never stick any object into a power socket, why you can shock friends by rubbing your shoes on the carpet, and how you can bring light into the world, and toasters, electric cars, Lego® technic toys….etc.

Hypothesis

You will use your pencil to draw two thick lines that will act as the electrical wires in a circuit. Use your knowledge of conductors, insulators, circuits and resistance to construct a hypothesis based on how conductive you think paper and graphite are and whether the graphite will work to make a circuit.

Consider what will affect the ability of graphite to conduct a current?
Consider how the length of your graphite circuits will affect the brightness of your LED?

Materials

Years 4-6
Pencil (2B or softer)
Clean sheet of paper
9V battery
LEDs (approx 3000MCD - millicandelas)

Extension for Years 7-9
Multimeter

Safety:
*Do not leave batteries connected to a circuit as this will cause the wires to heat up and be a possible fire hazard – a good example of resistance.
*Do not use damaged batteries as they may leak caustic chemicals.
*Do not connect the LED terminals directly onto the 9V battery. This will blow the LED.

Teacher notes	Teaching notes: running the activity
For each student, it is likely that there was a variety of distances the LED got from the battery before it stopped working. Can they explain why? Each student had the same battery, pencil and LED? Get students to consider what factors make each student's experiment different? How could they control for this difference should someone else want to repeat this experiment? Emphasize that controlling for variables as much as possible is an important	**Method** First step is to test the conductivity of the paper itself. Place the 9V battery and LED electrodes onto a clean part of the paper to see if you can get the LED to work. Move the LED and battery closer together, further apart to see if the LED will work. Draw some circuits and test the conductivity of graphite. Use the pencil to colour in the circuit lines on your sheet. If you are doing this at home or school, use the positive and negative terminals on your 9V battery to make

element of any experimental design to enable someone that wanted to repeat your experiment to be able to compare their results with yours and know if what you found is real or not.

Get students to consider whether people are insulators or conductors? How might they SAFELY test for this? Think about what happened in Activity 5 when you placed a finger between the two strips of negative charged plastic that were repelling each other at the time?

Extra fun stuff to do
Make squishy circuits
Get cooking and make insulating and conducting dough. Use the dough, your 9V battery and LED to make some creative circuits. The University of St. Thomas took squishy circuits to a new level and there are different YouTube experiences to be had. Here is one from Rough Science.

Question for students: what ingredients in the two doughs make them either an insulator or conductor? Answer: Salt is an electrolyte made up of Na+ and Cl- ions. The negative ions supply electrons and facilitate the flow of charge in the conducting dough. Sugar is not an electrolyte; it has no free ions to facilitate the flow of charge. It therefore makes the dough act as an insulator.

What is happening
This activity is about understanding circuits and resistance. If you have set up your experiment properly you will have formed a closed circuit from your battery along the wires (or graphite), through the LED and back to other battery terminal.

Electrons – the charged particles – can only move when there is a continuous (closed) circuit for the electrons to flow through. Any break in that circuit and the electrons will not flow and there will be zero current. An effective circuit needs a power or energy source, which in our case is a battery. The battery is a source of electrons (from the negative

two marks on the paper that you can use as guides to work out the width of your graphite circuit lines. See Figure 1. Make the lines about 0.5-1 cm wide and 8-10 cm long. You need to colour them quite heavily, so you need to go over them a few times.
Measure a distance of 1cm along the circuit from where you will place the battery on the graphite lines. At the 1cm mark, put one LED terminal on one graphite line, the other terminal on the other line. The longer LED leg (terminal) is the positive terminal. The longer leg on the LED must go on the same line as the battery's positive terminal. Once arranged correctly, the LED should light up (once you place the battery on the circuit also).
Grab your 9V battery and place the positive terminal on the same graphite line as the positive LED terminal, and the negative battery terminal on the other graphite line with the negative LED terminal. Does your LED light up? If so, do a happy dance to show that you got the light to work first go.
If the LED light does not switch on, make sure there is a good connection between the LED terminals and the graphite circuits and between the battery terminals and graphite circuits. Does your light work now? If not consider what might be going wrong. What can you change to make it work? What part of your experiment can you test, and how, to ensure it functions properly? Make detailed notes about what you do.

Consider the components: an LED light, a battery, a graphite circuit. You will need to test each of these components. How will you do that?

If your LED lights up, shift the LED further away from the battery. Do this in 1cm increments. For example, if your first test had the LED 1cm away from the battery, try it again with the LED 2cm away, then 3cm, then 4cm and so on. Do you notice anything happening with the LED the further you get from the battery? At what distance from the

terminal) and the force that pushes the electrons through a circuit once you have a closed or complete circuit. There are also the electrons in the wires connecting the two battery terminals. In a closed circuit, the positive terminal of the battery will also pull electrons through a circuit because of the attractive force between the positive and negative charges. **Remember it is only the electrons that move through the circuit.** It is this flow of electrons in one direction through the circuit that creates the electric current and provides the energy for our LED light. The protons – or positive charged particles – are fixed and cannot move. **Conductors and insulators** Electrical conductors have low resistance. The graphite from the pencil can form a circuit because graphite is an electrical conductor, which means current can flow easily through it, though there are other materials that are better conductors. Get students to think about why we use copper as the conducting material in our electrical wires? Electrical insulators have high resistance. The paper (made from wood pulp) cannot form a circuit because it is an electrical insulator, which means it does not allow current to flow, at least not without lots more force than you can get from the batteries we used in this experiment. Materials such as wood and plastic are good insulators. **Resistance** Every material has resistance, except some of those novel materials that FLEET is working on. Read about superfluids and topological insulators here. Copper, gold all conduct electricity well, but they still have some level of resistance, which is why your phones and laptops heat up when you start using them.	battery does the LED stop working? Record the distance. Create a whole-class table that records the brightness of the LED at each distance from the battery and the distance each student's LED stopped working. Plot this data on a graph. See an example table below. Have a competition to see who can make the longest circuit with the LED still lighting up. ***Extension*** Now we get to examine resistance in more depth and play with Ohm's Law. You will need your multimeter for this activity. Ohm's law is given by $V = IR$ where V = Voltage (measured in volts), I = Current (measured in amps) and R = Resistance (measured in resistance). Method. Use the same set up as before with your 9V battery, graphite circuits and LED. Note the distance from the battery where your LED stopped working. Mark that point. Switch the multimeter setting to measure resistance or ohms denoted by the symbol Ω. Note: remove the battery from the circuit for this exercise. At the marked point, use the multimeter to measure the resistance across one of the graphite wires. To do this, place one multimeter terminal on the graphite wire where the battery terminal was placed and the other multimeter terminal at the marked point on the graphite circuit where your LED stopped working. Record the multimeter reading, which will be in Ohms, to find out the resistance of your circuit.* ***Without*** using the current setting on the multimeter, use Ohm's law to calculate the threshold current needed to turn an LED.

The electrons in graphite are not bound too tightly to their atoms (carbon) so they can more easily become free and mobile to move through a closed circuit. The electrons in a material such as plastic or wood are tightly bound to their atoms and it is difficult to free them from their atoms. Such materials have a high resistance and will not easily conduct an electric current, which is why our electrical cords have a plastic coating. That coating protects us from being electrocuted. It is the copper wire inside the protective plastic coating that is the conductor.

Testing the components: Quickly touching the LED onto the battery terminals can test the LED – assuming you have a charged battery. However, holding the LED onto the battery for more than a split second will blow the LED.

You can use the multimeter to test the battery and the graphite circuits.

Ohm's Law: V=IR
You are solving for I, which means you can rearrange the formula to enable you to solve for I
I= V/R

Answers for I will vary widely, but you should observe, however, that the figure is extremely small. That is, the answers should reveal that the LED technology requires a tiny amount of current (or electrical energy) to turn on. Compare this to the old incandescent and fluorescent globes.

Reflection
Following completion of Activity 10, get students to draw a circuit again, this time labelling the direction of electron flow. Higher year levels could add a switch or include different circuits such as parallel or series. Compare this to what they drew in Activity 4.

You know your battery is 9 volts (V). Resistance will be in Ohms – the reading from your multimeter. Solve for I (current)

*Remember to convert your volts, Ohms and current to the same units (ie milli or micro volts, Ohms, amps)

Calculate the current (I) to work out what the minimum current required is to get your LED working. Compare your answer to the other students in your class.

Results
Did you get the LED to work in Step 1 where you tested the conductivity of the paper itself?

Did you get your LED to work with the graphite circuits?

What did you have to do to make it work? Describe what you did to make an effective circuit.

What happened when you moved the LED further away from the battery?

Record your results in your table, such as the one below, and then explain the data in words. Plot the data from the whole class on a graph to see if there is a relationship between brightness and length of the circuit.

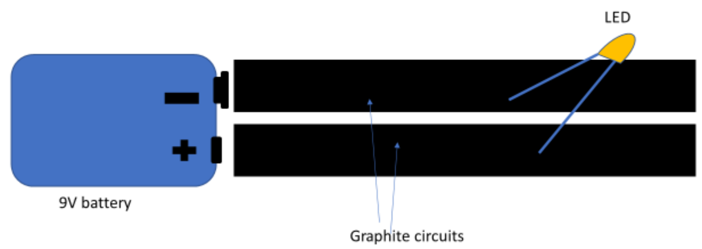
Discussion
What do you think was happening here? What does your data tell you that might help you answer this and the following questions?

Is graphite a conductor? What else can you say about the graphite wires?

What can you say about the paper? Is it a conductor or insulator?

What happened when you moved the LED further away from the battery? Can you explain the reasons for what you observed?

	Think about what you have learned about resistance and that less current (or electrical energy) can flow through materials that have greater resistance. How will the length of the graphite circuit affect resistance? You can quantify this in the extension below. What makes an effective or closed circuit and how does your knowledge of an effective/closed circuit match what you did in your experiment above? ***Extension*** Base your discussion on the following questions: What can you say about the relationship between the length of the graphite "wire" and resistance? How much current on average is required to get your type of LED to work? What would happen if you could create a graphite circuit (or any circuit) that enabled electrons to flow without resistance?



Activity 10. Figure 1. Graphite circuit with a 9V battery and LED

Table example. Recorded measurement of LED brightness with distance from the battery

Distance from Battery	Bright LED	Mid bright LED	Dim LED	No light
1cm				
2cm				
3cm, etc				

Piezo-electricity and wearable electronics

Piezoelectricity is the conversion of mechanical pressure into electrical energy. The source of piezoelectricity comes from crystals that have a certain structure. When you compress thin slices of these crystals their atoms rearrange in a way that puts a positive charge on one side of the crystal and a negative on the other. You can hook up a wire to the positive side and a wire to the negative side to make a circuit and the difference in charge on each side of the crystal can drive a current through the circuit. Conversely, if you put a current through a piezoelectric material it will cause a distortion in the crystal, which the basis of how speakers work.

See a great explanation on piezoelectrics in this TedX video - https://youtu.be/YEJ2qryXcIQ

Quartz is a natural piezoelectric crystal, but researchers have developed a range of artificial crystals that are more effective. FLEET has helped develop a new type of ultra-efficient nano-thin piezoelectric material that could advance self-powered electronics, wearable technologies and even deliver pacemakers powered by heart beats. The novel material is printable on machines similar to those that print newspaper sheets, it is 100,000 times thinner than a human hair and 800% more efficient than other piezoelectric materials based on similar non-toxic materials. See FLEET News http://www.fleet.org.au/blog/nano-thin-piezoelectrics-advance-self-powered-electronics/

Other interesting sources

BBC; Shock and awe. The story of electricity - https://www.youtube.com/watch?v=Gtp51eZkwoI

More on Ben Franklin and his work with electricity - https://www.emcs.org/acstrial/newsletters/fall06/franklin.pdf